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# Ecological impacts of fishing gears in Ko Chang, Trat Province, Thailand

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ECOLOGICAL IMPACTS OF FISHING GEARS IN KO CHANG, TRAT PROVINCE, THAILAND

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วิชิน สืบปาละ : ผลกระทบเชิงนิเวศวิทยาจากเครื่องมือประมงบริเวณเกาะช้าง จังหวัดตราด ประเทศไทย. (
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องค์ความรู้เกี่ยวกับผลกระทบเชิงนิเวศวิทยาจากการประมงโดยเฉพาะอย่างยิ่งในภาคการประมงขนาดเล็กมักมีอยู่น้อย จึงทำให้เกิดอุปสรรคในการจัดการประมงโดยใช้แนวคิดเชิงระบบนิเวศและความยั่งยืน หัวข้อวิทยานิพนธ์นี้ได้ถูกกำหนดขึ้นโดยมีวัตถุประสงค์เพื่อเพิ่มองค์ความรู้ดังกล่าว โดยดำเนินการวิจัยในประเด็นที่เกี่ยวข้องบริเวณหมู่เกาะช้าง จังหวัดตราด บริเวณอ่าวไทยฝั่งตะวันออก การวิจัยในครั้งนี้เน้นศึกษาผลกระทบหลักสองประเด็น ได้แก่ สัตว์น้ำพลอยจับได้และการทำลายถิ่นที่อยู่อาศัยตามธรรมชาติ ประกอบด้วยการศึกษาในสามส่วน ได้แก่ 1) การประเมินองค์ความรู้ที่มีอยู่ในปัจจุบันและช่องว่างของความรู้เกี่ยวกับผลกระทบดังกล่าวในประเทศไทย 2) การศึกษาผลกระทบของการประมงที่เกี่ยวข้องกับสัตว์น้ำพลอยจับได้และการทำลายถิ่นที่อยู่อาศัยตามธรรมชาติบริเวณหมู่เกาะช้าง จังหวัดตราด และ 3) วิเคราะห์ผลกระทบเชิงสัมพัทธ์และจัดลำดับความรุนแรงของผลกระทบของเครื่องมือประมงประเภทต่าง ๆ จากการทบทวนวรรณกรรมและการวิเคราะห์ช่องว่างของความรู้พบว่าองค์ความรู้ดังกล่าวในประเทศไทยยังมีช่องว่างอยู่มาก โดยเฉพาะอย่างยิ่งข้อมูลของสัตว์น้ำพลอยจับได้ (ทั้งที่นำมาใช้ประโยชน์และทิ้งเปล่า) และองค์ความรู้ด้านการทำลายถิ่นที่อยู่อาศัยตามธรรมชาติ การศึกษาสัตว์น้ำพลอยจับได้จากเครื่องมือประมงขนาดเล็ก 9 ประเภทในบริเวณเกาะช้าง พบว่าเครื่องมือประมงบางประเภท โดยเฉพาะอย่างยิ่งอวนจมปู อวนสามชั้น และลอบปู สามารถจับได้สัตว์น้ำมากทั้งในแง่ของมวลชีวภาพและจำนวนชนิด การศึกษาผลกระทบของการประมงลอบปลาในแนวปะการังแสดงให้เห็นว่าสามารถเกิดผลกระทบต่างๆ ต่อแนวปะการัง เช่น ปะการังเกิดความเสียหาย ผลกระทบจากการฟุ้งกระจายของตะกอน ระบบนิเวศเสียสมดุลเนื่องจากการจับปลาในแนวปะการัง รวมถึงการเกิดขยะทะเล  การสำรวจประชาคมสัตว์ทะเลหน้าดินขนาดใหญ่บริเวณที่มีการห้ามทำประมงอวนลาก อวนรุน และคราดหอยตลอดทั้งปีและบริเวณที่อนุญาตให้ทำประมงดังกล่าว 6 เดือน พบว่าในพื้นที่ที่อนุญาตให้ทำประมงดังกล่าว 6 เดือนมีความหนาแน่นของสัตว์ทะเลหน้าดินขนาดใหญ่ลดลง จากการจัดประชุมปรึกษาหารือกับผู้เชี่ยวชาญเพื่อวิเคราะห์ผลกระทบเชิงสัมพัทธ์และจัดลำดับความรุนแรงของผลกระทบของเครื่องมือประมงทั้งขนาดใหญ่และขนาดเล็ก โดยอาศัยข้อมูลเชิงวิชาการที่มีอยู่ และข้อมูลที่ได้จากการสำรวจ รวมถึงความรู้และประสบการณ์จากผู้เชี่ยวชาญ พบว่าอวนลากแผ่นตะเข้และอวนลากคู่ได้รับการจัดลำดับให้เป็นเครื่องมือประมงที่มีผลกระทบมากที่สุดทั้งในแง่ของสัตว์น้ำพลอยจับได้และการทำลายถิ่นที่อยู่อาศัยตามธรรมชาติ ในขณะที่ผู้เชี่ยวชาญยังมีความกังวลต่อเครื่องมือประมงขนาดเล็กบางประเภท เช่น อวนสามชั้นและอวนจมปูที่น่าจะก่อให้เกิดผลกระทบในแง่ของสัตว์น้ำพลอยจับได้ วิทยานิพนธ์ฉบับนี้จะช่วยสร้างความรู้ความเข้าใจเกี่ยวกับผลกระทบเชิงนิเวศวิทยาของเครื่องมือประมงต่อระบบนิเวศทางทะเลในประเทศไทย ที่จำเป็นต่อการจัดการประมงโดยใช้แนวคิดเชิงระบบนิเวศต่อไป



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| สาขาวิชา | วิทยาศาสตร์สิ่งแวดล้อม | ลายมือชื่อนิสิต ............................................... |
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Wichin Suebpala : ECOLOGICAL IMPACTS OF FISHING GEARS IN KO CHANG, TRAT PROVINCE, THAILAND. Advisor: Assoc. Prof. Charoen Nitithamyong, Ph.D. Co-advisor: Prof. Ratana Chuenpagdee, Ph.D.,Asst. Prof. Thamasak Yeemin, D.Sc.

Knowledge of ecological impacts of fishing, especially in small-scale sector, is not always readily available, making it difficult to employ an ecosystem-based approach to fisheries management and to achieve sustainability. The topic of this dissertation was formulated with the aim to enhance this knowledge through conducting researches in Mu Ko Chang, Trat Province, the Eastern Gulf of Thailand. This study focuses on two main types of impacts, i.e. bycatch and habitat damages, consisting of three research modules: 1) assessing existing knowledge and analyzing the knowledge gap regarding bycatch and habitat impacts of fishing methods in Thai waters; 2) investigating fishing impacts in terms of bycatch and habitat damages, of some fishing gears in Ko Chang, Trat Province, and; 3) analyzing relative ecological impacts of fishing gears and to rank the levels of severity caused by different fishing gears. According to the literature review and gap analysis, a major gap of knowledge on the ecological impacts of fishing gears in Thailand was found, particularly the data on bycatch (retained and discarded) and habitat damages. The onboard surveys of bycatch for nine small-scale fishing gears in Ko Chang revealed that some of the gears, particularly trammel nets, crab traps, and gillnets, produced the higher number of bycatch in terms of biomass and species richness. A study on the impacts of fish traps on coral reefs revealed various possible impacts including physical damages on corals, impacts from sediment dispersion, ecosystem imbalance due to exploitation of reef fish, and marine debris. A comparative study on macrobenthic community between permanent and six-month closure areas exhibited the impacts of fishing activities (trawlers, push nets, and dredges) in terms of the reduction on macrobenthic abundance. An expert consultation workshop was also convened aiming to rate the impacts of fishing gears including large- and small-scale based on existing knowledge, surveyed data, and personal experience of the expert. It showed that otter-board trawls and pair-trawls were rated with the highest score of bycatch and habitat impacts. In terms of small-scale fishing gears, bycatch impacts caused by shrimp trammel nets and crab gill nets were mostly concerned. This dissertation enhances understandings of the ecological impacts of fishing gears on marine ecosystems in Thailand that are highly required for ecosystem-based fisheries management.

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| Field of Study: | Environmental Science | Student's Signature ............................... |
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Last but not least, I would like to express my love to my father, mother, brother, and friends for supporting and encouraging me to pursue the PhD degree.

Wichin Suebpala

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# CHAPTER I
# INTRODUCTION

## 1.1 Rationale

Thailand has a coastline of about 3,000 kilometers spreading over 23 provinces in the Gulf of Thailand and the Andaman Sea with a total of Exclusive Economic Zone of about 323,488 $km^2$ (NRSA, 2017). Thailand is rich with various marine and coastal ecosystems with about 240 $km^2$ of coral reefs, 255 $km^2$ of seagrass beds, 2,455 $km^2$ of mangrove forests and other ecosystems contributing lots of goods and services to the society (DMCR, 2015). Thai waters are recognized as a high productive area with an average primary productivity of more than 300 $gC.m^{-2}.yr^{-1}$ (Piyakarnchana, 1999; TWAP, 2015a, 2015b) which supports the abundance of fisheries resources making these areas an important fishing ground in this region. Coastal and marine fisheries are important to the local and national economies of Thailand and the country's international trade and also play a very important role in food security (Juntarashote, 1998; Lymer et al., 2008). Marine capture fisheries are considered as the main subsector of capture fisheries in Thailand. In 2015, the marine capture production contributed 1,317,217 tons or 88 percent of the total capture production; most of them (about 72 percent of the marine capture production) were captured from the Gulf of Thailand while another 28 percent were from the Andaman Sea generating as much as 59,900 million Baht of national income (DoF, 2018a).

Due to the increased global demand of fisheries products, Thai fisheries were rapidly developed in terms of the number of fishing vessels and the introduction of new mechanized fishing gears such as trawls for catching demersal fish, purse seine fisheries for catching pelagic species (Pauly & Chuenpagdee, 2003). The number of fishing vessels had been increased rapidly since the mid-1960, contributing to high volume of landings. As a result, Thailand became one of the important global exporters of fisheries products (DoF, 2015c; Lymer et al., 2008). With a rapid increase in fishing intensity and lack of appropriate management, the long-lived fish with higher trophic level have been overexploited, transiting the fish stocks to short-lived species with lower trophic level. The phenomenon that Pauly et al. (1998) called "*Fishing down food webs*" illustrating unsustainable fisheries system took place in the Gulf of Thailand (Pauly & Chuenpagdee, 2003). The official statistics revealed that from 1995 to 2015 the quantity of marine fisheries production decreased from 2,827,400 to 1,317,217 tons with an average declining rate of 3.8% per year (DoF, 2018a). In addition, the catch per unit effort (CPUE) has also reduced with an average declining rate of about 15% per year according to the trawling surveys, conducted by the Thai Department of Fisheries (DoF, 2015c).

While the heavy exploitation has occurred, the concerns on the sustainability of fisheries resources have been increased. Several studies show that fishing impacts on ecosystems include habitat destruction, mortality of non-target species, and change in population dynamics, function and structure of ecosystem (Chuenpagdee et al., 2003b; Garcia et al., 2003; Pauly et al., 2005b; Pikitch et al., 2004; Rocchi et al., 2017; Zhang et al., 2018). These impacts need to be considered as an integral part of an ecosystem approach to fisheries management (Garcia et al., 2003), and also in accordance with the Code of Conduct for Responsible Fisheries which provides a framework for national and international efforts to mitigate fishing impacts on marine ecosystems (FAO, 1995). In 2002, the "Ecosystem Approach to Fisheries " (EAF) concept was articulated (FAO, 2003; Garcia et al., 2003), as follows: "an ecosystem approach to fisheries strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries." EAF is also one of the basic principles found in the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries (SSF Guidelines), which consider the linkage between ecosystem health and associate biodiversity with livelihoods and well-being of the small-scale fisheries sector (FAO, 2015).

Like many countries around the world, Thailand endorses several international fisheries instruments, such as the FAO Code of Conduct for Responsible Fisheries, Convention on Biological Diversity (CBD), Convention on International Trade in Endangered Species (CITES), and SSF Guidelines. Hence, the Department of Fisheries

(DoF), the main institution responsible for fisheries management in Thailand, has set rules and regulations, including conservation measures, and incorporated them into the fishery national plans. For instance, the DoF Strategic Plan for 2017–2021 illustrates strong efforts to contribute sustaining fisheries resources and biodiversity and complying with the international regulations and conventions (DoF, 2017a), while the Marine Fisheries Management Plan 2015–2019 has been drawn up to ensure sustainable management of marine fisheries in Thailand, by focusing on reducing fishing effort and mitigating illegal, unreported and unregulated fishing (IUU) (DoF, 2015c). As part of the latter plan, efforts to reduce catch of juveniles, restore critical habitats, and improve fisheries data information management are also mentioned (DoF, 2015c). In accordance with EAF, implementing these plans requires a broad set of supporting data, including those related to ecological impacts of fishing.

While numerous studies have been conducted to investigate various aspects of fisheries in Thailand, it is not clear what is currently known about fishing impacts. The comprehensive information and knowledge about the fishing impacts in Thailand is limited making it difficult to implement the EAF and to achieve sustainability. Hence, this dissertation is highly required to support the establishment of regulations and policies to mitigate the fishing impacts in Thailand.

## 1.2 Research questions



Essentially, this research was inspired by a lack of comprehension on the environmental impacts generated by different fishing gears on marine and coastal resources in Thai waters. Hence, the core research question can be drawn as *what are the ecological impacts of fishing gears in Thai waters?* The supporting research questions can be established as follows:

1) What is the existing knowledge and gap regarding by-catches and habitat damages of fishing gears in Thai waters?

2) What is the current state of by-catches and habitat damages of small-scale fishing gears in Ko Chang and the Strait of Ko Chang?

3) What are the relative ecological impacts and the levels of severity of ecological impacts caused by different fishing gears?

## 1.3 Objectives

In this study, several research objectives are established to answer the research questions above:

1. To review existing knowledge and analyze knowledge gap regarding and habitat impacts of fishing methods in Thai waters.
2. To investigate fishing impacts in terms of by-catches and habitat damages, of some fishing gears in Ko Chang and the Strait of Ko Chang, Trat Province.
3. To analyze relative ecological impacts of fishing gears and to rank the levels of severity caused by different fishing gears and to suggest proper policies to mitigate the impacts.

## 1.4 Scope of the Study

In regards with above research questions, the dissertation consists of three parts (Figure 1). Firstly, existing knowledge and knowledge gap were analysed regarding by-catches and habitat impacts of fishing methods in Thai waters. Secondly, the estimation of by-catches and habitat damage of fishing gears were examined in Ko Chang and the Strait of Ko Chang, Trat Province with the following topics: 1) Analysis of small-scale fisheries bycatch in Mu Ko Chang, Trat Province; 2) An in-situ study of impact of fish traps fisheries on coral reefs in Ko Kut and Ko Mak, Trat Province; 3) the impacts of trawl, push net, and dredge fisheries on macrobenthic communities in the Strait of Ko Chang, Trat Province, Thailand. Finally, the expert-based gear impacts assessment was conducted to analyze and assess the relative ecological impacts of fishing gears using transdisciplinary approach.

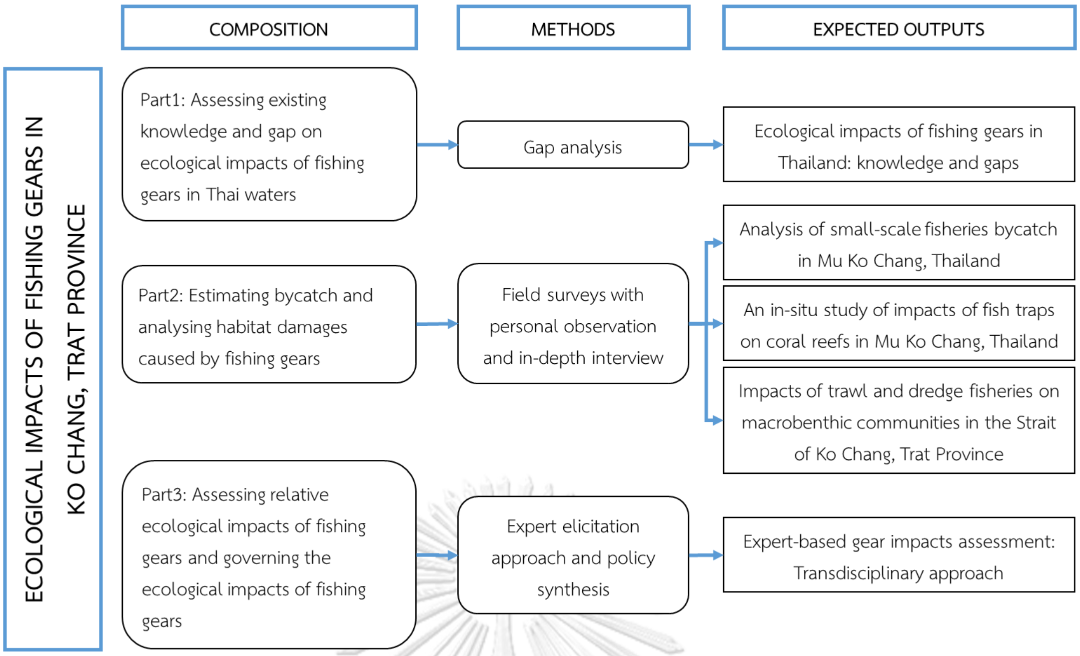


**Figure 1** Framework of the study

## 1.5 Expected Benefits

1. The knowledge and its gap regarding by-catch and habitat impacts of fishing methods in Thai waters.
2. Understanding the ecological impacts in terms of bycatch and habitat damages of fishing gears in Ko Chang and the Strait of Ko Chang, Trat Province.
3. The comprehension of ecological impacts of fishing gears and the levels of severity of different fishing gears.

### 1.6 List of acronyms

| | |
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| CBD | Convention on Biological Diversity |
| CCCIF | Command Center for Combating Illegal Fishing |
| CITES | Convention on International Trade in Endangered Species of Wild Fauna and Flora |
| CPUEs | Catch per Unit Efforts |
| DoF | Department of Fisheries, Thailand |
| EAF | Ecosystem Approach to Fisheries |
| EEZ | Exclusive Economic Zone |
| EU | European Union |
| FAO | Food and Agriculture Organization of the United Nations |
| GRT | Gross register tonnage |
| IUCN | International Union for Conservation of Nature |
| IUU | Illegal, unreported and unregulated fishing |
| NRSA | National Reform Steering Assembly |
| SDGs | Sustainable Development Goals |
| SEAFDEC | Southeast Asian Fisheries Development Center |
| SSF Guidelines | Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication |
| TPSO | Trat Provincial Statistical Office, Thailand |
| TWAP | Transboundary Waters Assessment Programme |
| UNEP | United Nations Environment Programme |

# CHAPTER II
# LITERATURE REVIEWS

## 2.1 Marine fisheries in Thailand

### 2.1.1 Development of Thai marine captured fisheries

With 323,488 $km^2$ of the total economic zone (NRSA, 2017), Thai waters harbor diverse marine and coastal ecosystems with the high primary productivity of more than 300 $gC.m^{-2}.yr^{-1}$ (Piyakarnchana, 1999; TWAP, 2015a, 2015b) which supports the abundance of fisheries resources making these areas an important fishing ground in this region. Like other countries, marine fisheries in Thailand has a long history with the periods of rapid development, stagnation, and declined.

Before 1925, the marine fisheries in Thailand were totally artisanal or small-scale and operated near the coasts. Simple fishing gears such as cotton net, harpoons or spears, and traps were created using materials found in their locality and operated with non-powered vessels. Wing set bag, set bag net and the bamboo stake trap were common stationary fishing gears found during that time and those had been used since 1897 (Panayotou & Jetanavanich, 1987). The use of Chinese purse seine, recognized as '*Uan tang-ke*', was introduced to Thailand in 1926 to catch pelagic fish such as anchovies, sardines, mackerels, etc. Before that, the Siamese purse seine or '*Uan Chon',* had been created by Chinese fishers, however no official record of this fishing gears was found (Yingyuad & Chanrachkij, 2010). Meanwhile, drive-in net, called '*Muro Ami*', was introduced to Thailand and other Southeast Asian countries by Japanese fishers to catch demersal fishes especially the Family Caesionidae in coral reefs and underwater pinnacles (G. R. Morgan & Staples, 2006).

Although the paired trawl with motorized vessels had been firstly introduced in Thai marine fisheries in 1930, the use of this fishing gear was not much popular. During 1950 to 1980, several modern mechanized fishing gears were introduced, especially, a rapid growth number of trawlers in Thailand during 1950 – 1960. The otter-board trawlers were introduced by Germany (Nitithamyong, 2000; UNEP, 2007).

According to the fishing vessel statistics during 1960 – 1981, the number of trawlers was sharply increased from 99 vessels in 1960 to 3,114 and 6,633 in 1970 and 1981, respectively catching the demersal fishes as much as 1,058,000 tons (DoF, 1983). Trawling had been heavily operated in the Gulf of Thailand from shallow to the deeper areas with the maximum depth of 50 meters. The total catch in 1981 was about 4 percent higher than the maximum sustainable yield estimated by the DoF. It is estimated that the Gulf has been facing with overfishing since 1973 (Boonyubol & Pramokchutima, 1982). Both demersal and pelagic fishes were continuously and heavily caught in Thai Waters during this period.

In early 1970s, push net fisheries, particularly the commercial ones, were developed and extensively operated in shallow water (lower 15 meter in depth) while light luring fisheries were developed to catch small pelagic fishes using traditional lamp and then some of the traditional lamps were later replaced with electric lamps in 1978 contributing to the increases in landings of small pelagic fishes since 1978. In addition, other fisheries-related industries including ice production, cold storage, food processing, etc had been developed. However, without proper fisheries management, the total catch has been decreasing since 1995 as well as the catch rate, has continuously declined (Boonyubol & Pramokchutima, 1982; Pauly & Chuenpagdee, 2003; UNEP, 2007).

Since the rapid decrease of marine fish stocks as well as an increased number of fishing vessel operated in the Gulf of Thailand, Thai fishers seek for new fishing grounds in neighboring waters in the South China Sea, the Indian Ocean. However, the Thai fishing vessels had to return to fish in Thai waters because of the compliance according to the United Nations Convention on the Law of the Sea (UNCLOS) which has been effective since 1982. Each coastal country declared its own Exclusive Economic Zones (EEZs), for example, Cambodia (declared on 15 January 1978), India (declared on 15 January 1977), Indonesia (declared on 21 March 1980), Malaysia (declared on 25 April 1980), Myanmar (declared on 9 April 1977), Philippines (declared on 11 June 1978), and Singapore (declared on 15 September 1980). Thailand claimed its EEZ on 23 February 1981.

This declaration made the loss of previous fishing areas where Thai fishers had operated before resulting in the reduction of the national fisheries production (UNEP, 2007). Yet, the fishing gears and methods in large scale fisheries have still developed to catch more fishes using more advanced technology such as echo sounder, sonar, hydraulic hauler etc. Some historical timeline in regards with Thailand fisheries development are shown in Table 1.

**Table 1** Timeline and important events regarding marine fishing development in Thai waters

| Year | Event |
|---|---|
| Before 1925 | Traditional fisheries were found in Thai coastal waters using simple fishing gears such as set net, set bag, wing set bag, traps, gill net etc. as well as collecting shells along the coasts. |
| 1925 | Chinese purse seine with traditional vessel was introduced to catch Indian mackerels and Indo-Pacific Mackerels. Drive in net called “Muro Ami” was introduced to catch fish on rocky areas such as reefs and underwater pinnacles. |
| 1930 | Paired trawl with motorized vessels was introduced in Thai marine fisheries |
| 1934 | The Act of Fishing Right in Siam was enacted. |
| 1935 | The number of fishing vessels using Chinese purse seine was increased to 200-300 vessels |
| 1947 | The first Fisheries Act was established. |
| 1950 | The survey on aquatic resources, in cooperation with the Kingdom of Denmark, was done during 1950 – 1952 using the vessel named “Galathea”. |
| 1952 | Trawl fisheries were developed by introducing otter board trawl |

**Table 1** Timeline and important events regarding marine fishing development in Thai waters (Continued)

| Year | Events |
|---|---|
| 1959 | The NACA project was launching during 1959 – 1961 in order to conduct surveys on aquatic resources in the Gulf of Thailand using the vessel named "Stranger" of the Scripps Institution of Oceanography, USA. |
| 1964 | With an increased number of large scale fisheries, the National Fisheries Association of Thailand was established. |
| 1965 | The project on 'Pacific mackerel investigation' to study the life history of Pacific mackerel (*Rastrelliger* spp.) in the Gulf of Thailand |
| 1971 | Push net fisheries were extensively operated in shallow water (lower 15 meter in depth). |
| 1974 | Light luring fisheries were developed using traditional lamp and then some traditional lamps were replaced with electric lamp in 1978. |
| 1977 | Neighboring countries (Burma, Vietnam, Cambodia, the Philippines, Indonesia, and Malaysia) stared claiming their exclusive economic zones (200 nm). |
| 1980 | Electronic devices such as echo sounder, sonar, hydraulic hauler were applied in large scale fisheries. |
| 1981 | Thailand announced its exclusive economic zones |
| 1999 | The Revised version of Fisheries Act were initially drafted. |
| 2010 | The Association of Thai Artisanal Fishers was registered. |
| 2011 | The European Commission started evaluated the Thai's fishery management system in relation to IUU fishing. |
| 2014 | The European Commission has officially issued 'yellow card' for not taking sufficient measures in combating the Illegal, Unregulated and Unreported fishing problems. |
| 2015 | Fisheries Act 2015 was taken into force in order to mitigate IUU fishing problem. |

**Table 1** Timeline and important events regarding marine fishing development in Thai waters (Continued)

| Year | Event |
|---|---|
| 2015 | The command center for combating illegal fishing (CCCIF) has been established. |
| 2015 | The European Commission believed that the Fisheries Act 2015 does not have enough measures to combat the IUU fishing. Consequently, the DoF urgently drafted up the Royal Ordinance on Fisheries which has been taken into force since 2015. |
| 2015 | Marine Fisheries Management Plan of Thailand: A National Policy for Marine Fisheries Management 2015 – 2019 was created. |
| 2017 | The second amendment of the Royal Ordinance on Fisheries is taken into force. |

Sources: DoF (1965, 2011, 2015c); Nitithamyong (2000); UNEP (2007)

In summary, Thailand has a long history of fisheries development starting from artisanal to commercial purposes. With a high demand of seafood and the technological development of fishing gear and vessels, the fisheries resources in Thailand has been heavily exploited leading to a significant decline in fish stock. This reflects the imbalance between the rapid fisheries development and the suitability of fisheries management. Meanwhile, global concerns on food security as well as environmental impacts of fishing, has also been increased asking all countries to take measures to support the sustainability of fisheries resources. Thai government has paid much attention on these issues, particularly the IUU fishing. Several efforts have been done to support the implementation on combatting the IUU fishing. However, more efforts and actions as well as researches are still required to comply with relevant international agreement and conventions to achieve the Sustainable Development Goals.

2.1.2 Thai marine captured fisheries production

Coastal and marine fisheries have been recognized as one of the important sectors contributing to the local and national economies, local livelihoods, and food security (Juntarashote, 1998; Lymer et al., 2008). Particularly, marine capture fisheries are the major contribution to capture fisheries in Thailand. Considering the statistics of fishery production since 1979 to 2012 (Figure 2), it can be divided into two phases; a significant increase of the marine fish caught were reported until 1995 because of the development of fishing in Thailand. Several fishing gears were introduced and modified to catch more fish. In 1995, a total landing of marine fish reached to 2,827,400 tons. Since then, declining phase was started exhibiting that the annual catches has been decreased with the average of 3.8% per year. In 2012, the total landings was only 1,500,200 tons generating a value of 54,911,059 baht. Most of them were from the Gulf of Thailand (1,061,847 tons), while 438,353 tons of the total landings were from Andaman Sea. About 61.1 % of total landings are food fish, followed by trash fish (21.4%), squids and cuttlefishes (8%), shrimps (3%), crabs (2%), mollusks (1%), and other marine species (2.8%) (Department of Fisheries, 2014a). Importantly, about 40% of the trash fish were juveniles of economic species (Tossapornpitakkul et al., 2008). In 2015, the marine capture production contributed 1,317,217 tons or 88 percent of the total capture production; most of them (about 72 percent of the marine capture production) were captured from the Gulf of Thailand while another 28 percent were from the Andaman Sea generating as much as 59,900 million Baht of national income (DoF, 2018a).

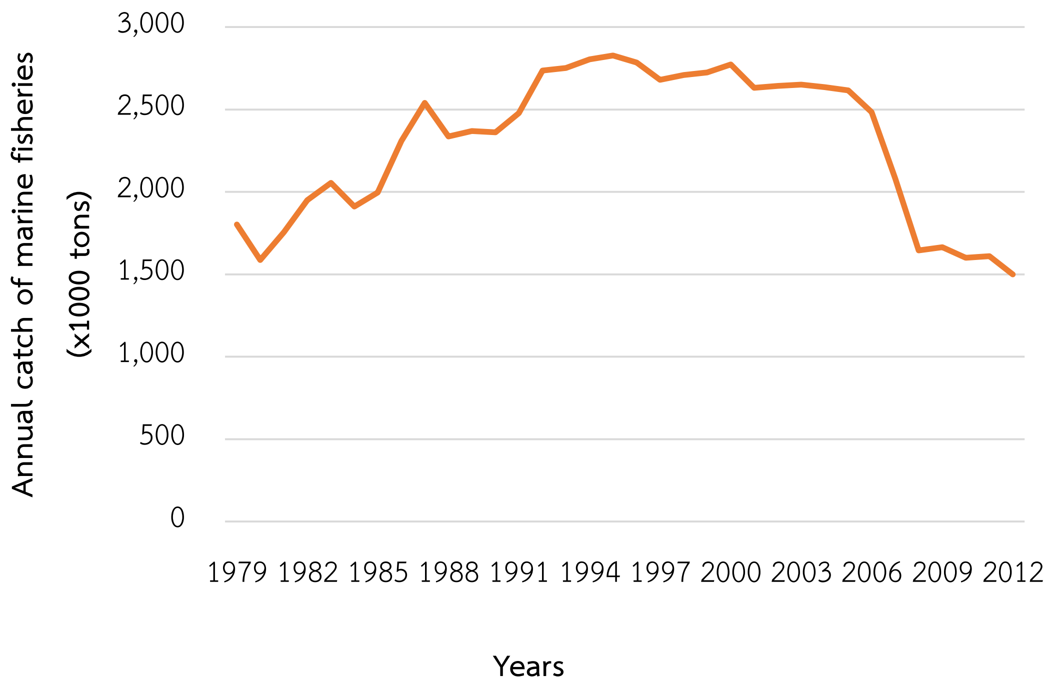



**Figure 2** Marine Fisheries production in 1979-2012

Source: Department of Fisheries (2005, 2014)

The surveys on marine fisheries resources, continuously conducted by Department of Fisheries, also show reduction in Catch Per Unit Efforts (CPUEs) illustrating the critical state of Thailand's fisheries resources. The DoF's research vessels with otter-board trawl, which has a cod-end mesh size of 4 centimeters, have been used for assessing the CPUEs. The surveys are implemented annually at 85 stations in the Gulf of Thailand and 64 stations in the Andaman Sea covering a total area of 115,270 and 60,327 square kilometers in the Gulf of Thailand and the Andaman Sea.

In the Figure 3, CPUEs have declined from about 151 kg per hour in 1967 to about 25 kg per hour at present. As the reduction of the CPUEs reflecting a decline in fish stock, the fishing gears have been modified using small-mesh size net to catch more fish, or spend more time in each fishing trip as well as do fishing in the neighbors' fishing areas.

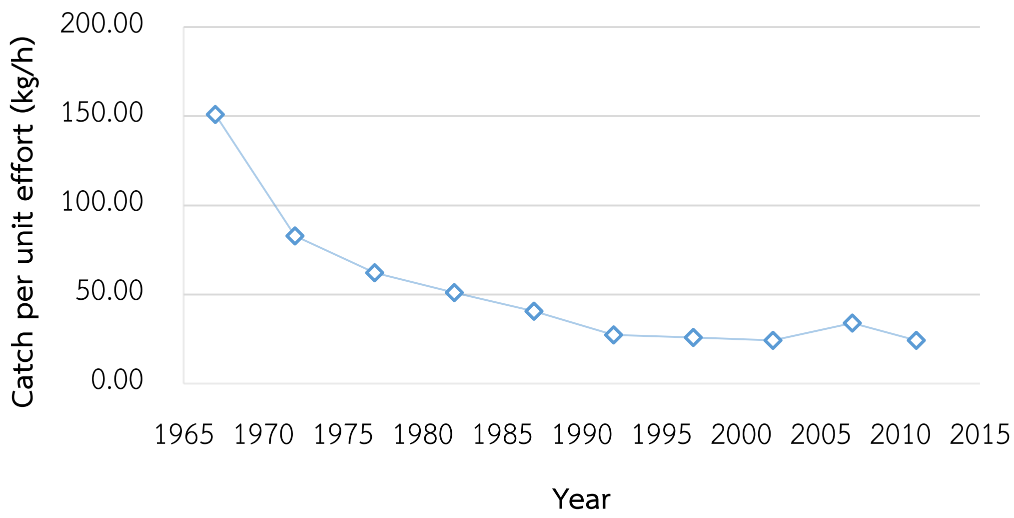



**Figure 3** Average catch per unit effort of Thai fisheries from the DoF research vessels with otter-board trawl

Sources: Department of Fisheries Online Statistics

2.1.3 Fishing vessels and gears in Thailand

Like other countries, fishing gears in Thailand are very diverse ranging from large-scale with sophisticate operation to simple, small operation. Small-scale (artisanal) fisheries tend to operate inshore with smaller vessels, while large-scale (commercial) fisheries are conducted further offshore. According to the fishing vessel statistics of Thailand, as of April 2018, a total of 37,698 registered fishing vessels were reported. Of which about 70% (26,373 vessels) are small-scale while another 30% (11,325 vessels) are large scale. Most of small-scale fishing vessels (86%) are less than 5 GRT in size. The fishing vessels with the size of 20 – 60 GRT were mostly found accounting for 48% of total large scale fishing vessels. Trawlers (3,601 vessels) were mostly found in large scale fishing vessels followed by falling nets (2,048 vessels), traps (1,089 vessels). Otter-board trawls (34%) are predominant in trawlers, followed by pair-trawls (20%) and beam trawls (10%) (DoF, 2018b). However, the number of registered fishing vessels is still below the real number of fishing vessels, particularly the small-scale fishing vessels which have not yet registered with the Department of Fisheries.

The fishing gears in Thailand can be broadly classified into 12 categories including: trawl nets,  seine nets, surrounding nets, dredges, lift nets, falling nets, gill nets and entangling nets, push nets, traps and pots, pound nets or set nets, hook and lines, and miscellaneous gears (DoF, 1997; SEAFDEC, 2004). According to the Royal Ordinance on Fisheries B.E. 2558 (2015), artisanal and commercial fishing is classified by the gross tonnage of the fishing vessel. Commercial fishing generally refers to the fishing operations that use a mechanized fishing vessel with its size of ten gross tonnage or above. However, the commercial fishing can also be classified with the specific fishing gears according to the notifications of the Ministry of Agriculture and Cooperatives as listed in the Table 2.

The use of some fishing gears were also prohibited in Thai waters, according the Royal Ordinance on Fisheries B.E. 2558 (2015) including (1) several types of set bag nets or any other gears that their characteristics and operation are similar to those set bag nets; (2) an elongated collapsible trap  (in Thai called ‘Ai Ngo’); (3) a trawl net with its cod-end mesh size of smaller than that announced by the Department of Fisheries and the Ministry of Agriculture and Cooperatives; and (4) a push net with a mechanized fishing vessel except a Acetes push net (Figure 5). The uses of fishing gears are also controlled spatially and seasonally in order to protect or reserve fish stocks from overexploitation, particularly in fragile habitats or during spawning periods.

**Table 2** List of large- and small-scale fishing gears generally found in Thailand

| Large-scale fishing gears[1] | Small-scale fishing gears[2] |
|---|---|
| 1. All types of trawlers (otter board trawl, pair trawl, beam trawl etc) | 1. Fish gillnet |
| | 2. Crab gillnet |
| 2. Purse seine | 3. Shrimp trammel net |
| 3. Dredge | 4. Squid trammel net |
| 4. Fish gillnet with its length of more than 2,500 meters | 5. Mackerel and mullet gill net |
| | 6. Beach seine |
| 5. Crab gillnet with its length of more than 3,000 meters | 7. Acetes push net |
| | 8. Lift net |
| 6. Shrimp trammel net with its length of more than 2,500 meters | 9. Squid falling net |
| | 10. Anchovy falling net |
| 7. Squid trammel net with its length of more than 2,500 meters | 11. Cast net |
| | 12. Long line |
| 8. Crab trap with its mesh-size of 2.5 inches and the quantity of not greater than 200 units | 13. Bottom long line |
| | 14. Hand line and pole & line |
| | 15. Trolling line |
| 9. Squid trap with the quantity of not greater than 100 units | 16. water set net |
| | 17. Fish trap |
| 10. Octopus trap with the quantity of not greater than 2,000 units | 18. Crab trap |
| | 19. Squid trap |
| 11. Falling net, lift net or squid lift net with light luring | 20. Octopus trap |
| | 21. Shrimp trap |
| 12. Falling net, lift net or anchovy lift net with light luring | 22. Long trap |
| | 23. Bamboo stake trap |
| 13. All gears with light used to lure fish underwater | 24. Jellyfishes scoop net |
| | 25. Shellfish collecting |
| | 26. Harpoon |
| | 27. Other gears |

Sources: [1]Notifications of the Ministry of Agriculture and Cooperatives on the establishment of fishing gears, fishing methods, and fishing areas prohibited in coastal seas B.E. 2560 (2017), dated on 9$^{th}$ November 2017; [2] DoF (1997)

(a) (b) (c) (d)

**Figure 4** Fishing vessels in Thailand: (a) non-motorized vessel, (b) motorized vessel with outboard engine (c) motorized vessel with inboard engine, (d) motorized vessel with inboard engine (large-scale fishing vessel)

Source: personal observation

(a) (b)

**Figure 5** Photos of some illegal fishing gears in Thailand: (a) elongated collapsible trap, (b) push net

Source: (a) http://www.samutsongkhram.go.t, (b) personal observation

## 2.2 Ecological impacts of fishing

Marine fisheries is one of the ecosystem services provided by marine and coastal ecosystems contributing an important food source to human worldwide (Bene et al., 2016; Pauly et al., 2005a). However, such exploitation also causes various negative impacts on marine ecosystem which have been a globally challenging issue in fisheries management and governance to sustain fisheries resources and maintain healthy ecosystem health (Bundy et al., 2017; Crespo & Dunn, 2017; Dayton et al., 2002; Dayton et al., 1995). Fishing generates both direct and indirect impacts on ecosystems. Reduction of fish population due to overfishing can be seen as direct impacts. Indirect or collateral impacts are still existed but less attention has been paid to including habitat destruction and mortality of non-target species or bycatches. Both of the impacts could lead to the imbalance of the marine ecosystem resulting in negative consequences such as change in population dynamics, ecosystem function and structure as well as their services and goods (Chuenpagdee et al., 2003b; Corrales et al., 2015; Crespo & Dunn, 2017; Dayton et al., 1995; Jackson, 2008; Pitcher et al., 2017; Stephenson et al., 2017).

### 2.2.1 Bycatch



Bycatch becomes a significant issue on fisheries governance and marine biodiversity conservation (Brandini, 2014; Hall et al., 2000; Kelleher, 2005). Studies on fisheries bycatch and discards have been increased worldwide after that FAO promoted conversion from discards to utilization in 1982 (Matsuoka, 2008). Bycatch and discards have also been mentioned in various international regulations in order to actively mitigate bycatch impacts. In response to that, the issue on bycatch is involved in various international instruments such as:

- the Code of Conduct for Responsible Fisheries in which the issues of bycatch and discards are mentioned in the section of fisheries research stating that "*States should collect reliable and accurate data which are required to assess the status of fisheries and ecosystems, including data on bycatch, discards and waste. Where appropriate, this data should be* *provided, at an appropriate time and level of aggregation, to relevant States and subregional, regional and global fisheries organizations"* (FAO, 1995);

- International Guidelines on Bycatch Management and Reduction of Discards which were developed by relevant parties including fisheries experts, fishery managers from governmental bodies, related fishing industries, researchers and non-governmental and intergovernmental organizations. The guidelines aim to provide a management framework and measures to conserve target species, bycatch as well as natural habitats. These guideline are voluntary that States and Regional fishery bodies may applied them to formulate appropriate measures for managing bycatch and discards in the fishing activities (FAO, 2011);
- Indicators for the Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets in which bycatch and discards are focused in the target 6 Sustainable management of marine living resources. The target aims to reduce adverse impacts of fishing activities on threatened species and vulnerable ecosystems including target stocks, bycatch and habitat damages (https://www.cbd.int/sp/targets/).

Regional action plans regarding bycatch have been initiated, for example, the EU Action Plan on Cetacean Bycatch plays an important role in conserving cetacean bycatch (harbour porpoises, dolphins and whales) in Europe. The EU Member States formulated strategies aiming to reduce those bycatch towards zero (Dolman et al., 2016). Beside the cetacean bycatch, EU also developed measures to reduce seabirds in fishing gears including avoiding fishing in critical areas and/or duration, limiting or deterring bird access to or taking baited hooks, and decreasing the baited hooks' attractiveness and visibility (EU, 2012). In the Southeast Asian region, there were some efforts on bycatch management through the project on Strategies for Trawl Fisheries Bycatch Management (REBYC-II CTI). The project is financially supported by the Food and Agriculture Organization of the United Nations (FAO) and Global Environment Facility (GEF). Indonesia, Papua New Guinea, Philippines, Thailand and Viet Nam were participated in while the Southeast Asian Fisheries Development Center (SEAFDEC) is a coordinating body. The main goal of this project is to encourage the responsible trawl fisheries to reduce retained and discarded bycatch as well as other possible fishing impacts on marine biodiversity in the Coral Triangle and Southeast Asian waters (http://www.rebyc-cti.org/).

In a global context, FAO is currently working to address the issues of bycatch and discards to the International Guidelines on Managing Bycatch and Reduction of Discards. Global assessments of discards are an important projects that FAO is currently conducting to provide an up-to-date global status and information on the amount and rate of discards in various fisheries as well as the projection of discarding trends. In addition, best practices, fishing methods, guidelines strategies are also disseminated to mitigate bycatch, discards and other collateral impacts through various projects, for example, the strategies for trawl fisheries bycatch management in the Coral Triangle and Southeast Asian waters (REBYC-II CTI) and in Latin America and Caribbean (REBYC-II LAC). Furthermore, the FAO's efforts on fisheries bycatch and discards also aim to contributes to the Sustainable Development Goals (SDGs), particularly the 14$^{th}$ SDG (sustainably use and conserve the oceans) including the SDG14.1 (preventing and reducing marine pollution, particularly marine debris and nutrient pollution), SDG 14.2 (avoiding significant adverse fishing impacts on and strengthening the resilience of and restoring the marine ecosystems to achieve healthy oceans), and SDG14.4 (regulating fishing and terminating overexploitation, illegal, unreported and unregulated fishing and destructive fisheries and implementing science-based management plans for fish stock restoration) (FAO, 2018).

The definition of bycatch varies on the objective of each research and study. Generally, catch consists of two components that are target and non-target catch (called bycatch) while the bycatch can be further divided to retained or discarded bycatch (Alverson, 1994; Hall et al., 2000). Discarded bycatch or discards is marine species discarded either at sea or land for whatever reasons. For example, the species has little or no economic value due to that they have less consumption preference or poor condition (spoilage). The catching of the species is prohibited due to management regulations, the species is undersize or poisonous etc (Chuenpagdee et al., 2003b; Hall et al., 2000). Discarded bycatch is commonly considered as a waste of fishery resources (Huang & Liu, 2010; Kelleher, 2005). Some other definitions of bycatch can be available, for example, Davies et al. (2009) suggests that bycatch can be simply defined as the catch that is either unused (consumption, selling, or use as bait) or unmanaged. According to the Magnuson Fishery Conservation and Management Act, bycatch is defined as “fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards” (Benaka & Dobrzynski, 2004).

The discard of the world’s marine fisheries was firstly assessed by Alverson (1994) and later updated by Kelleher (2005) revealing that the weighted discard rate (the proportion of catch discarded and total catch) is estimated at 8 percent. About 7.3 million tons per year of discards are estimated during 1992-2001. Trawlers catching shrimp and demersal fish generate over 50% of the total estimated discards, especially the ones operating in tropical region which produce the highest discard rate (27% of total estimated discards) (Kelleher, 2005). Relative low discard rates can be found with purse seine, handline, jig, trap, and pot fisheries. Based on the study of Zeller et al. (2018), the amount of global discarded bycatch estimated from the reconstruction catch data varies through time. Before the year 2000, about 10 – 20 % of the total annual catch was discarded but after that it is dropped to about 10%. Large scale fisheries still contribute a majority of the global discards.

Marine mammal bycatch is one of the most concerns for the conservation of marine mammal. They have been threatened by anthropogenic impacts, especially fishing activities (Avila et al., 2018). They are incidentally caught or entangled by many fishing gears such as gillnets , trawlers, purse seine etc, resulting in injury and direct mortality. (Allen et al., 2017; Hamilton & Baker, 2016; Song, 2018). Also, sea turtles have been considered as one of the vulnerable species which are accidentally caught by various type of fishing gears, particularly longlines (Abdulqader et al., 2017; Carlson et al., 2016), trawls (Meyer et al., 2017), purse seine (Bourjea et al., 2014), and gillnets (Lucchetti et al., 2017). Elasmobranch bycatch (especially sharks and rays) have been investigated because they are one of the important meso and top predators playing important roles in regulating marine food web and trophic structure (Heupel et al., 2014). Besides other commercial fishing gears, elasmobranch species are important component bycatch in small-scale fisheries such as gillnets, shrimp trammel nets, longlines, etc (Baeta et al., 2010; Piovano & Gilman, 2017). A diverse range of benthic invertebrates including bivalves, gastropods, corals, sponges, echinoderms, sea pens and other invertebrate species are generally found as bycatch in fishing gears that touch seafloor, particularly bottom trawlers and dredges (Broadhurst et al., 2006; Prena et al., 1999; Salgado et al., 2018).

Although some studies reported that bycatch discarded at sea are food for other marine species such as fish, amphipods, isopods, cephalopods, ophiuroids, decapods (Bozzano & Sarda, 2002) seabirds (Bicknell et al., 2013), marine mammals (Heath et al., 2014), serious ecological concerns regarding bycatch are well perceived especially the impacts on entire marine ecosystems (Dayton et al., 1995; Kappel, 2005; Torres et al., 2013).

Knowledge on bycatch impacts in Thailand is limited. The study on bycatch in Thailand highly focused on trawl fisheries, particularly otter board trawls, reporting the amount of trash fish and undersized/juvenile. Shrimp trammel nets produces large proportion of discards (50 – 87% of total catch) as reported by Boutson et al. (2007b) and Preecha et al. (2011). Most of them being true trash fish and marine invertebrates. Crab gill nets is one of small-scale fishing gears that highly threatens crab diversity as 69 – 82% of total species of crabs caught from this gear had no commercial value (Wisespongpand et al., 2013) . Whilst, the proportion of discarded species from crab gillnet fisheries in Pattani Bay, Southern Thailand, ranges from 26 % - 47 % (Fazrul et al., 2015). Gillnet fisheries is also illustrated that it threatens to marine mammals (dugong, dolphins) (Adulyanukosol, 2010; Hines et al., 2005a; Hines et al., 2015; Whitty, 2014; Wongsuryrat et al., 2011). Boutson and Arimoto (2011a) reported that the discard rate of small-scale crab trap fisheries in the inner Gulf of Thailand (using less than 300 traps) and large-scale fisheries (operating with 2,000 traps) was significantly different accounting for 22 % and 30 %, respectively. Based on the study of crab trap fisheries in Kung Krabaen Bay, the eastern Gulf of Thailand, 49% of the total crabs were discarded and died. Besides, those are considered as trash crabs that has less consumption preference (Kunsook & Dumrongrojwatthana, 2017).

Recent studies mentioned above reveal considerable amount of bycatch generated by small-scale fisheries in Thailand which illustrates some potentially ecological impacts of the fishing gears on marine environment. However, no comparative study of bycatch across different fishing gears was found in Thailand. Lacking of such comparative data makes it very challenging for fisheries governance and impact mitigation to support the implementation of ecosystem-based fisheries management (Garcia & Cochrane, 2005; Hobday et al., 2011; Shester & Micheli, 2011).

Bycatch types are varied from different fishing gears and method of fishing due to varying degrees of species and size selectivity of different fishing gears (Hall et al., 2000; Shester and Micheli, 2011). Due to the recent declines of large marine vertebrates such as sea turtles, seabirds and marine mammals, have drove the attention on the ecological impacts of bycatch worldwide (Lewison et al., 2004). Also, studies on bycatch have increased during the past decade reflecting a growing concern on this issue (Soykan et al., 2008). However, lack of bycatch information, especially on small-scale fisheries, is still occurred especially in developing countries (Komoroske & Lewison, 2015; Shester & Micheli, 2011).

Ghost fishing refers to abandoned, lost, or discarded fishing gears but they still have potential to catch a wide range of marine species (Ozyurt et al., 2017; Stelfox et al., 2016; Wilcox et al., 2015). Ghost nets (microfilament lines and rope) cause the entanglement of cetaceans and turtles (Stelfox et al., 2016). Lost fishing nets can be laid on coral reefs resulted in limiting coral growth or mortality (Matsuoka et al., 2005). Abandoned and lost traps or pots can continue to catch fishes causing injury and mortality (Butler et al., 2018; Butler & Matthews, 2015; Renchen et al., 2014). Crabs and fish have mostly been reported in abandoned traps/pots. Abandoned fishing gears are also caused by interaction with mobile fishing gears, such as trawl fisheries (Gilman, 2015). For examples, Broadhurst and Millar (2018) investigated the ghost fishing of crab trap in southeastern Australia. They found that about 60% of entrapped crabs were injured while 5% of them were died. Putsa et al. (2016) also suggests that escape vents should be established in crab trap to reduce impacts of the ghost fishing, especially the small crabs.

2.2.2 Habitat damage

Fishing is one of the critical threats to important marine habitats, especially the coastal and continental shelf. Benthic habitats are risky to towed fishing gear (trawls and dredges) which touch the seafloor resulting in destruction of the seafloor physical environment and biological structures.

1. Changes in physical environment

Bottom trawling disturbs the physical structure of sea floor and its complexity that is a unique structure for marine biota. However, the disturbance level depends on frequency and geographic scale of trawling (Jackson, 2008). (Martín et al., 2014). Hydraulic dredging seems to generate higher level of impacts on physical structure of seafloor as its penetrating depth (16.1 cm) is considerably higher than what observed in bottom trawling (2.4 cm) and the positive relationship between penetration depth and the disturbance level on macrofaunal community is found (Hiddink et al., 2017). The seafloor change by beam trawlers varied by the intensity of trawling as well as the trawling operation. It was reported that conventional tickler-chain trawl produced higher level of seabed alteration compared with pulse electric trawl (Depestele et al., 2016). However, the use of pulse electric beam trawls is still controversial over the negative impacts of electrofishing (ICES, 2018).

Bottom fisheries also cause the instability of sediment system and chemical change because of the fluctuation of carbon flux between anoxic and oxic compartments (Kaiser et al., 2002). Suspension of anoxic sediments may also cost anoxic condition which is harmful to some marine species. A study by Chanrachkij (2012), who investigated the environmental change due to calm dredging in Thailand, revealed that dredging significantly increases the high value of total suspended solid affecting water transparency and light penetration. Besides, overall concentration of nutrients such as Ammonium-Nitrogen, Silicate-Silicon, and Orthophosphate-Phosphorus tended to be increased. An increased concentration of the nutrients generated by dredging activities may further encourage the occurrence of algal bloom (Anderson, 2009; Livingston, 2007).

2. Impacts on benthic community and biogenic structure

Recent studies support the scientific evidence of the impact of towed bottom fishing on biogenic structures and benthic communities. Towed bottom fishing gears especially dredges, otter-board trawls, and beam trawlers have been mostly studied (Harris, 2012; Jackson, 2008; Kaiser et al., 2002; Martín et al., 2014). Hydraulic dredges showed that higher impacts on biological disturbance compared with trawlers. It was reported that hydraulic dredges and bottom trawlers destroyed 6% and 41% of biota in the disturbed areas, respectively (Hiddink et al., 2017). In the coast of southern Portugal, the impact of bivalve dredge fishing on macrobenthic community structure was found having less abundance and diversity in dredged areas compared to undredged areas. Crustacean is considered to be the most vulnerable species to dredging (Gaspar et al., 2009). Similarly, the abundance of some polycheates in soft-bottom substrate in trawled area was less than what observed in untrawled areas, according to the study of (Romano et al., 2016).

According to Turner et al. (1999), fish stocks are depending on the fertility of habitat structure and biological condition. Hence, the loss of large epibenthic organisms has the effects on fish species. Coral reefs are important marine ecosystem with high diversity and productivity and they have been facing with human and natural disturbances (Hughes et al., 2003). Coral reefs provide lots of ecosystem services to society especially fisheries resources and also highly interact with local livelihoods (Cinner, 2014). Fishing activities in or near coral reef, however, generate the impacts on coral reefs, particularly physical damage from trap/pot fisheries and exploitation of reef-associated organisms (Al-Jufaili et al., 1999; Mangi & Roberts, 2006; Samoilys et al., 2017). Some reports illustrate that bottom trawling activity has an impact on the abundance of on coral reefs, deep-sea corals, sea anemones, sponges, and hydroids (Pierdomenico et al., 2018; Rooper et al., 2011). Destructive fishing practices like dynamite or blast fishing also cause destruction of reef structure and the impacted reefs show lots of rubble which is not suitable for new coral recruitment (Fox & Caldwell, 2006). Sediment suspension generated by trawling or dredging activities may cause impacts on coral growth (Erftemeijer et al., 2012).

Due to the high sensitive of seagrass to sediment loading, the seagrass can also impacted by dredging activities. Plowing the soft sediment may also cause negative impacts on seagrass productivity (Erftemeijer & Lewis, 2006). Sediment resuspension caused by bottom trawling may induce the redistribution of dinoflagellate cysts which may lead to dinoflagellate blooms (Brown et al., 2013).

## 2.3 Methodology review on fishing impact assessment

### 2.3.1 Field surveys

Bycatch data can be obtained from various methods such as sampling at landing sites, interviewing the fishers, fisheries logbook etc. However, the most reliable and accurate methods for collecting actual bycatch, especially discarded bycatch is onboard observation (Gray & Kennelly, 2018; Kelleher, 2005). This observation is useful for obtaining discarded bycatch, particularly discarded at sea. Onboard survey is also useful to observe the bycatch of marine mammals and reptiles because fishers usually release them into the sea as quick as possible (Gonzalez-But & Sepulveda, 2016; Kovacs & Cox, 2014; Machado et al., 2016). In some countries, those protected species cannot be caught and kept on board. Interview-based approach is also popular to collect data on rare marine species and historical data (Dmitrieva et al., 2013; Moore et al., 2010).

Ecological surveys are extensively applied in order to assess the impacts of fishing activities on natural habitat and benthic communities. Prior to conducting the ecological surveys, comprehensive review is conducted to understand the information of fishing activities and the characteristics of natural habitat (Grabowski et al., 2014; Pitcher et al., 2017). The change of biogenic structure and benthic community have been used as a bioindicator for assessing the fishing impacts (de Juan & Demestre, 2012; Vergnon & Blanchard, 2006).



### 2.3.2 Expert elicitation method

Expert elicitation refers to a board range of methodologies to assess and gather knowledge and information from experts. Knol et al. (2010) describes it as "*A structured approach of consulting experts on a subject where there is insufficient knowledge and seeks to make explicit the published and unpublished knowledge and wisdom of experts. Expert elicitation can serve as a means to synthesize the (limited) available knowledge in order to inform policies which have to be made before conclusive scientific evidence becomes available*". The expert elicitation deals with the complex situation where scientific knowledge is limited (Cook et al., 2010) and also promotes collaboration between key scientists, policymakers, private sectors, and local communities.

Expert elicitation is extensively applied to various disciplines. Expert knowledge is useful for environmental management (Burgman et al., 2011). In terms of marine and coastal management, expert elicitation was applied in policies and decision-making process. Expert knowledge are highly required not only for assessing the ecosystem vulnerability to human stressors to support ocean management (Kappel et al., 2012), but also in determining uncertainty and vulnerability of ecosystem from natural disturbances (Teck et al., 2010). Expert knowledge also plays significant roles in fisheries management and governance. Irwin et al. (2008) used the expert elicitation as a part of decision analysis which further support stochastic simulation models to evaluate the policies for yellow perch fishing in southern Lake Michigan. Schuhbauer and Koch (2013) mentioned that information from expert opinions from different stakeholders are useful to understand the nature of the recreational fishery in the Galapagos Marine Reserve. In determining ecological impacts of fishing gears, Chuenpagdee et al. (2003a) assessed collateral impacts of fishing in the US using damage schedule approach as a tool for eliciting judgement and information on the severity of fishing gear impacts from relevant stakeholders including fishers, scientists and managers. The damage schedule approach consists of integrating the knowledge, expert elicitation, and pair comparison to rank the fishing gear impacts revealing that bottom fishing gears such as bottom trawlers, gillnets, dredges, and midwater gillnets were assessed as the high impact level. The authors suggested the use of those gears in the US should be prohibited in ecologically sensitive areas. Similarly, Fuller et al. (2008) also applied the expert elicitation in assessing ecological impact of fishing gear in Canada. Bottom trawls showed the highest severity of impacts in both west and east coasts of Canada, followed by bottom gillnets and dredges etc. In order to mitigate the impacts related to bycatch and habitat damages, spatial management was suggested to incorporate with fisheries management in order to protect sensitive areas from destructive fishing gears. Lately, Grabowski et al. (2014) assessed the vulnerability of marine benthos to fishing gears impacts in which expert knowledge is used to rate susceptibility and recovery of marine benthos for each type of gears and substrates in case that scientific literature is shortage or inconsistent.

2.3.3 Environmental damage schedule

The Environmental damage schedule is one of the tools used for fishing impact analysis which is conceptually originated by Rutherford et al. (1998). The concept is mostly dependent on the judgements of relevant resource stakeholders including local communities, managers, and other related groups on the importance of resources and the preferences for changes in the environment. Participants are asked to select which option is least and most preferred. This exercise reflects the importance of resources based on local judgement which can be useful for formulating management policies and environmental decision-making process (Chuenpagdee, 1998).

Quah et al. (2006) applied the concept of environmental damage schedule to rank the relative importance of people's opinion on the values of various environmental damages or losses of urban in Singapore. One aspect of this study was focused on the state of environmental quality for different resources revealing that the four most important environmental problems included deterioration of coastal and marine environment, air pollution, ozone depletion, and an unhygienic environment relating to food and water.



Kukak (2009) also employed the damage schedule approach to exhibit the importance of natural resources in St. Paul's, a small outport community, Newfoundland, Canada. The findings revealed that lobster, forest, and herring were the most important natural resources according to the local residents and managers. Local residents and residents in surrounding communities agreed that oil development and exploration was the most beneficial activity to the area, closely followed by local research and management of fish stocks, the first choice of managers and tourists. This study illustrates that this approach is a useful tool to assess the values of resource interest groups which is further useful for formulating policies and the success of implementation.

Besides, the environmental damage schedule was used as a tool for determining ecological impacts of fishing gears in the United State (Chuenpagdee et al., 2003b) and Canada (Fuller et al., 2008) during 2002 and 2008, respectively. Both works applied the environmental damage schedule to assess the ecological impacts of fishing gears by integrating scientific knowledge regarding ecological impacts of fishing gears, then rating such impacts of fishing gears through convening expert workshop and raking the severity of those impacts.

A relative scale of importance and a damage schedule offer advantages in various aspects of environmental management including resource allocation, restoration efforts, and conservation initiatives. Applications of this concepts in various environmental resources which have been conducted globally illustrate that it is a reliable method in exhibiting the importance of natural resources without considering monetary values. This damage schedule method would be one of the reliable assessment frameworks for identifying the severity of ecological impacts of fishing gears in Thai waters. The findings under this study are beneficial to decision-making and further effective management of fishing gears.

**2.4 Fisheries in Mu Ko Chang, Trat Province**

Mu Ko Chang archipelago is located in Trat Province, the eastern Gulf of Thailand (Figure 6). Ko Chang is the largest island in the archipelago with its total area of about 212 $km^2$ surrounded with about 40 islands. Ko Kut and Ko Mak are located southward of Ko Chang. The archipelago is influenced by with tropical climate. Wet season starts from May to October driven by the southwest monsoon while dry season covers December to April. In 2017, a total precipitation of 5,733 mm was recorded while the temperature ranged from 30.8 - 34.6 °C (TPSO, 2017). With diverse terrestrial and marine ecosystems such as tropical rainforest, mangroves, seagrass beds, and coral reefs, Mu Ko Chang serves an important tourist destination of Thailand. While intensive tourism is occurred in the west coast of the island, other parts of the island remain traditional local livelihoods. In 2017, there are 8,087 local people with 5,485 households in Ko Chang (TPSO, 2017). Their occupations of the locals include plantations of fruits, coconut, pineapple, para-rubber tree, fisheries and aquaculture, tourism business, retailers, general workers etc.

Most marine capture fisheries in Ko Chang is small-scale with about 220 small-scale fishing vessels (Pers. Comm.). The fishing vessels are either non-motorized or motorized with outboard or inboard engine. Most of them operate in coastal water, generally 3 nautical miles. One or two crews who are family members or local people, or Cambodians are involved in fishing and other post-harvest process. Fishing gears generally found include drift nets, bottom nets, trammel nets, Acetes push nets, shellfish dredging, fish traps (reef and coastal fish traps), squid traps, crab traps, bottom longlines, trolling lines, pole and line  (Lunn & Dearden, 2006b; Songjitsawat et al., 2011).

Since Mu Ko Chang National Park was established in 1982 covering some terrestrial and marine areas of about 650 $km^2$, all natural resources of both marine and terrestrial environment are belonged to Mu Ko Chang National Park, the Department of Wildlife and Plant Conservation. According to the National Park Act 1961, the national park is basically a no-take zone. However, about 95% of fishing activities in Ko Chang are still found in the national park boundary (Lunn & Dearden, 2006a). Department of Fisheries (DoF) is responsible for monitoring and managing fishing activities outside the national park boundaries.

In the provincial level, as of 1st April 2018, a total of 1,445 fishing vessels with fishing licenses were registered to the Department of Fisheries consisting of 146 fishing vessels with its capacity of less than 10 GRT while the rest have its capacity of more than 10 GRT. A total of 614 fishing vessels are register with handline followed anchovy falling net (208 vessels) and otter-board trawl (135 vessels) (DoF, 2018b).

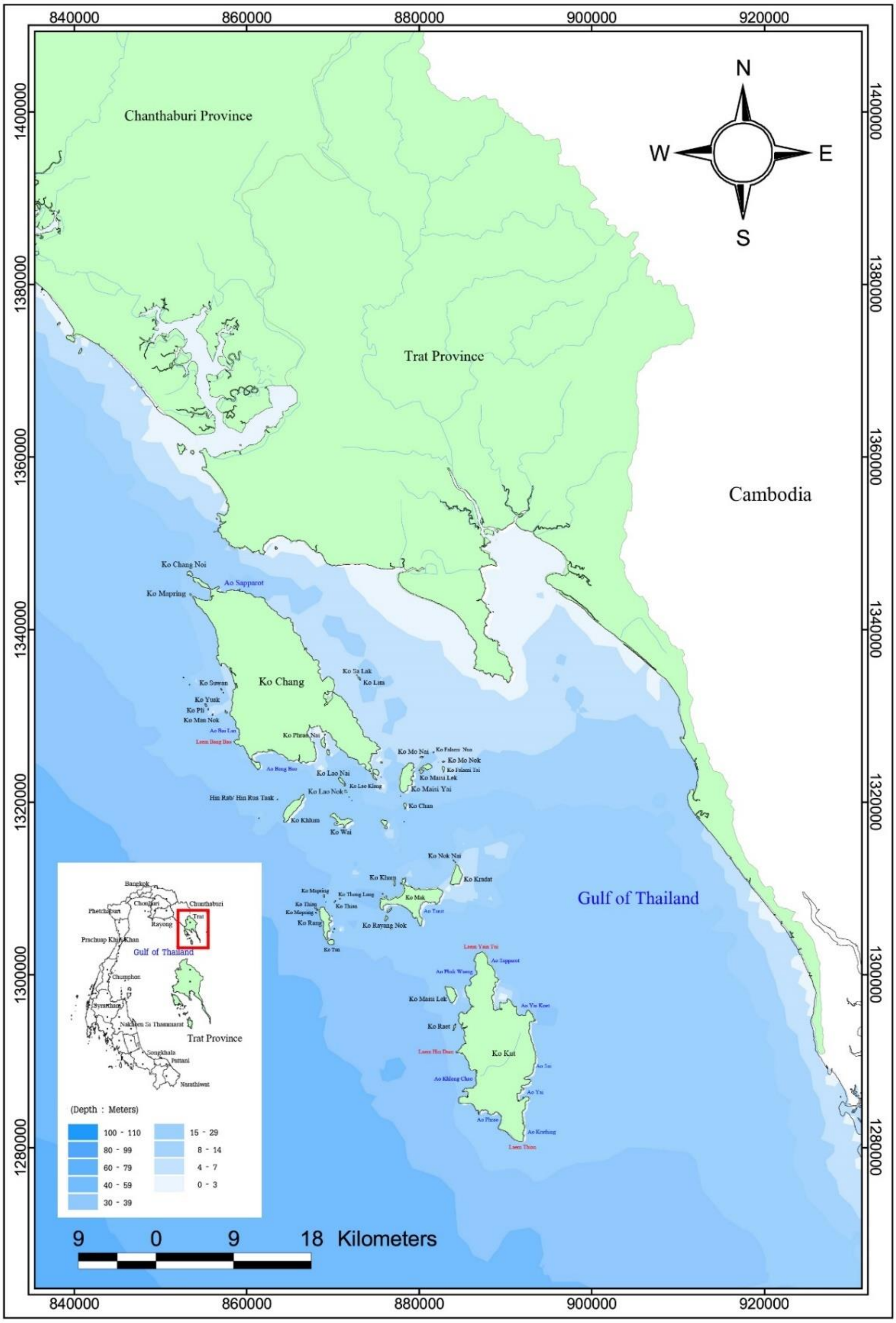



**Figure 6** Map of Mu Ko Chang , Trat Province

Before conducting the field studies, preliminary surveys were done during December 2014 – February 2015 in eight fishing communities located along the Strait of Ko Chang to observe and collect some information on fishing gears in Trat Province. The fishing communities included Ban Prong Lam Pid, Ban Ao Krud, Ban Mai Rood, Ban Nam Chiew, Ban Yai Mom in main land; Ban Klongson, Ban Salak Kok, and Ban Salak Phet in Ko Chang during. At least 10 small-scale fishing gears were generally found in the eight fishing communities namely gill nets, crap net, shrimp trammel nets, fish traps, crab traps, squid traps, octopus traps, bottom longlines, hand lines and trolling lines, and Acetes push nets. Whilst, push nets and dredges are usually considered as large-scale because they usually use medium to large vessel with a length  of more than 10 meters. Some information of each fishing gears were summarized in the Table 3.

**Table 3** Some fishing gears in Trat province

| Gear type | Target species | Gear description | Fishing operation | Mesh size (cm) | Bait | General bycatch found |
|---|---|---|---|---|---|---|
| Push net | Shrimp and fish | Consisting of a net and two poles that are generally made of bamboo or pine tree trunk or iron pipe. The net is opened by those poles like a V-shape. | The net is pushed toward by motorized vessel, the skis usually touch seafloor. | 1 - 5 | None | Snakes, sharks, starfish, rays algae, juvenile fish, squids, forage fish, gastropods, bivalves, crabs; about 30% of catch was discarded. |
| Acetes push net | Acetes | The structure of the gear is similar to push net. The push net is simpler and it can also be used by human power. | Fishers investigate a group of Acetes and then push them by pushing the net toward using either hand or motorized vessel. The skis are not touched seafloor. | 0.6 - 1 | None | Shrimp, juvenile fish and squid |
| Dredge | Short-necked clam, Blood cockle, Scallop | A box-shave sieve with a dimension of 40x60x50 cm for blood-cockle dredge, and 130x200x20 cm for short-necked clam. | The operation is similar to trawler. The box-shave sieve is hauled fishing on muddy or sandy substrates. | 1-2 | None | Snakes, rays starfish, squids, other gastropods and bivalves, crabs |

**Table 3** Some fishing gears in Trat province (Continued)

| Gear type | Target species | Gear description | Fishing operation | Mesh size (cm) | Bait | General bycatch found |
|---|---|---|---|---|---|---|
| Gillnet | Mullets, Promfet Mackerels | Single-layered of nylon filament with 1–3m deep and 20–1,000 m long. | Fishers encircled school of fish with their nets, then the fish entangled into their nets | 1–5 | None | Shrimp, crabs, Rays, sharks, dolphins, mantis shrimp, forage fish |
| Crab net | Swimming crabs | Nylon monofilament net with about 120 cm high. The length could be from 200 – 2,000 meters. | The net is operated in shallow coastal waters ranging from 3- 30 meters. | 10-12 | None | Mantis shrimps, shark, ray, gastropods, scallops, other bivalves, fish |
| Shrimp trammel net | Shrimp | Three-layered entangling net, measuring 1.5 m deep and 40–1000 m long, with light-weight sinkers lining the base of the net and small floats spread across the top | Designed to float vertically in the water column, nets were tied to bamboo poles at either end and left to drift in the current for 10–90 min | 4.2 for inner layer and 14 cm for outer layers | None | Cuttlefish, mantis shrimps, shark, ray, gastropods, scallops, other bivalves, fish |

**Table 3** Some fishing gears in Trat province (Continued)

| Gear type | Target species | Gear description | Fishing operation | Mesh size (cm) | Bait | General bycatch found |
|---|---|---|---|---|---|---|
| Collapsible crab trap | Swimming crabs, Mud crabs, and Stone crabs | Collapsible traps with the dimension of about 35 x50x15 cm which is made with a metal frame and nylon mesh | About 20 traps are attached on one set of main line at 5 m intervals, dropped close to the bottom and tied to buoy at the surface. The traps are hauled once or twice a day. | 2 | Bait fishes | Mantis shrimps, fish |
| Squid trap | Big-fin reef squid and Cuttlefish | Semi-cylindrical traps, made from wood and Polyethylene netting | Held vertically in the water column, about 2-4 m from the seafloor connected with rock and buoy. | 5 | Squid eggs with white plastic bag. The trap is covered with palm leaves | Fish, sea snakes, eels |
| Fish trap | Groupers and Snappers | Semi-cylindrical or cubical traps, made with wooden frames covered with nylon mesh. The dimension is ranged from 0.5–2.5 m long 2.2 –1 m wide 0.2 – 0.8 m high. | Traps were weighed to the bottom | 1.0 - 2.5 | Small non-commercial fishes or unbaited | Other fish |

**Table 3** Some fishing gears in Trat province (Continued)

| Gear type | Target species | Gear description | Fishing operation | Mesh size (cm) | Bait | General bycatch found |
|---|---|---|---|---|---|---|
| Octopus trap | Octopus | About 200-600 noble volute shells are attached on one line with at 2.0-6.5 m intervals. | The lines are dropped close to the bottom of sandy substrate with the depth of about 6-10 meters. The traps are hauled once a day. | - | None | None |
| Hook-and-line | Spanish mackerel, barracuda, squid, trevallies, and fourfinger threadfin | Still lines, measuring 10–15 m, or trolling lines, measuring 40–100 m, affixed with 1–3 large hooks (2.5 cm across, 7 cm long) | Still lines were attached to floats and dropped directly below the surface, whereas trolling lines were attached to rods and extended behind fishers' vessels | - | Artificial lures or Bait fishes | Sharks, rays sea turtles |
| Bottom longlines | Ray, Spanish mackerels, red snappers, bigeye snappers, groupers, threadfin | The bottom longlines consists of a main line with many branch lines (40-60 cm long) attached with hooks. The interval between two branch lines is 2.0-2.5 m. | The bottom longlines is placed on the seafloor for about two hours or more before hauling. | - | Bait fishes or squid | Shark, sea turtle, other fish |

Sources: Personal observation, Lunn and Darden (2006)

(a) (b) (c) (d)

**Figure 7** Some bycatch caught from fishing (a) bivalves and gastropod shells from push net and dredge, (b) gastropods and trash fish from bottom nets, (c) some trash fish from push net, (d) fish caught from fish trap.

Note: Photos taken from Ko Chang, Trat Province



According to table 3, a board rage of non-target species can be caught with the fishing gears. Some species which are protected by law or regulation, or risky to extinction (whales, dolphins, sea turtles, dugongs etc.) are categorized as regulatory bycatch. Furthermore, juvenile economic species were also categorized as bycatch. Fishers also added that there was significant amount of trash fish and other non-target species accidentally caught in push net which may cause a drastic decline of fisheries resources and habitat damages.

# CHAPTER III
# METHODOLOGY

## 3.1 Analyzing existing knowledge and gap on ecological impacts of fishing gears in Thai waters

### 3.1.1 Objective

The objective of this part is to compile existing literatures and analyse knowledge gaps of ecological impacts of fishing gears in Thailand. The study involves a comprehensive review of existing literature, including scientific articles, technical papers, newsletters, theses and dissertations, project reports, government reports and unpublished documents, based primarily on information available on websites, coupled by personal contacts.

### 3.1.2 Data collection

The web search was conducted during January to April 2016, using international and national research databases such as Web of Science, SCOPUS, and Thai Library Integrated System (ThaiLIS). The main search words were 'impacts', 'fisheries', 'fishing gear', 'bycatch, 'habitat' and 'trash fish.' The search was done in English and Thai language. Known fisheries experts were contacted by email and telephone to inquire about additional data, especially those that can only be found in unpublished reports and other gray literature. Finally, visits to relevant organisations were made to obtain information not available online.

### 3.1.3 Data treatment and analysis

Internet search results were checked for relevance and to eliminate duplication. The final set of data was then categorised into bycatch and habitat damage based on fishing gears, before performing content analysis. For the purpose of the study, habitat and bycatch definitions provided by Morgan and Chuenpagdee (2003) Morgan and Chuenpagdee (2003) are used. Bycatch includes non-target catch, consisting of catch of low-value species and discards. Habitat damage refers to damage to the living sea floor as well as alteration to geological structures including coral reefs, seagrass beds, and soft and hard bottom. Content analysis was done to extract the key information from each literature for analyzing existing knowledge and gap on ecological impacts of fishing gears in Thailand.

## 3.2 Analysis of small-scale fisheries bycatch in Mu Ko Chang, Trat Province

### 3.2.1 Objective

The objective of this part is to comparatively study the quantity and diversity of bycatch from nine small-scale fishing gears to assess ecological impacts of fishing gears in Ko Chang, Trat Province

### 3.2.2 Gear selection

Nine small-scale fishing gears including drift nets, bottom nets (shrimp trammel nets, crap nets), mid-water trap (squid traps), bottom trap (crab traps and fish traps), Acetes push nets, bottom longlines, and trolling lines. These selected fishing gears were chosen based on their differences in their operating position in water column (surface/mid-water column and near sea floor). Drift nets, squid trap, Acetes push net, and trolling line are usually operated in surface/mid-water column; while shrimp trammel nets, crab nets, crab traps, fish traps, and push nets are operated near or on sea floor. Besides, these selected fishing gears are generally found in every fishing communities of the study site. Description of gears and illustrations used in this are shown in Table 4 and Figure 8.



### 3.2.3 Sample collection and processing

Onboard surveys were conducted during both wet and dry seasons with cooperation with small-scale fishers. At least three distinct fishing trips were surveys for each fishing gear and season starting from July 2015 – February 2016. Hence, a total of 54 data sets were obtained from the field surveys. In order to prevent the loss of discard data of which fisher might discard those bycatch at sea, data collection were done immediately after fishing. The information on gear description and fishing operation is shown in Table 4. Small-scale fishing vessels, used in this study, range from 4 – 10 meters in length (Med = 4.5) with the engine of 6 – 50 hp (Med = 6).

Each fishing trip, all species caught were sorted, weighed and identified. The species were photographed, preliminary identified with local name by fishers, then those specimens were further identified into the species level, if possible, using the FAO Species Identification Guide for Fishery Purposes (Carpenter & Niem, 1998) and other web-based reference databases such as FishBase, Marine Species Identification Portal, World Register of Marine Species etc. The fishers also helped specify the species whether it is target species, retained or discarded bycatch.

3.2.4 Data treatment and analysis

To calculate the catch rate of each fishing gear, a total catch, number of gears, length of nets, and soaking/fishing time of each fishing trips were used and the catch rate is expressed as kg per gear-unit per day. Seasonal variation of catch rate were tested with Student's t-test. Since the some of the selected small-scale fishing gears are operated seasonally, seasonal variation of species composition of catch is basically occurred. To reduce the seasonal variation, the data from six fishing trips (covering wet and dry season) were aggregated before calculating the proportions of target, non-target catches (retained and discarded bycatch) which were expressed as percentage of total wet weight.



In terms of species diversity and diversity indices were calculated using abundance data to illustrate diversity of total catch, retained bycatch, and discarded bycatch of each fishing gear (Lezama-Ochoa et al., 2015) as the followings:

Shannon–Wiener diversity index (H′) $= -\Sigma(p_i \cdot \log(p_i))$

Margalef's species richness (d) $= (S-1)/\log(N)$

Pielou's eveness (J′) $= H'/\log(S)$

N = Total number of individuals, s = Total number of taxa

The higher species diversity may further imply the higher degree of bycatch generation of the certain fishing gears. Utilization of the catch was also assessed using biomass data to illustrate how much of those catches were household consumed, sold, or discarded.

**Table 4** Description of fishing gears used in this study

| Fishing Gears | Gear dimension | Mesh size (cm) | Bait | Fishing operation | Fishing ground characteristic |
|---|---|---|---|---|---|
| Crab Gillnets* | Nylon filament with its dimension of 1.2 x 900 m | 10.2 | None | The net is set on the seafloor for about 12 – 24 hours before hauling | Muddy/sandy substrate with 2 – 20 m deep |
| Mullet Gillnets** | Nylon filament with it dimension of 2.5 x 400 m | 4 | None | School of fish was encircled and entangled with the net. | Muddy substrate with 1 – 5 m deep |
| Shrimp Trammel Nets** | Three-layered net with its dimension of 2 x 3,600 m | 4 and 9 for inner and outer layers | None | The net is released and driven by current for 1/2 - 1 hr before hauling. | Muddy/sandy substrate with 2 – 30 m deep |
| Acetes push Nets** | A conical bag net is fixed on scissors like cross-wooden sticks (6.5 m long) | 2 mm | None | When a school of Acetes is found, it is harvested by pushing the bag net toward and lifting the net. | Muddy substrate with 2 – 4 m deep |
| Crab Traps* | Collapsible traps with its dimension of about 0.45 x 0.3 x 0.15 m | 3 | Small-pelagic fish | About 400 traps per trip are dropped on the seafloor for 12-24 hrs before hauling. | Muddy/sandy substrate with 3 – 7 m deep |
| Fish Traps* | Semi-cylindrical traps with its dimension of 0.5 x 1 x 0.3 m | 7.6 | Small-pelagic fish | About 30 traps per fished were deployed to the seafloor for 24-48 hr. before hauling. | Coastal rocky habitat with 2 – 10 m deep |
| Squid Traps* | Collapsible semi-cylindrical traps with its dimension of 1 x 1 x 1.5 m | 5 | Squid eggs | About 50 traps were vertically positioned in the water, about 2-3 m from the seafloor for 48 hrs. | Sandy substrate with 15 - 30 m deep |

**Table 4** Description of fishing gears used in this study

| Fishing Gears | Gear dimension | Mesh size (cm) | Bait | Fishing operation | Fishing ground characteristic |
|---|---|---|---|---|---|
| Bottom Longlines* | A main line (200 m long) consists of about 130 branching lines (50 cm long) with hooks. | - | Small pelagic fish or squid | The bottom longlines were placed on the seafloor for about 2-3 hours or more before hauling. | Muddy substrate with 1 – 3 m deep |
| Trolling Lines** | Fishing rod is 2 m long connected with a line (50 –100 m) on which 2 hooks with baits attached. | - | Artificial lures or small pelagic fish | Two fishing rods are laid perpendicularly on both side of a vessel. Lines and hooks are submerged in the water. Towed speed is about 2 knots | Sandy substrate with 15 – 40 m deep |

Note: *Fixed gears, **Mobile gear

(a) (b)

(c) (d)

(e) (f)

**Figure 8** Photos of fishing gears used in this study: (a) crab gillnets, (b) mullet gillnets, (c) shrimp trammel nets, (d) Acetes push nets, (e) crab traps, (f) fish traps
Note: Photos taken from Ko Chang, Trat Province

(g)

(h)

(i)

**Figure 8** Photos of fishing gears used in this study: (g) squid traps, (h) bottom longlines, (i) trolling lines (Continued)

Note: Photos taken from Ko Chang, Trat Province

### 3.3 An in-situ study of impacts of fish traps on coral reefs in Ko Kut and Ko Mak, Trat Province



3.3.1 Objective

This part aims to investigate the fishing impacts on natural habitat through an in-situ observation of a fishing operation, in this case fish trap fisheries in Ko Mak and Ko Kut was observed through underwater observation.

3.3.2 Fishing operation and data collection

A total of 82 fish traps in Ko Kut and Ko Mak, located in the south of Ko Chang, Trat Province (Figure 9) were investigated during January – October 2016. Generally, the fish trap is placed on the spaces between coral reefs or near underwater pinnacle at an average depth of 15 meters. Fish traps are made of wooden frame (1.5 x 2 x 1 m) with polyethylene and iron wire having a mesh-size of 2.5 cm. Fishing vessel with inboard engine of 150 hp was used in this study. A fisher who dive for placing and retrieving the fish traps used a mask with plastic air tube that connected to air supplier onboard. A few crew members were available onboard to facilitate the fisher who placed and retrieved the traps. The traps were submerged for about 1 – 2 weeks depending on climate condition.

At each trap, a SCUBA diver underwater investigated the fish trap deployment from the surface to sea bottom as well as the retrieval of the trap. Number of traps that touched corals was counted and calculated as percentage of total traps. Other possible impacts of fish trap deployment were also investigated. After retrieving, all species found on each trap were counted, weighed, and photographed. In the laboratory, all of the species were identified to species level, if possible using the FAO Species Identification Guide for Fishery Purposes (Carpenter & Niem, 1998) and other web-based reference databases such as FishBase, Marine Species Identification Portal, World Register of Marine Species etc. The fishers also helped specify the species whether it is target species, retained or discarded bycatch.

3.3.2 Data treatment and analysis

To specify the target species, the fishers were asked to help specify which of the species target species, retained or discarded bycatch. The average CPUEs were calculated as the following formula (Butler and Heinrich, 2007):

$$\text{Average CPUE} = \frac{\sum_{i=1}^{n} CPUE_i}{n}$$

$CPUE_i$ (kg/trap/day) = Weight of total $catch_i$ (kg)/soaking $time_i$ (days)

n= a total number of trap investigated

The average catch rates of the fish traps operated during dry season (January – April) and wet season (May – October) was compared using non-parametric Mann-Whitney U test in order to detect seasonal variation.

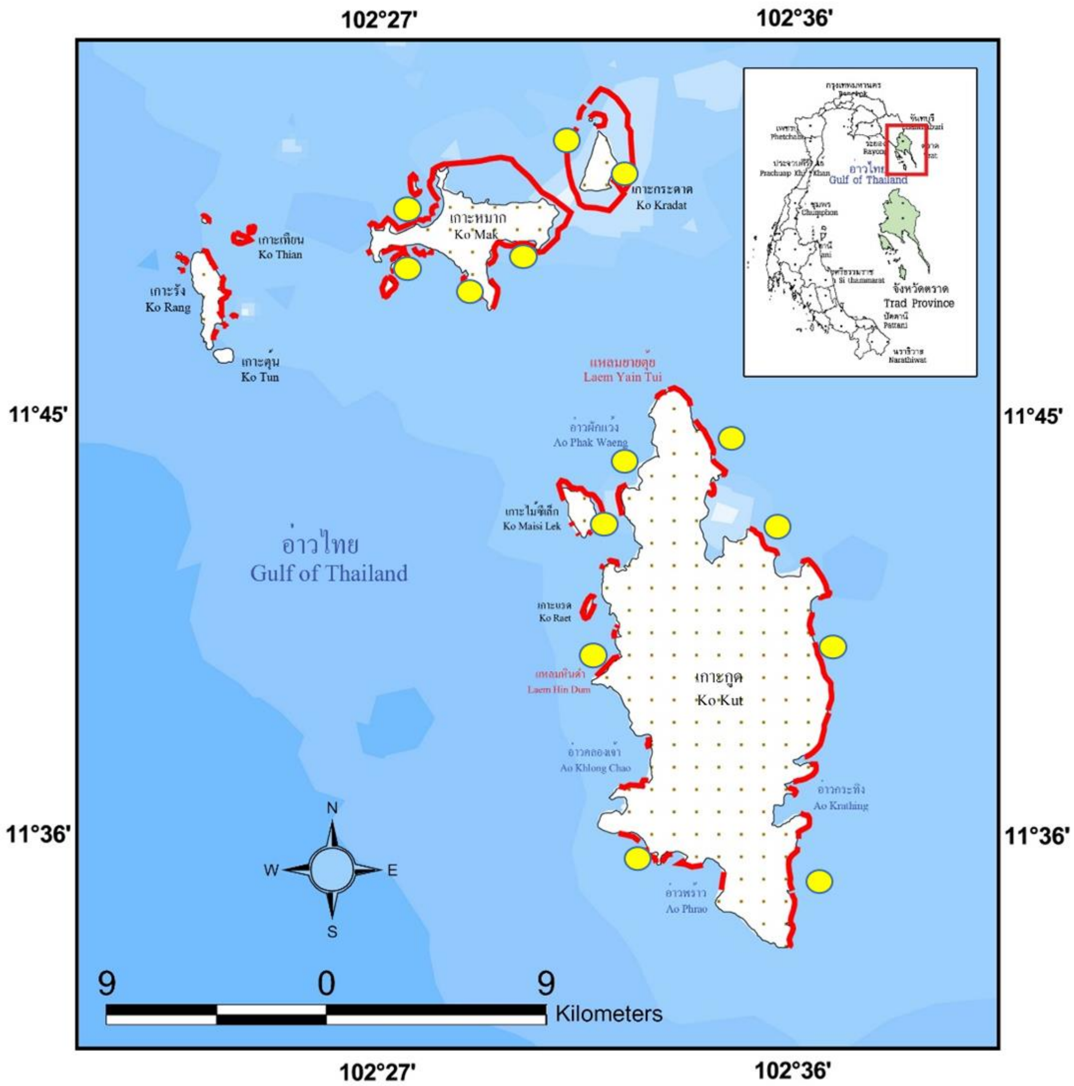



**Figure 9** Locations of fish trap deployment in Ko Kut and Ko Mak (red line denotes coral reefs)

**3.4 Impacts of trawl, push net and dredge fisheries on macrobenthic communities in the Strait of Ko Chang, Trat Province**

3.4.1 Objective

This part aims to investigate the impacts of trawl, push net and dredge fisheries on macrobenthic communities in the Strait of Ko Chang, Trat Province.

3.4.2 Sampling design and site selection

Abundance and composition of macrofauna community were investigated in two different zones in the Strait of Ko Chang where different fishing regulations were posed as the followings:

The zone where trawls, push nets, and dredges with motorized vessel are completely prohibited, in which a total of six study sites including station A, B, C, D, E, and F were investigated (Figure 10).

The zone where trawls, push nets, and dredges with motorized vessel were prohibited during June – November according to the Notification of Trat Province, in which four study sites including station G, H, I, and J were investigated.

3.4.3 Sampling and sample processing

Vann veen grab with the surface area of 900 $cm^2$ was used for macrobenthos and sediment sampling. Six replicates were collected from each of ten permanent sampling sites in the Strait of Ko Chang. Sampling was done in both in wet and dry season.

The samples were washed over a 0.5 mm mesh-sized sieve. Macrobenthic species retained on the sieve were fixed in 10% buffered formalin for further identification. Sediment samples were also collected and fixed in 10% buffered formalin to analyze organic matter content and particle size analysis.

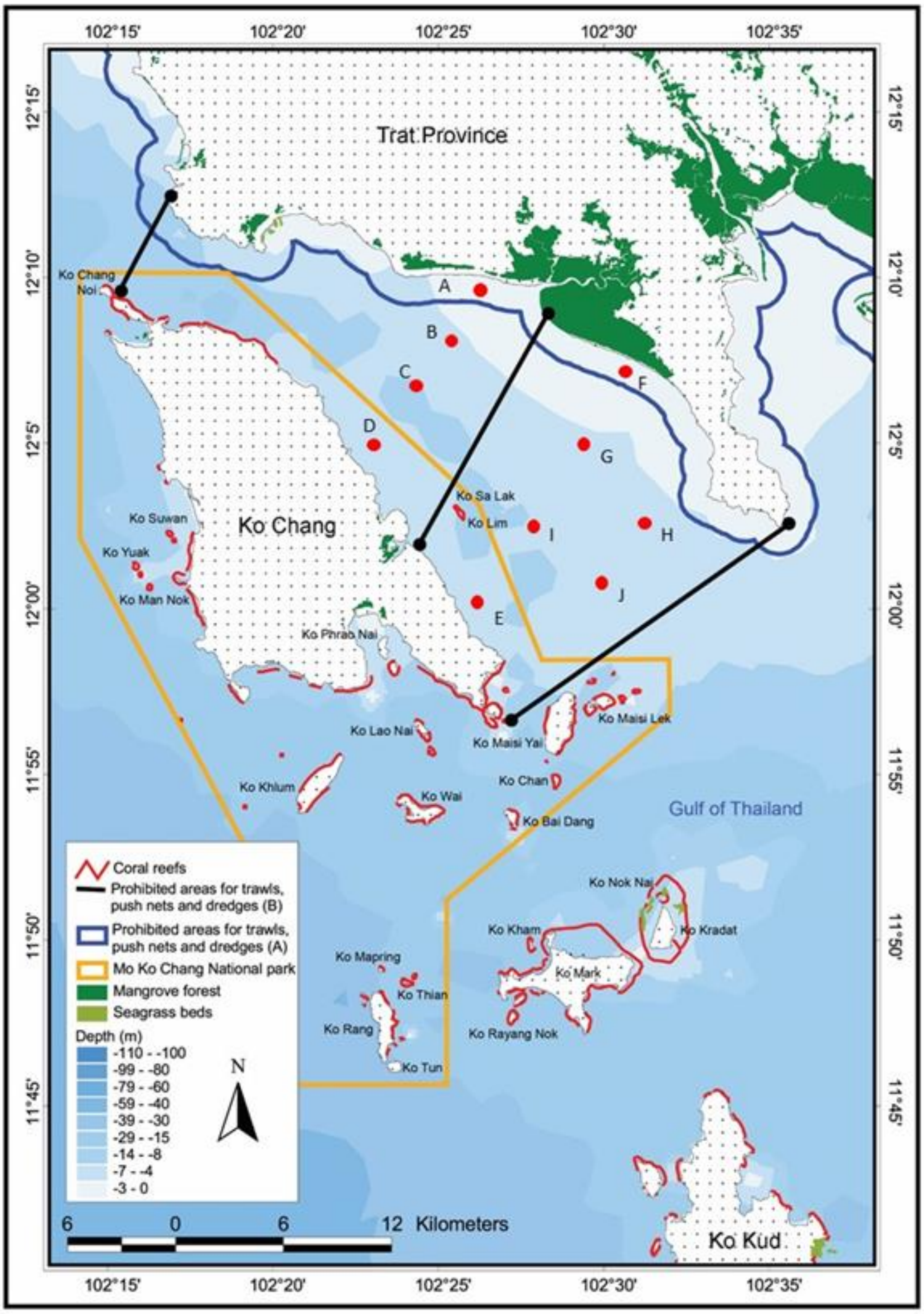



**Figure 10** Sampling sites investigated for macrobenthic community in different fishing regulation

At each sampling station, some parameters such as depth, temperature, salinity, dissolved oxygen, pH, salinity, total dissolved solid (TDS) and conductivity, were measured using the YSI 556 MPS water quality monitoring device.

In laboratory, the samples were stained with Rose Bengal before sorting and identification. The individuals of each taxon were counted and recorded under microscope. Content of organic matter in sediment sample was analyzed using loss on ignition method (Heiri et al., 2001). Dry-sieve method was used to find sand fraction in the sediment samples while particle-size fractionation was further used for determining silt and clay fraction (English et al., 1997).

3.4.4 Data treatment and analysis

Densities of each taxa were totaled to give total densities of in each replicate and sampling station. Since raw data were not normally distributed, all of the data were treated with square root transformation before testing the differences of the mean total densities between six-month closure zone and the permanent closure zone with two-way ANOVA while the spatial variation among site was tested by one-way ANOVA with Tukey's HSD (honestly significant difference) test. All univariate data analyses were performed using SPSS version 22.

In addition to these individual species, number of taxa (family level) and density data for all macrobenthic species was used to calculate diversity indices as the followings:

Shannon–Wiener diversity index (H′) $= -\Sigma(p_i \cdot \log(p_i))$

Margalef’s species richness (d) $= (S-1)/\log(N)$

Pielou’s eveness (J′) $= H'/\log(S)$

N = Total number of individuals

S = Total number of taxa

Difference on total number of taxa in between six-month closure zone and the permanent closure zone was tested with Mann-Whitney U test.

Similarity of species composition based on Bray-Curtis Similarity between zones and seasons was conducted with Permutational multivariate analysis of variance (PERMANOVA). The Similarity Percentage (SIMPER) was performed to identify which taxa are responsible for major contribution to similarity or it could help identify the taxa that are generally found in a certain group. A distance-based linear model (DISTLM) and distance-based redundancy analysis with ordination (dbRDA) were done to find out the relationship of environmental gradients and similarities of sampling station. Diversity Indices, PERMANOVA, SIMPER, DISTLM and dbRDA were done using PRIMER version 7.0. Four-root transformation were required prior to conducting the multivariate data analyses.

### 3.5 Expert-based gear impacts assessment: Transdisciplinary approach

#### 3.5.1 Objective

In this study, expert elicitation approach was applied to assess relative severity of gear impacts in terms of bycatch and habitat damage of selected thirteen fishing gears used in Thailand. Within this approach, actual impacts of the thirteen fishing gears were analyzed and severities of fishing gear impacts were rated based on integration of existing knowledge (from both literature and the preliminary results of the research mentioned in the earlier parts) and experts' knowledge and experiences. Another important objective of this part is to synthesise policy and measures to mitigate the ecological impacts of fishing gears.

#### 3.5.2 Gear selection and categorization of bycatch and habitats

Gears are selected based on their importance (landing quantity, amount of gear units) and as the representatives of each gear types including large- and small-scale fishing gears, mobile or fixed fishing gears, touching and non-touching the seafloor. Hence, four large-scale fishing gears and nine small-scale fishing gears were selected including pair trawls, otter board trawls, king mackerel drift gill nets, anchovy purse seines, mackerel gill nets, mullet gill nets, shrimp trammel nets, trolling lines, Acetes push nets, crab gill nets, crab traps, fish traps, and bottom longlines. In terms of bycatch and habitats, categories were made based on the information from literature reviews. Finally, ten categories of bycatch (demersal fish, forage fish, large pelagics, crabs, shrimps, shells, squids, epifauna, infauna, and marine mammals and sea turtles) and four categories of habitats (coral reefs, seagrass beds, soft and hard bottom were used for the workshop.

### 3.5.3 Selection of experts

Experts were identified and selected using snowball technique (Davis & Wagner, 2003) with the consideration of their academic and experienced professional on gear experts, fisheries biology, fisheries management, and marine and coastal resources. This list of experts was come up with official staffs of governmental institutions, university professors and researchers, representative of NGOs, large- and small-scale fishers. The invitation letters were mailed out to the 35 selected experts and 21 experts were confirmed to attend the workshop. The workshop participants included 7 university professors and researchers, 5 large- and 4 small-scale fishers, 4 official staffs of governmental institutions, a representative of NGOs. Based on the profession, 10 are gear and fishing experts, 7 are fisheries biologists and managers, and 4 are marine scientists who are knowledgeable in marine habitats.

### 3.5.4 Consultation workshop preparation

A workshop document was prepared and mailed out to the confirmed participants to review before the workshop. The document was developed based on the literature review regarding the ecological impacts of fishing gears in Thailand, starting by introducing background of the study, definitions, list of fishing gears in Thailand, important fisheries statistics of each gear, and existing knowledge of bycatch and habitat damages. Two proper exercises were developed for the experts to rate fishing gear impacts on each category of bycatch and habitats. Moreover, poster exhibition was also convened to illustrate essential data of the selected fishing gears that participants are able to study before or during the workshop.



### 3.5.5 Conducting consultation workshop

A one-day workshop was convened in January 2016 at Ramkhamhaeng University, Bangkok, Thailand. The workshop was started with poster session that participants were able to study the summary of bycatch and habitat damages of the selected 13 gears. This could help enhance discussion and interaction among participants. Each expert was then asked to do self-introduction and to provide his/her background on fisheries. Next, the findings from literature analysis and some field surveys were presented to the workshop starting by reviewing the possible impacts of fishing gears on ecosystem in terms of bycatch and habitat damages, then providing some important of the Thai Fisheries Statistics, and providing the knowledge gaps of this study. After the presentation session, the experts were asked to review and discuss on the knowledge gaps of ecological impacts of fishing gears in terms of bycatch and habitat damages and provide their knowledge to fulfill the gaps.

Rating of fishing gears impacts through exercises was then started by introducing the exercises. The participants were informed with a brief of the objectives and how to do the exercises. Then experts are grouped to four groups where each group consist of experts on different fields. Exercise A is designed to elicit the severity of each fishing gear impact. At the small-group discussion, each group was asked to rate the main question “How much impacts of each fishing gear would you rate on each type of bycatch and habitat damages?” The experts were free to discuss among group members and make consensus score from 0 – 5 reflecting the fishing impacts on each category of bycatch and habitats, where the given score of zero means ‘no impact’ while five means ‘high impact’. Exercise B was also used for eliciting expert’s concerns on gear impacts on ecosystems through individual voting. Each expert had thirty dots that they could freely vote for any gears that they think such gear contribute serious concern to bycatch and habitat damages. After conducting those exercises, presentation and discussion of the preliminary results were convened. This session is organized to discuss the preliminary results of the exercises. Experts are freely to express their opinions and the reasons to support the rated scores. Experts are able to make suggestion or additional data.

3.5.6 Post consultation workshop and data analyses

Focus group meetings were conducted at three villages in Mu Ko Chang to gather some of relevant supporting data for further evaluation as well as cross-validation of the data can be done through the post consultation workshop.

3.5.7 Data Analysis

Both quantitative and qualitative data were analyzed. The results of exercise A were tabulated and the overall impacts of each fishing gear were then rated using median while another results from preference voting through exercise B were normalized to rank severity of fishing gear impacts. Kendall's tau-b ($\tau$b) correlation coefficient was also calculated in order to detect the strength and direction of association between the ranks of rating and ranking results.

# CHAPTER IV
# RESULTS AND DISCUSSIONS

## 4.1 Analyzing existing knowledge and gap on ecological impacts of fishing gears in Thai waters

In the first part of this dissertation, the results from the analysis of existing knowledge and gaps on ecological impacts of fishing gears in Thai waters is presented. The internet search yielded more than 400 publications on seemingly relevant topics during 1995 to 2015. Of these, 134 publications were considered pertinent to the study and thus retained for further analysis. These publications were evenly spread from 1992–2015, with about 1–14 studies per year. An exception was found, however, in 2006 when as many as 14 studies were found, accounting for 10 % of all publications. The majority of publications were technical papers (70 %), written in Thai and mostly produced by the DOF, Thailand. Content analysis revealed that studies about ecological impacts of fishing gear were highly skewed towards bycatch (93 %), especially in relation to trawl fisheries (43 %), as detailed below.

### 4.1.1 Existing knowledge on ecological impacts of fishing



As previously mentioned, only a small fraction of studies was about habitat damage (9 out of 134). Further, about 44 % of the studies were focused on large-scale fishing gear such as otter board trawl (22 %), purse seine (9 %), pair trawl (9 %), pelagic longlines (3 %) and encircling net (1 %). Among small-scale fishing gear, fish gillnets, followed by crab traps and crab gillnets, were most documented (9 %, 7 % and 7 %, respectively). The huge proportion of literature on bycatch is due largely to the mandate of DoF in regular stock assessment and catch composition analysis. The number of publications helps one to get an overview of issues at the national level; for example, many publications on otter board trawls and pair trawls can be used to illustrate the general proportion of economic fish, true trash fish, and juvenile economic species from those gears.

1) Bycatch impacts of fishing

Among the literature related to bycatch, the majority of the studies (64 %) concerned catch composition. Specifically, about 38 % of them provided information about the proportion of juvenile economic fish species in catch composition. Few studies (less than 10 %) mentioned fishing impacts on marine mammals and sea turtles, and only in qualitative terms (Figure 11). Details on bycatch from fishing are provided below for the eight main gear categories except dredge since no literature related to bycatch from dredging was found.

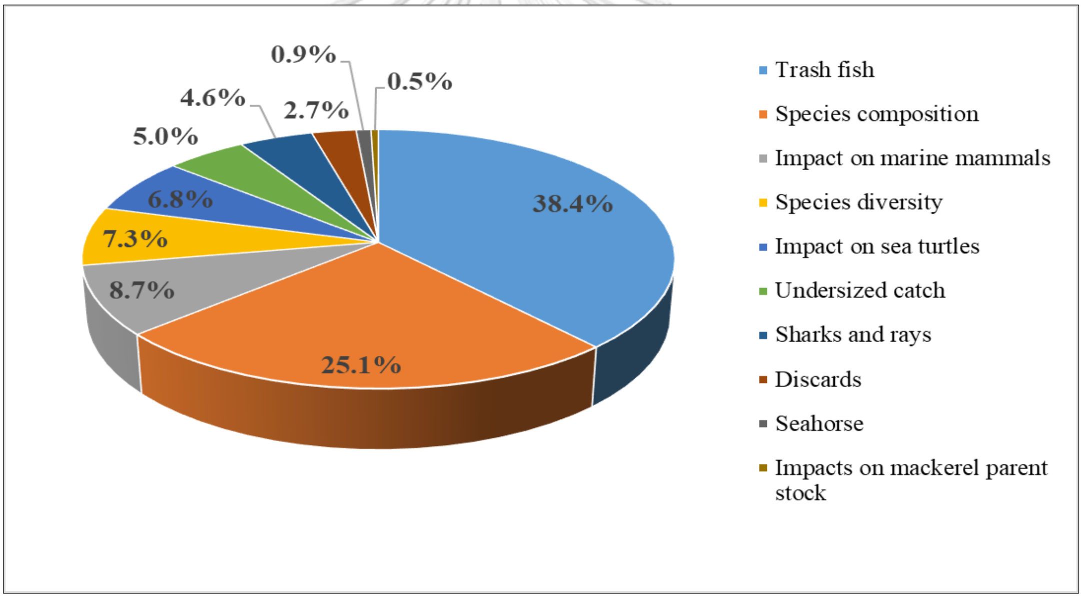



**Figure 11** Proportion of studies related to bycatch in Thai waters (by percentage of all studies)

a) Surrounding nets: Purse seines are mobile gear that target pelagic fish, especially mackerels, anchovies and tunas. Landings from purse seines constitute about 35 % of the total landings in Thai fisheries. According to 2013 landing statistics (DoF, 2014, 2015b), 70 % of the purse seine catches were pelagic fish, such as Indo-Pacific and Indian mackerels, sardines, scads and tunas, while anchovy dominated catches in the anchovy purse seine. Only 7 % and 2 % of trash fish were reported from purse seines and anchovy purse seines, respectively (DoF, 2014, 2015b). Light-luring purse seine operating at night produced a higher level of trash fish compared to day-time purse seine fisheries using fish aggregating devices (FADs). In Thailand, FADs are made of bamboo poles with coconut leaves attached to lure schools of fish by floating the FADs on the sea surface and anchoring them with concrete blocks that are placed on the sea floor (Noranarttragoon et al. 2012). An average of close to 10 % of trash fish (with a range of 1 % to 30 %) was found in the light-luring purse seine operating at night (Loychuen et al., 2010; Sanitmajjaro et al., 2012), while the day-time purse seine fisheries using FAD had a lower average of less than 4 % (0.6 % to 8.8% in range) as reported in Noranarttragoon et al. (2006) and Sanitmajjaro et al. (2012). The tuna purse seine is another type of purse seine designed to catch mainly tunas. This gear is very selective with only about 3.5 % to 6.3 % of all catch being non-target species (Siripitrakool & Thapanand-Chaidee, 2009; Uttayamakul et al., 2010). A few studies reported that dugongs and sea turtles were accidentally caught in purse seine fisheries, especially when they operate closer to the shore (Hines et al., 2005a; Syed & Abe, 2009).

b) Trawls: Three types of trawls, i.e. otter board, pair, and beam trawls, are generally found in Thai waters, targeting demersal fish. The majority of them are otter board trawls and together, they contribute almost half of the total annual landings (DoF, 2015a). Trawls are mobile gear, which mostly touch the seafloor during operation. Species composition and trash fish from otter board and pair trawls were well documented in several studies, while none of them reported on beam trawls. Information on discards was also scarce. Based on the 2013 catch statistics, at least half of the catches from pair trawls were trash fish. The proportion of trash fish from otter board trawls was lower at 44 %, for vessels of 14–18 metres long. Some studies indicated that most of the low-value fish or trash fish from trawlers in Thailand are supplied to feed industries (Achavanuntakul et al., 2014; Kaewnern & Wangvoralak, 2005; Supongpan & Boonchuwong, 2010). Trash fish composition in trawl catches poses a major ecosystem concern especially when they consist of juvenile economic species, as studies show (Table 5).

These data illustrate differences in bycatch depended on the type of trawls, size of fishing vessels, and fishing locations. In general, higher percentages of juvenile economic species are found in otter-board trawls and pair trawls operating in the Andaman Sea compared to those in the Gulf of Thailand (Supongpan & Boonchuwong, 2010). In addition, sharks and rays have been reported as bycatch in trawl fisheries (Deechum, 2009; Krajangdara, 2005), with other studies mentioning that sea turtles and marine mammals are at risk in areas where trawls operate (Adulyanukosol, 2010; Chanrachkij et al., 2010; Hines et al., 2005a; Kittiwattanawong, 2004; Syed & Abe, 2009). For instance, Adulyanukosol (2010) reported four incidents of dugong being caught in trawlers operating within 3 km from the shore. These mammals later died even fishers had tried to release them from the nets.

**Table 5** The average percentages of economic fish, trash fish, and juvenile economic species from otter board trawls and pair trawls, by size of vessels (in metres).

| % of catch | Gulf of Thailand | | | | Andaman Sea | | |
|---|---|---|---|---|---|---|---|
| | Otter board trawls | | Pair trawls | | Otter board trawls | | Pair trawls |
| | <14 m | 14-18 m | <=18 m | >18 m | <14 m | 14–18 m | All sizes |
| % Economic fish | 45.7 | 50.3 | 64.6 | 56.0 | 31.6 | 39.7 | 29.6 |
| % True trash fish | 30.6 | 32.2 | 17.0 | 13.1 | 31.9 | 28.5 | 18.0 |
| % Juvenile economic species | 23.7 | 17.5 | 18.4 | 30.9 | 36.5 | 31.8 | 52.4 |

Sources: Roongratri et al. (2000); Isara and Phoonsawat (2002); Phoonsawat (2002); Auawithoothij (2003); Khamakorn (2004); Kongprom et al. (2004); Kaewpradit, (2005); Kaewnern and Wangvoralak, (2005); Chuapun (2006); Puteeka (2006); Sanitmajjaro and Khongchai (2006); Kongprom et al. (2006); Kongprom et al. (2007); Sanitmajjaro et al. (2007, 2012); Premruetai and Khianiam, (2008); Tossapornpitakkul et al. (2008); Sanitmajjaro et al. (2008); Chamason and Chuapun, (2009); Siripitrakool et al. (2011); Sinanun and Kaewmanee, (2012); Thongsila and Sinanun, (2013); Achavanuntakul et. al. (2014); Keereerut et al. (2014); Hoimuk et al. (2015)

c) Lift nets and falling nets are mobile gear, operating from vessels of about 14–18 metres in length, equipped with large nets or castnets, targetting mostly pelagic fish. Fishing is generally operated in coastal waters with no more than 45 metres depth or 3–40 nautical miles from the shore (Loychuen et al., 2010; Sinanun et al., 2012). Similar to large-scale surronding net fisheries, lights may be used during the operation to aggregate fish before catching.

At present, light-luring liftnets and light-luring falling nets for squid and anchovy are prohibited from operating in coastal waters (usually within 3 nautical miles from the shoreline), based on the announcement of the Ministry of Agriculture and Cooperatives on prohibition of the use of fishing gear and methods in fishing areas (Thailand Ministry of Agriculture and Cooperatives 2016a). Some fishers also use echo sounders to find schools of fish. There are various kinds of lift nets but squid lift nets, Acetes lift nets and anchovy lift nets are common. These gears are highly selective, with squids and Acetes dominating the catches. Nonetheless, about 13 % of the catches are trash fish (DoF, 2015a). Comparative studies of species composition between day-time anchovy purse seine and light-luring anchovy lift net fisheries showed that trash fish was found in higher percentage in the latter (1.2 % vs. 0.3 %) (Boonkerd et al., 2008; Boonkerd & Anugun, 2008). No report was found about marine mammals or other bycatch related to these gears.



d) Gill nets and entangling nets can be either mobile or fixed. Drift nets and trammel nets are common mobile gill nets, while bottom nets and fixed nets are semi-stationary. Different mesh sizes are used in gill net fisheries to target a wide range of fish species. The majority of gill net fisheries in Thailand are king mackerel drift gill nets, with about 11 % of the total catch comprising trash fish (DoF, 2014, 2015b). Additional research showed that 93 % of catch from king mackerel drift gill net fisheries were fish of economic importance, while 0.5 % and 7.2 % were sharks and other non-target species, respectively (Pramokchutima, 1993), and the rest was trash fish (Chantawong et al., 1994). Similarly, in mackerel encircling gill nets, less than 1 % of total catches were trash fish (DoF, 2014, 2015b). While the trash fish quantity is generally low in net fisheries, the study by Nakrobru and Saikliang (2003) illustrated other ecosystem concerns. Specifically, they found that 65 % of Indo-Pacific mackerels caught by encircling nets in the western Gulf of Thailand were mature female fish with an estimated 6,360 thousand eggs, which could mean an increase of about 15,000 metric tons of the mackerel stocks. This estimation was reported based on the assumption of the natural mortality factor of 3.53 per year and no encircling gillnet fisheries was found. Shrimp trammel nets are another mobile gear in this category. Consisting of three layers of nets, with decreasing mesh sizes from the outer to the inner layers, trammel nets catch shrimps while drifting with the currents. The bottom of the net often touches the sea floor when operating in shallow water.

According to Boutson et al. (2007a), about 87 % of catch from shrimp trammel nets is discarded. The dominant discarded species were true trash fish, e.g. silver-biddy (*Gerres* sp.) and pony fish (*Leiognathus* sp.), as well as other species with no commercial value, such as sea urchins, tiny jellyfish, gastropods and starfish. They also suggested that increasing mesh size in the middle layer and reducing net height may reduce the catch of non-target species. A study by Preecha et al. (2011) revealed similar findings, with nine species reported as discards (50 % of total species caught), most of them being true trash fish (pony fish, Family Leiognathidae). Unlike shrimp gill nets, crab gill nets are semi-stationary and are normally set on the sea bottom for 1–2 days before retrieving. According to several studies, 75 % of total catches from this gear, on average, are crabs (see, for instance, Loychuen et al. (2013); Petsalapsri et al. (2013). Another study showed, however, that a total of 55 crab species were caught in crab gill nets, 69 % of which had no commercial value (Jaingam et al., 2007). Thus, Wisespongpand et al. (2013) asserted that this group of fishing gear highly threatens crab biodiversity since as much as 82 % of the total number of species could be “trash”. With respect to non-fish bycatch, studies show that sea turtles can be possibly caught in drift nets operating in Southeast Asia (Syed & Abe, 2009). However, no official number of sea turtles caught by the drift nets was reported. Most of the entangled turtles die due to drowning while some are injured (Chanrachkij et al., 2010; Kittiwattanawong, 2004). Marine mammals such as dugongs and dolphins are also threatened from gillnet fisheries (Hines et al., 2005b; Marsh et al., 2002; Whitty, 2014). Dugongs, for instance, are easily entangled in fishing nets and can die from drowning in a few minutes (Adulyanukosol, 2010; Wongsuryrat et al., 2011). While total landings from this group of gears is low (about 6 % of the total landings in 2013), their impacts on bycatch are well documented and raise concerns on ecosystem health.

e) Push nets are mobile fishing gears, targeting mostly shrimp and Acetes, and can be either motorised or operated by hand. About 32 % of the catch is trash fish, followed by demersal fish (15 %), shrimps (15 %) and Acetes (14 %) (DoF, 2014, 2015b). Sompong (2009) found at least 62 species in catches by these gears. Further, several studies (Suksumran & Thongsila, 2015; Thongsila & Sinanun, 2013) indicated that close to 30 % of the trash fish were juvenile economic species. Additionally, because push nets usually operate in coastal waters with 2–15 metres depth, they can have an impact on young crabs and other juvenile species.

For instance, studies show that about 90 % of blue swimming crabs sampled from push nets, especially in Samut Prakan Province, were immature, with carapace width at under-maturity stage (Arunrojprapai et al., 2010; Jindalikit et al., 2010). Hines et al. (2005) also expressed concern that these gears could be risky to dugongs when operating close to shore, especially in seagrass beds. On the other hand, Acetes push nets or Acetes push nets mainly catch Acetes (*Acetes* spp.), which comprised about 94.9 % of the total catch (Arunrojprapai et al. 2004).



f) Traps and pots are semi-stationary gears developed to catch a range of species. Crab, fish, and shrimp traps are placed on the sea floor while squid traps are arranged in the water column. Petchkamnerd et al. (2004) reported that about 62 % of female crabs from crab trap fisheries were under-matured. Boutson and Arimoto (2011b) highlighted that the discard rate of small-scale crab trap fisheries (using less than 300 traps) and large-scale fisheries (operating with 2,000 traps) was 22 % and 30 %, respectively. Fourteen and 25 species caught respectively from small- and large-scale crab fisheries were discarded although some of them were economically important species, such as Grunters (*Terapon* sp.), cuttlefish (*Sepia* sp.) etc., because there were too few of them in the catch which were also very small in size (Boutson and Arimoto 2011). Putsa et al. (2016) conducted experiments to assess impacts of ‘ghost fishing’ of 12 crab traps throughout 454 observed days and found that 520 individuals (25 species) were trapped and 25 % of them died. High mortality was found in Japanese flathead fish *Inegocia japonica* (Cuvier 1829)), pony fish (*Leiognathus* spp.), catfish *Plotosus lineatus* (Thunberg 1787), and eel-catfish *Plotosus canius* (Hamilton 1822).

In the case of fish traps, which target demersal fish of high economic value, especially groupers (*Cephalopholis* spp., *Epinephelus* spp.) and red snappers (*Lutjanus* spp.), studies indicated a high level of selectivity of this gear, resulting in very small bycatch (Kalaya, 2007; Tunvilai & Suksumran, 2012). Similarly, squid trap fisheries show a low proportion of non-target species (Srikum & Binraman, 2008). However, the recent introduction of new octopus traps using noble volute shell *Cymbiola nobilis* (Lightfoot 1786) to catch octopus raises ecological concerns, both in terms of the decline of octopus and of the noble volute shell population (Petchkamnerd & Suppanirun, 2004).

g) Bamboo stake traps and set bagnets are stationary fishing gears, located close to shore, especially near river mouths. The majority of landings from bamboo stake traps were pelagic fish (50 %) while trash fish constituted about 16 %. Landings from set bagnets generally include 50 % of shrimp, with 24 % trash fish and 10 % Acetes (DoF, 2015a). Boonpukdee and Sujittosakul (2004) studied the species composition of bamboo stake traps in Trat province, Gulf of Thailand, and reported that the majority of the catch was adult fish (71 %), followed by juvenile economic fish (20 %), squid (7 %) and true trash fish (2 %). Another study on species composition in bamboo stake traps in the Andaman Sea showed that trash fish constituted as much as 50 % of the total catch and these were used as feed in coastal aquaculture (SEAFDEC, 2005). Some reports showed concerns about the risk of dugongs getting caught in bamboo stake traps. When the dugongs are trapped, they try to get out of the traps by hitting their bodies against the bamboo, nets and wires, thus causing injuries to themselves. Studies show that about 85 % of trapped dugongs died (Adulyanakosol et al. 2010; Wongsuryrat 2011), after being trapped for less than an hour, especially in shallow water or during low tide. In the case of set bagnets, about 87–157 species are normally caught, the majority of which were fish (Chamason et al., 2015). Other studies show that the proportion of juvenile economic species can be high, ranging for instance, from 36 % to 43 % of total catch, reflecting ecological issues and economic loss of many juvenile species (Phoonsawat et al., 2009).

h) Hooks and lines can be mobile (such as pelagic longline and trolling line) or semi-stationary (like bottom longline and pole and line). Hooks and lines are usually operated with small-scale vessels, except in tuna longline fisheries, which use larger vessels and operate offshore. The main bycatch of tuna longlines and bottom longline are sharks (Bunluedaj et al., 2010). Studies also report sea turtle bycatch in pelagic and bottom longlines (Syed and Abe 2009; Chanrachkij et al. 2010).

2) Habitat damage from fishing gears

As previously mentioned, there are significantly less studies on habitat damage from fishing gears than on bycatch. Studies on habitat impacts were related to seagrass beds (50 %), impacts on coral reefs (18 %), reduction of seawater quality (18 %), impacts on benthic communities (9 %), and seafloor destruction (5 %) (Figure 12).

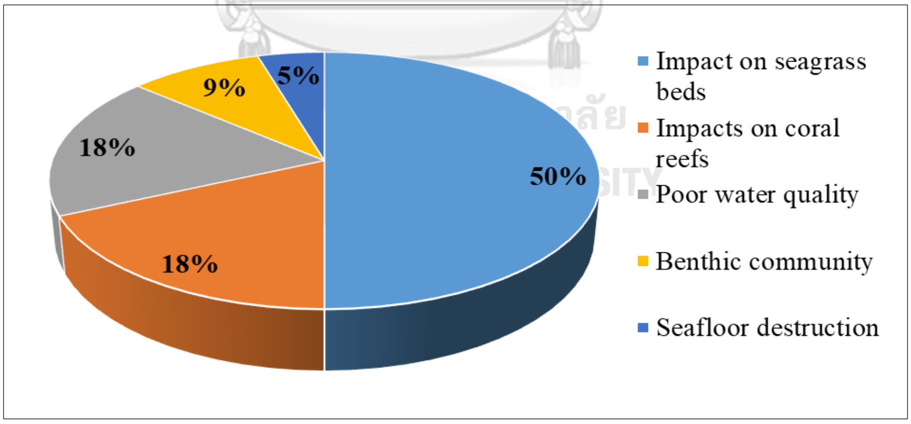



**Figure 12** Proportion of studies related to habitat damage in Thai waters (by percentage)

In the South China Sea and Gulf of Thailand, demersal trawls were identified as threats to coral reefs and seagrass (Vo et al. 2013). Sediments generated during trawling or dredging near coral reefs also contribute to coral reef deterioration

(Sudara, 1999) and affect coral growth (Chansaeng et al. 1992). Further, push nets have been identified as one of the destructive fishing gears that destroy seagrass beds and benthic organisms(UNEP, 2004; Vo et al., 2013).

In the case of beach seine nets, Wungkhahart (1994) found that they operate in a similar manner as trawlers and thus can cause negative effects on seagrass beds and marine benthic species. Several research studies have been conducted on environmental impacts of bivalve dredging fisheries. Dredging causes direct ecological impacts such as seafloor destruction (Chanrachkij 2012), affects water quality by increasing sediments and concentration of hydrogen sulphide ($H_2S$), as well as raises the level of silicate-silicon in water (Chanrachkij, 2012; Jindalikit & Thaochalee, 2008; Supongpan & Jindalikit., 2015). In terms of the impacts on benthic communities, the study by Yeemin et al. (2010) revealed that after dredging, less polychaetes and brittle stars were observed in the soft sediment community, while Chanrachkij (2012) noted that the increased sediments and nutrients from dredging may cause temporary hypoxic conditions which further affect marine organisms.

4.1.2 Gap analysis on bycatch and habitat damage

1. Major knowledge gap on bycatch and habitat damage

Although as many as 134 documents were found related to fishing gears in Thailand, few focused specifically on bycatch and habitat damage. As shown in this part, the data on bycatch are focused on trash fish and juvenile economic fish in trawling, especially otter board trawlers. Little is known about the proportion of juvenile economic species in catch composition, in different sizes of fishing vessels and fishing grounds. Scientific evidence of fishing gear impacts on marine mammals (dugongs and dolphins) and sea turtles is only available in qualitative form. Information about habitat damage from all gears is generally limited although there were a few studies qualitatively describing the impacts of seine nets, trawls, dredges, and push nets on seagrass beds, coral reefs and benthic communities.

2. Trash fish and its ecological concerns

Because trash fish are part of retained bycatch and some have commercial value, they are reported in the national fisheries statistics, with landing amount by fishing gear. It is clear, however, that some of them are juvenile economically important fish, which raises concerns in both ecological and economic terms (Nunoo et al., 2014; Pikitch et al., 2012). This study reflects the importance of scientific studies for the implementation of EAF. For example, many publications on otter board trawls and pair trawls help illustrate the general proportion of economically important fish, true trash fish, and economically important juvenile species from those gears at the national level. Spatially, higher percentages of economically important juvenile species found in fisheries operating in the Andaman Sea compared to those in the Gulf of Thailand, could reflect that fisheries resources in the former are more abundant than in the latter, where fishing down the food web occurred because of heavy overfishing as mentioned by Pauly and Chuenpagdee (2003).

Trawl fisheries, especially demersal trawlers, are an unselective gear, producing a high quantity of trash fish, resulting in a decline of mean trophic level in the Gulf of Thailand marine food web (Pauly and Chuenpagdee, 2003). In addition, only one-fifth of total trawlers in Thai waters are found in the Andaman Sea (DoF, 2017b), reflecting the lower fishing effort in the Andaman compared to the Gulf of Thailand. The high number of trawlers is found in the Gulf of Thailand because the seafloor is shallower than the Andaman Sea.

In general, true trash fish is composed of many small marine species including finfish, crabs, and shellfish (Hoimuk et al., 2015). Among small fish, 45 species from 21 families were identified as true trash fish caught by trawlers (Siripitrakool et al., 2011), dominated by pony fish (family Leiognathidae), which makes up as high as 27–63 % of the true trash fish (Sanitmajjaro et al. 2012). High species diversity of economic juveniles in trash fish from trawl fisheries has been reported, including 72 species of demersal fish, 23 species of pelagic fish, 12 species of squids, 11 species of shrimps, and 7 species of crabs (Hoimuk et al. 2015). The major component is demersal fish comprising 23–37 % of total economically important juveniles in trash fish (Hoimuk et al., 2015; Tossapornpitakkul, 2008). When the proportion of these juvenile trash fish is considerable, as in the case of trawl fisheries (e.g. Supongpan and Boonchuwong 2010; Achavanuntakul et al. 2014), more awareness on the issue is needed. The study on the use of trash fish in fishmeal production is also pertinent, given the increasing concern over aquaculture development, especially shrimp farming in Thailand and elsewhere (Edwards et al., 2004; Funge-Smith et al., 2005). Only a handful of studies provide information about the amount of trash fish found in small-scale fishing gear. While it may be argued that the majority of catches from small-scale fisheries are utilised, lack of information on this topic may lead to inappropriate policies.

More research on the ecological impacts and economic losses of catching juvenile economically important fish and the utilisation of trash fish in Thailand is highly desirable. Discard issues have been of global concern as they pertain to a significant proportion of global catches and pose important challenges for sustainable fisheries (Kelleher, 2005; Matsuoka, 2008). Besides the impacts on the fish population, non-fish species such as benthic organisms, marine mammals, sea turtles, etc. may be threatened as a result of being caught and discarded.

3. Discard problems

The discarded species may not be valuable to market but they are still key components of marine ecosystems and might be the support for other species. Kelleher (2005) reported the global discard rate at 8 %, giving an estimated average discard of 7.3 million mt per year during 1992–2001. More than 50 % of the estimated discards were from trawl fisheries, especially tropical shrimp trawl fisheries, with discard rate as high as 62 %. He also argued that increased utilisation of bycatch for human and animal food could help reduce the quantity of discards (Kelleher, 2005). Supongpan and Boonchuwong (2010) supported the statement, saying that no marine fisheries discards in Thailand were found because all landings are utilised. However, Matsuoka (2008) argued that the estimation of global discards is not reliable and factual issues on discards should be more scientifically discussed.

Discard rate can vary greatly in different locations and fishing periods as well as between fishers who may have different practices although the same fishing gear is used. For examples, Boutson et al. (2007) reported that the discard rate of shrimp trammel nets in Thailand was 87 %, which is very high compared to that reported by Ean (2000) in Penang, Malaysia. Ean (2000) also reported that 69 % of total catch was bycatch, consisting of 53 % discards and 16 % retained bycatch, which is either sold or consumed by the household. Discard rates of trammel nets in the Mediterranean countries range from 10 % to 43 % (Tsagarakis et al., 2014).

Finally, even within the same country, some variations are expected. For instance, the study of crab gillnet fisheries bycatch in Pattani Bay, Southern Thailand, reveals that the proportion of discarded species from the Bay (26 %) was lower than that from offshore (47 %) (Fazrul et al., 2015). Based on our analysis, lack of discard information shows a huge gap of knowledge on ecological impacts of fishing gears in Thailand. This is a major concern, especially in the context of IUU fishing, where discards contribute to unreported catches. As illustrated by Teh (Teh et al., 2015), about 13 million MT or 5 % of Thailand's reconstructed catch during 1950–2010 is unreported discards. Degraded fish caused by poor storage or handling during transportation, usually kept in buckets, is still valuable and can be sold directly to fishmeal producers. This could be categorised as unreported catch since these fish are not included in fisheries statistics as trash fish (Achavanuntakul et al. 2014).

4. Marine megafauna as bycatch

Fishing impacts on marine mammals (dugongs, dolphins) and sea turtles and impacts on habitats are mostly reported in qualitative terms. Trawlers, push nets, gill nets and bamboo stake traps have been reported as the main fishing gears threatening these marine mammals and sea turtles (Hines 2005; Kittiwattanawong 2004; Adulyanakosol 2010). This implies that impacts on marine mammals and sea turtles can be generated from both large-scale and small-scale fishing gears. Impacts of fisheries on marine mammals and sea turtles have been reported globally (Moore et al., 2010). In the US, impacts of midwater gillnets on both marine mammals and sea turtles are of major concern, while pelagic longlines are also harmful to sea turtles (Chuenpagdee et al. 2003). In Canada, the gear impact study of Fuller et al. (2008) reveals that bottom gillnets cause 'medium-high' impact on marine mammals, while other gears generate 'medium' to 'low' impact. Besides trawlers, these studies emphasised the potential impacts of gillnets on marine mammals and sea turtles. In Thailand, laws have been issued with the aim of protecting marine mammals (dolphins, dugongs, whales) and sea turtles from fishing impacts (Thailand Ministry of Agriculture and Cooperatives 2016b). This measure supports Thailand's efforts related to implementation of the CBD Aichi Targets on sustainable management of marine living resources, especially to mitigate fishing impacts on threatened species and vulnerable ecosystems (CBD undated).

4. Habitat damage

In terms of knowledge about habitat damage, large-scale fishing gears, especially demersal trawlers and push nets, have been well studied, particularly in terms of their threats to coral reefs and seagrass beds. However, no in situ research has been conducted to quantify the direct impacts of these gears on seagrass beds and coral reefs (UNEP 2004; Vo et al. 2013). Some studies mention the indirect effect of trawling on coral reefs through sediment generation, based also on research conducted in other countries. Environmental impacts of dredging, in terms of changes in water quality and the sea floor, are well explained (for example, Chanrachkij (2012), while impacts on benthic communities are less understood. In conclusion, knowledge gaps exist with respect to the understanding of habitat damage caused by many bottom oriented fishing gears, particularly small-scale.

The results obtained from this part provide a useful information on existing knowledge and research gaps on ecological impacts of fishing gears in Thailand. Limited existing information and a huge gap of knowledge on bycatch and habitat damage emphasize that the researches on these topics are highly needed to increase understandings and scientific evidence for the implementation of EAF, and to a lesser extent, the efforts to combat IUU fishing. The results highlights that the scientific data of both bycatch and habitat damage in most gears are limited, particularly small-scale fishing gears. Under the framework of this dissertation, the estimation of by-catches and habitat damage of fishing gears were examined in Ko Chang and the Strait of Ko Chang, Trat Province with the following topics: 1) Analysis of small-scale fisheries bycatch in Mu Ko Chang, Trat Province; 2) An in-situ study of impact of fish traps fisheries on coral reefs in Ko Kut and Ko Mak, Trat Province; 3) the impacts of trawl, push net, and dredge fisheries on macrobenthic communities in the Strait of Ko Chang, Trat Province, Thailand. Finally, the expert-based gear impacts assessment was conducted to analyze and assess the relative ecological impacts of fishing gears using transdisciplinary approach.

## 4.2 Analysis of small-scale fisheries bycatch in Mu Ko Chang, Trat Province

### 4.2.1 Catch description

More than 7,000 individuals of fish with the biomass of about 1,300 kg were caught during the 54 fishing trips with nine small-scale fishing gears in Mu Ko Chang. High variation of catch rate was detected among gears. In this study, the highest average catch rate was found with bottom longlines accounting for 16.67 kg.100 m$^{-1}$ longlines.day$^{-1}$. About 30% of the total catch of this gear was catfish (*Plotosus* spp.). Acetes push nets caught mainly Acetes (*Acetes* sp.) with an average of 12.61 kg.day$^{-1}$, accounting for 97% of the catch. The catch rate of mullet gillnets was 5.33 kg.100 m$^{-1}$net.day$^{-1}$ and about 70% of the total catch was mainly mullets (*Liza* spp., *Moolgarda* spp.). The traps with different design and operation basically gave different catch rates and different target species, for examples, the catch rate of squid traps (3.64 kg.10 trap$^{-1}$.d$^{-1}$) was lower than that of fish trap (8.44 kg.10 trap$^{-1}$.d$^{-1}$) while crab trap has an average catch rate of 0.96 kg.10 trap$^{-1}$.d$^{-1}$ (Table 6).

In this observation, high seasonal variation of catch of target species were detected with bottom longlines, Acetes push nets, crab gillnets, and shrimp trammel nets. Bottom longlines, Acetes push nets, and shrimp trammel nets had the higher rate of the target species compared to those observed in dry seasons. (Figure 12). In terms of bycatch, seasonal variation was not detected because of the extremely high variation of bycatch rate among fishing trips whereas the rate of bycatch from bottom longlines was significantly different between seasons. However, the catch rate of bycatch species was influenced by the gear position (bottom and mid/surface) and different gear categories (fixed and mobile gears). The results showed that the gears placed near/on seafloor (1.94 kg.unit$^{-1}$.day$^{-1}$) tended to have higher catch rate of bycatch compared to those operated in the mid/surface of the water column (1.03 kg.unit$^{-1}$.day$^{-1}$) ($t=3.01$, $p<0.01$). Similarly, fixed gears (generated higher catch rate of bycatch than those of mobile gears ($t=2.18$, $p<0.05$) due to that most of fixed gears are generally placed on/near seafloor).

**Table 6** Average catch rates of total catch and target species of the nine small-scale fishing gears

| Gear | Average catch rate (SE) | Units | Target species* |
|---|---|---|---|
| Crab gillnets | 2.72 (0.62) | $kg.100\ m\ net^{-1}.day^{-1}$ | Swimming crab (*Portunus pelagicus*) |
| Mullet gillnets | 5.33 (2.26) | $kg.100\ m\ net^{-1}.day^{-1}$ | Mullets (*Liza* spp., *Moolgarda* spp.) |
| Shrimp trammel nets | 0.89 (0.30) | $kg.100\ m\ net^{-1}.day^{-1}$ | Shrimps (*Penaeus* spp., *Metapenaeus* spp. *Litopenaeus* spp.) |
| Acetes push nets | 12.61 (6.13) | $kg.day^{-1}$ | Acetes (*Acetes* sp.) |
| Crab traps | 0.96 (0.45) | $kg.10\ traps^{-1}.day^{-1}$ | Swimming crab (*Portunus pelagicus*) |
| Fish traps | 8.44 (2.99) | $kg.\ 10\ trap^{-1}.day^{-1}$ | Groupers (*Epinephelus* spp.) and snappers (*Lutjanus* spp.) |
| Squid traps | 3.64 (1.85) | $kg.\ 10\ trap^{-1}.day^{-1}$ | Big-fin reef squid (*Sepioteuthis* spp.) and cuttlefish (*Sepia* spp.) |
| Bottom longlines | 22.23 (9.29) | $kg.100\ m\ line^{-1}.day^{-1}$ | Catfish (*Plotosus* spp.), groupers (*Epinephelus* spp. ) and snappers (*Lutjanus* spp.) |
| Trolling lines | 0.8 (0.23) | $kg.pole^{-1}.day^{-1}$ | Indo-Pacific king mackerels (*Scomberomorus* spp.) Needlescaled queenfish (*Scomberoides tol*) |

Note: *Target species are identified by the fishers.

Seasonal variability of marine species depends on various factors, particularly oceanographic condition and often shapes the patterns of small-scale fisheries worldwide (Cetra and Petrere, 2014). Globally, small-scale fisheries, especially in tropical region, are often multispecies and multigear (Chuenpagdee and Jentoft, 2015). The use of fishing gears is different spatially and seasonally and depends on preferable target species with fishing experience with traditional knowledge on weather, characteristics of currents, wind direction etc. Using multigear, particularly using the high selective gear with the right time may help reduce the number of bycatch (Werner et al., 2006).

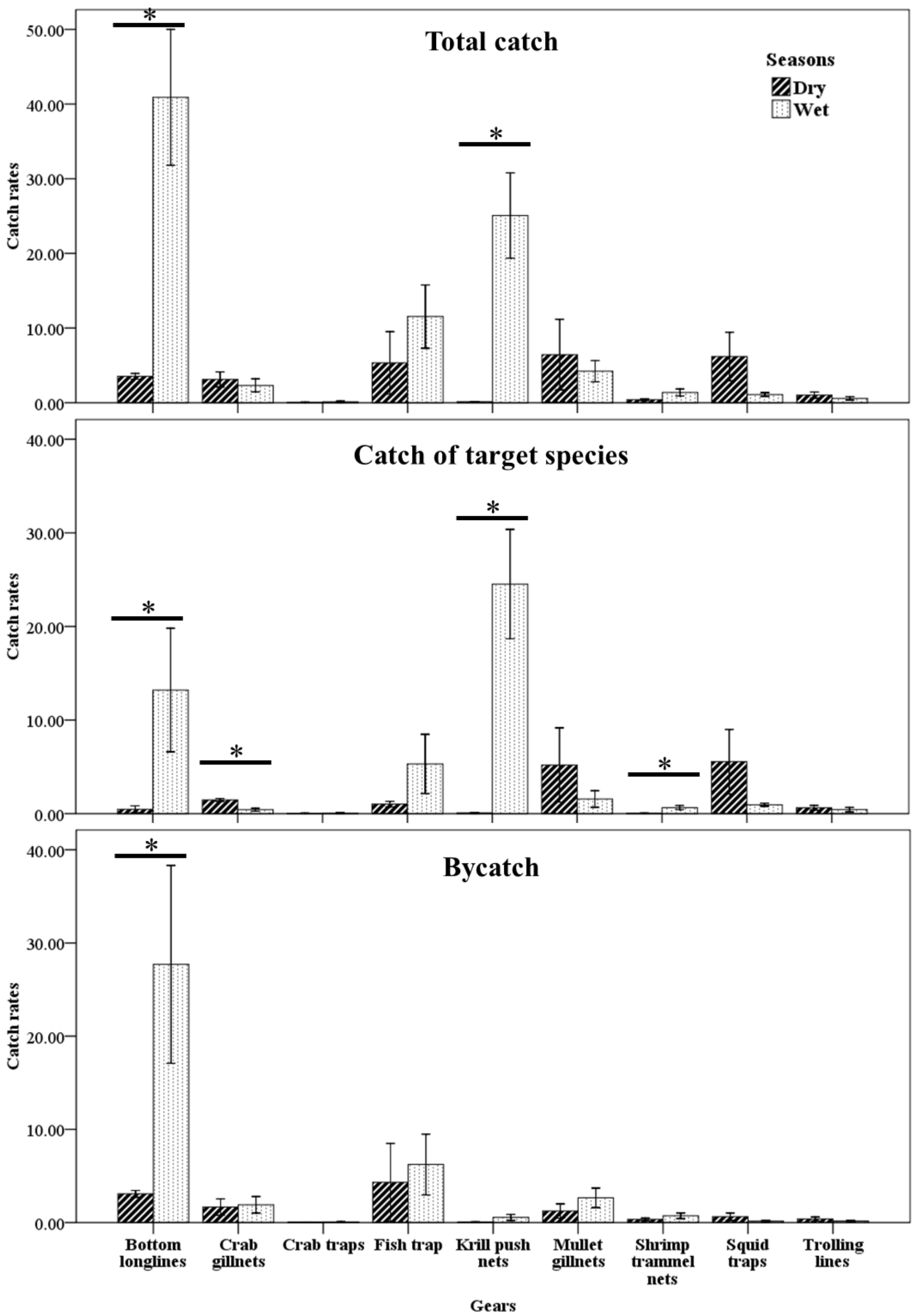



**Figure 13** Seasonal variability of catch rates of each fishing gear. Asterisk denotes significant different between wet and dry seasons (t-test, $p<0.05$).

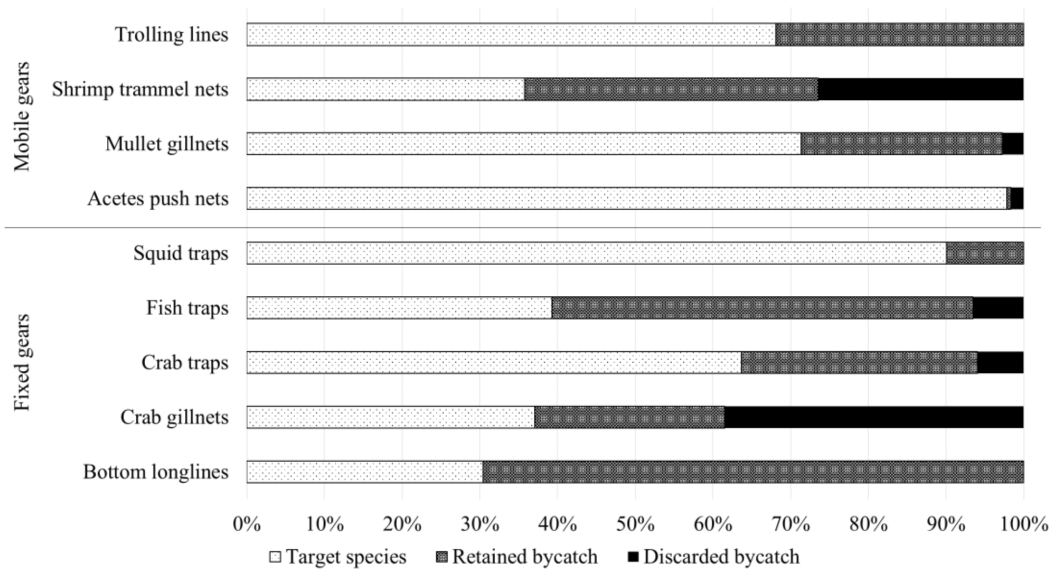



**Figure 14** Percent of target species, retained bycatch, and discarded bycatch (% of total weight).

4.2.2 Catch composition

The proportion of target species, retained and discarded bycatch greatly varied among gears. The highest proportion of target species was found with Acetes push nets accounting for 98% of the total catch biomass, followed by squid traps (90%), and mullet gillnets (71%), showing that these gears had relatively high selectivity. Bottom longlines showed the highest proportion of retained bycatch (70%) in which sharks and rays made up the highest proportion of the retained bycatch species. High percentages of retained bycatch was also recorded from fish traps (51%). Very little of retained bycatch (<1%) was found with Acetes push nets. In terms of discarded bycatch, crab gillnets exhibited the highest percentage (38%), followed by shrimp trammel nets (26% of the total catch) while no discarded bycatch was found with the catches of bottom longlines, squid traps, trolling lines. Acetes push nets, mullet gillnets, crab traps and fish traps fell in a low range of discarded bycatch, accounting for 2 – 7% of the total catch biomass (Figure 14).

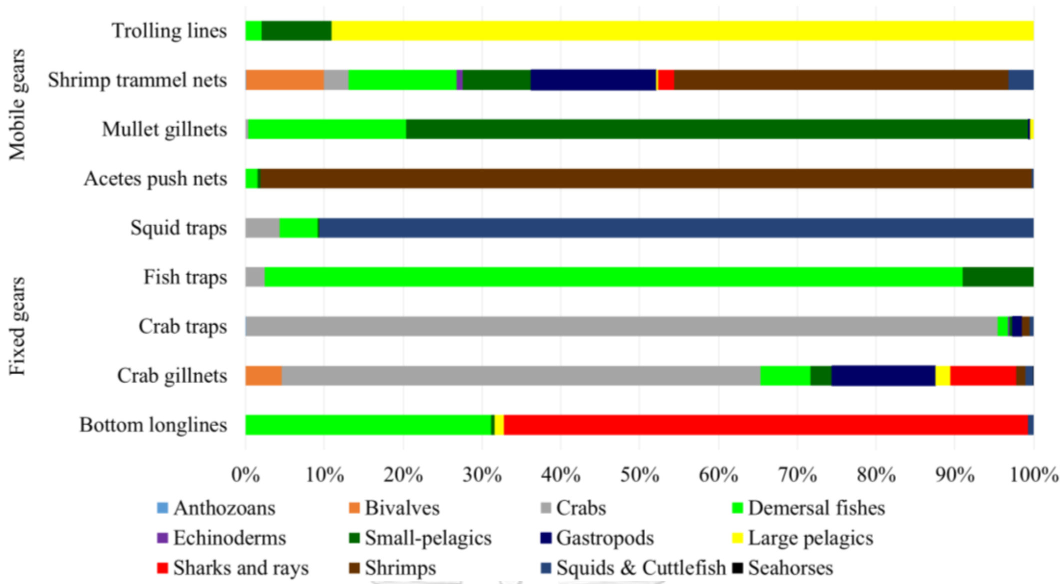



**Figure 15** Composition of total catch from nine small-scale fishing gears (% of total weight).

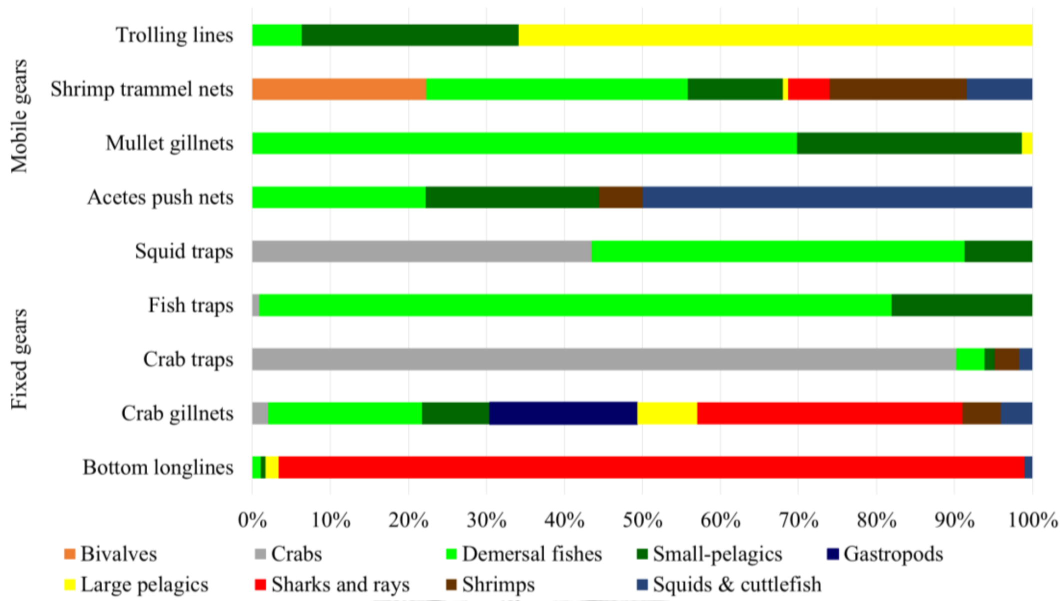
In terms of catch composition, as diverse as 138 species of total catches belonged to 66 families were recorded. Based on the biomass data, catch composition varied considerably among gears. Crab gillnets and shrimp trammel nets captured diverse taxa of marine species. However, crab (61% of the total biomass) and shrimp (43% of the total biomass) were still a majority of total biomass of crab gillnets and shrimp trammel nets, respectively. Small pelagics made up the most proportion in mullet gillnets (80% of the total biomass) and large pelagics contributed about 90% to the total biomass of trolling lines. Acetes push nets and crab traps were recorded as the gears with high selectivity to Acetes (*Acetes* spp.) and crabs (various species of crabs), respectively, constituted more than 95% of the total biomass. In addition, squid traps was also selective to capturing squids which was about 90% of the total catch biomass. Sharks and rays were mostly captured by bottom longlines although the fishers target catfish (*Plotosus* spp.), groupers (*Epinephelus* spp.) and snappers (*Lutjanus* spp.) (Figure 15).

4.2.3 Diversity of bycatch

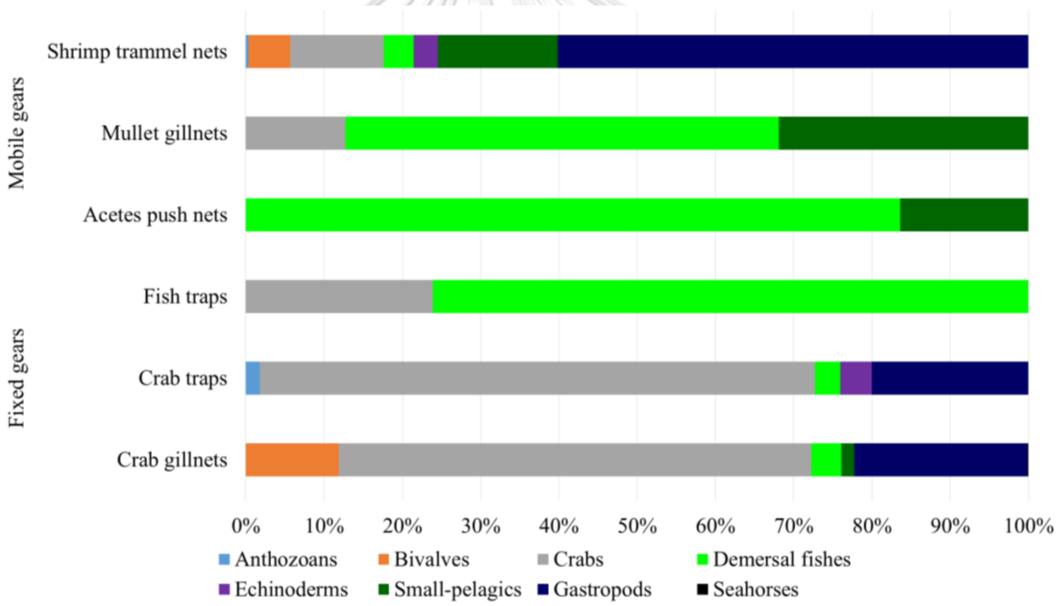
A total of 54 fishing trips captured about 413 kg of bycatch biomass consisting of 311 kg retained bycatch and 102 kg discarded bycatch, representing 75% and 25% of the total bycatch, respectively. Considering the number of individuals of bycatch, the proportion of retained (2,140 individuals or 45%) and discarded bycatch (2,643 individuals or 55%) was not much different. A total of 89 species of retained bycatch were recorded. Most of the retained bycatch were demersal fishes (35 species) followed by small pelagic fishes (19 species), crabs (8 species). About 55 species were considered as discarded bycatch dominating by 17 species of demersal fishes and 16 species of crabs (Figure 16).

In considering the diversity of total catch among gears, crab gillnet produced highest value of bycatch diversity (Shannon-Wiener Index (H') = 1.15), followed by shrimp trammel net (H' = 1.11) and mullet gillnet (H' = 1.05), while diversity of bycatch from Acetes push net (H' = 0.0095), squid trap (H' = 0.62), and bottom longlines (H' = 1.26) remained low. Mullet gillnet shows the high diversity of retained bycatch (Table 7).

Diversity of bycatch depends on many factors including selectivity of fishing gear, fishing method and period, species composition, natural characteristics of fishing ground etc (Murawski 1993; Kelleher, 2007; Major et al., 2017). A wide range of bycatch was reported mostly with gillnet and shrimp trammel net, for examples, trash crab remains a concern on the impacts of crab gillnet on crab biodiversity. The species richness of crabs as trash fish was quite high comprising 81.93 percent of total numbers of species. (Wisespongpand et al., 2013). In Pattani Bay, the southern Thailand, 95 and 87 bycatch species were caught with crab gillnet in the bay and offshore, respectively. Additionally, Boutson (2007) reported a total of 38 species of were found as bycatch in shrimp trammel net in Rayong Province consisting of demersal fish, crab, gastropods, star fish, sea urchin, squid and octopus etc.




(a)




(b)

**Figure 16** Composition of retained (a) and discarded bycatch (b) from nine small-scale fishing gears (% of total weight).

**Table 7** Some diversity indices of total catch, retained and discarded bycatch from nine small-scale fishing gears.

| Fishing Gears | Total catch (Target and non-target) | | | | Non-target | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Retained bycatch | | | | Discarded bycatch | | | |
| | *S* | *d* | *J'* | *H'* | *S* | *d* | *J'* | *H'* | *S* | *d* | *J'* | *H'* |
| Crab gillnets | 45 | 5.66 | 0.70 | 1.15 | 23 | 4.15 | 0.81 | 1.09 | 20 | 2.94 | 0.73 | 0.98 |
| Mullet gillnets | 31 | 4.84 | 0.70 | 1.05 | 20 | 3.74 | 0.84 | 1.10 | 9 | 2.06 | 0.90 | 0.86 |
| Shrimp trammel nets | 43 | 5.35 | 0.68 | 1.11 | 19 | 2.82 | 0.63 | 0.80 | 20 | 2.82 | 0.54 | 0.71 |
| Acetes push net | 11 | 0.64 | 0.00 | 0.01 | 5 | 0.99 | 0.75 | 0.53 | 5 | 0.69 | 0.83 | 0.58 |
| Crab traps | 30 | 4.10 | 0.58 | 0.86 | 18 | 2.69 | 0.62 | 0.78 | 11 | 2.05 | 0.65 | 0.68 |
| Fish traps | 17 | 2.92 | 0.78 | 0.96 | 9 | 1.65 | 0.71 | 0.68 | 5 | 1.41 | 0.80 | 0.56 |
| Squid traps | 11 | 1.83 | 0.59 | 0.62 | 8 | 1.81 | 0.69 | 0.63 | NA | NA | NA | NA |
| Bottom longlines | 12 | 2.08 | 0.84 | 0.91 | 9 | 1.56 | 0.84 | 0.80 | NA | NA | NA | NA |
| Trolling lines | 16 | 2.77 | 0.81 | 0.98 | 14 | 2.48 | 0.77 | 0.88 | NA | NA | NA | NA |

Notes: *S, d, J'*, and *H'* denote total species, species richness (Margalef), Pielou's eveness, and Shannon-Wiener Index, respectively. NA means no discarded bycatch was found.

### 4.2.4 Catch utilization

Overall, most fish (based on their total weight) were sold as fresh fish (52%) and processed fish (15%). Household consumption as food, preserved food, and use as baited fish were about 20%, while another 13% of that was discarded. Almost of the target species were sold as fresh fish, most catch from Acetes push net and crab trap were processed and sold as shrimp paste and crab meat, respectively (Figure 17). Like other parts of Thailand, Acetes paste production is generally found in every coastal province because it can be kept for a period of time and can be sold with high price.

Retained bycatch were either sold as fresh fish or use as household consumption depending on what they caught. Edible fish were generally sold as fresh fish while forage fish (pony fish) were either sold or used as baited fish for other fisheries such as crab traps, longlines, etc. Non-target crabs were mostly processed and sold as crab meat (Figure 18). Some bycatch are high value such as mantis shrimp that is sometime caught from bottom net and shrimp trammel net. The selling price could reach to 1,500 Baht/kg of live mantis shrimp. Most of bycatch are still sellable although they are inexpensive.

The major groups of discarded bycatch were demersal fish, crustaceans, and gastropods. Discarded crabs or it is usually call 'trash crab' are dominant in crab gillnet and crab trap. Demersal fish were mostly found as discards in mullet gillnet, fish trap, and Acetes push net. Gastropod were found as a major discard in shrimp trammel nets (Fig 16b).

This study reveals that the highest discard rate is found with crab gillnets (38%) and shrimp trammel nets (27%) while other gears remain low. Still, the discards of shrimp trammel net are quite low compared to other studies, for example, Boutson et al. (2007b) reported that the discard of shrimp trammel net in Rayong province was as high as 87% in which the dominant discarded species were true trash fish, e.g. silver-biddy (*Gerres* sp.) and pony fish (*Leiognathus* sp.), as well as other species with no commercial value, such as sea urchins, tiny jellyfish, gastropods and sea stars. Ean (2000) also reported the high discard rate of shrimp trammel net in Malaysia as much as 53% of the total catch. The discard rate in the use of shrimp trammel net in the Mediterranean ranged from 10-43% of total catch (Tsagarakis et al., 2014). Discard rate varies considerably through locations and consumption preferences. In Ko Chang, the discard rate was still relative low because of that the fishers utilize bycatch as much as possible, rather than discard them (Table 8).



In this survey, non-marketable size, low consumer preferences, and low quantity were the reasons for discards. Clucas (1996) mentioned that the fishers discarded the fish with many reasons, for examples, the fish may be undesirable in terms of species and size; damaged; incompatible with catch; poisonous or non-edible; spoiled rapidly. Fishers do not have enough space on board to keep fish; overquotas; prohibition on species, season, and gear, closure of fishing grounds. For example, in Bay of Biscay (the Atlantic), the main reasons for discarding are, firstly, market-related issues are the main reasons for discarding, followed by quality-related issues while discards related to the application of regulations are minor consideration (Morandeau et al. 2014).

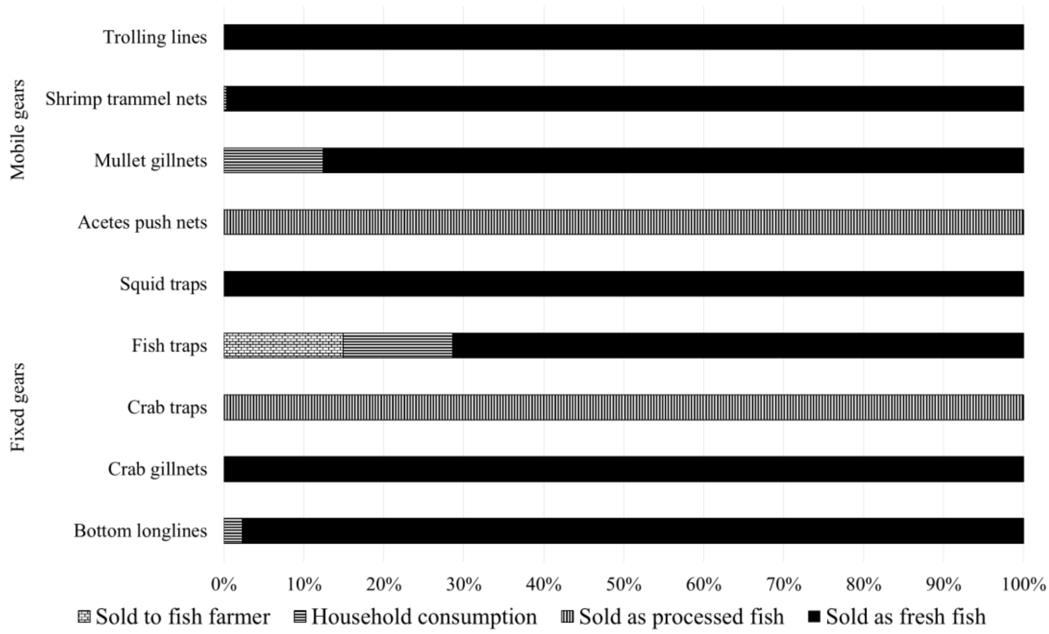



**Figure 17** Utilization of target species (% of total weight)

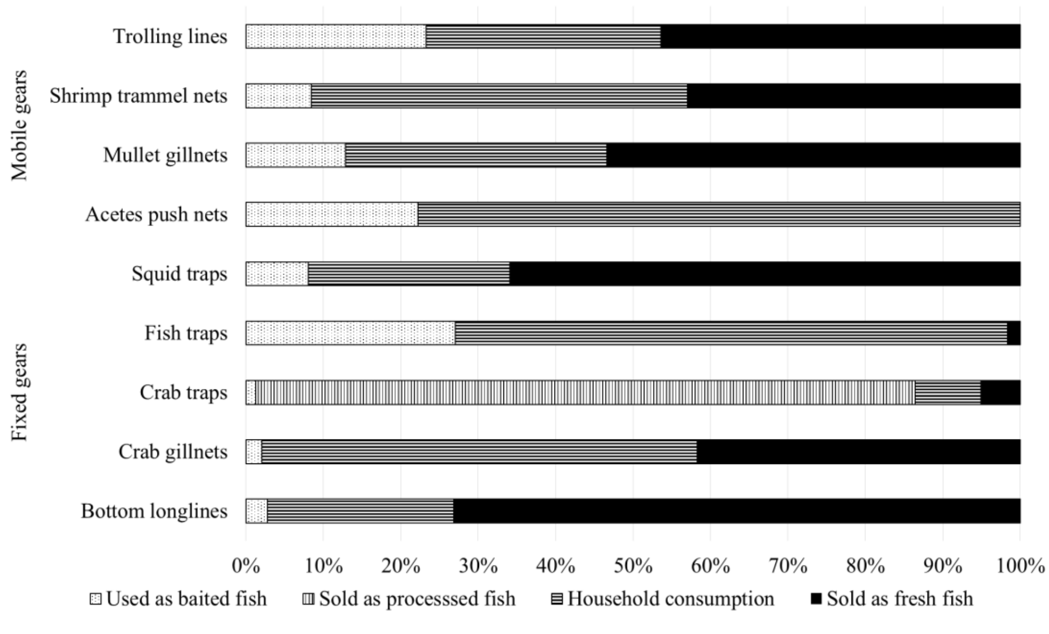



**Figure 18** Utilization of retained bycatch (% of total weight)

**Table 8** Discard rate of nine fishing gears

| Fishing Gears | Discard rate (%) | |
|---|---|---|
| | This study | Other works |
| Crab gillnets | 38% | Pattani: 26 - 47% (Fazrul et al., 2015) |
| Shrimp trammel nets | 27% | Rayong: 87% (Boutson, 2007)<br>Malaysia: 53% (Ean, 2000)<br>Mediterranean countries: 10% - 43% (Tsagarakis et al., 2013)<br>Portugal, Spain, Greece: 15% – 49 % (Goncalves et al. 2007) |
| Mullet gillnets | 2.6% | Turkey: 22. 8 - 77.8% (Aydın et al 2008) |
| Crab traps | 6.3% | Chantaburi: 49% (Kunsook and Dumrongrojwatthana, 2017) |
| Fish traps | 6.1% | Kenya: 3.1 – 6.5 (Mangi and Roberts, 2006) |
| Krill push nets | 1.68% | - |
| Trolling lines | 0% | - |
| Bottom longlines | 0% | Global estimate: 7.5% (Kelleher, 2005) |
| Squid traps | 0% | Italy: 9% (Fabi and Grati , 2005) |

4.2.5 Ecological concerns on discarded bycatch

In this study, a total of 2,643 individuals were observed as discarded bycatch. Most discarded bycatch species have no economic value and less consumption preference. Those species are either discarded at sea or land depending on the fisher's conveniences. According to the results, several discarded species should be considered as they might be more ecologically important although they has less or no market value.

The most dominant discarded bycatch was spine murex (*Murex* sp.) with a total of 765 individuals or about 29% of total discards. This was mostly caught by shrimp trammel nets and crab gillnets. Spine murex is a gastropod, belong to the Family Muricidae, and generally feeds on other molluscs and barnacles while the major predator of the spine murex are crabs. Some species of this genes consume particulate organic matter (POM) and polychaetes (Kwan et al., 2018). This illustrates that the murex is important as a pray for crab and some other marine species. In some localities, murex is used for decorations or even used as dye (Oliver, 2015). Besides discarding, overexploitation may cause the impacts on their population.

Trash crab has been concerned as fisheries bycatch (Kunsook & Dumrongrojwatthana, 2017; Wisespongpand et al., 2013). Three crabs were mostly discarded including anemone crab (*Dorippoides facchino*, Family Dorippidae), long-eyed swimming crab (*Podophthalmus vigil*, Family Portunidae) and spider crabs (Family Majoidae). All of them were mostly caught by crab gillnets while only anemone crab was found as bycatch in trammel net. Generally, decapods are omnivore. According to Wisespongpand et al. (2014), only shell are found in the stomach of anemone crab, so their main food is shellfish. Several studies reveal that spider crab ranged from macroalgae to benthic invertebrate while some members of spider crab pray feed on seaweed and Coralline algae, mollusks, gastropods, bivalves, echinoderms etc (Bernárdez et al., 2000). A study also shows that spider crab food webs are quite complex as the bio-magnification of polychlorinated biphenyls along the food web is detected by stable isotope analysis (Bodin et al., 2008). This reveals an ecological importance of crabs since it connects to various species in the higher trophic levels.

Hammer oyster (*Malleus albus*, Family Malleidae) and spiny oyster (*Spondylus* sp., Family Spondylida) are filter feeding bivalve found in shallow water inhabiting in muddy-sandy to hard substrate. They feed on phytoplankton, plant detritus, bacteria, and algae. The main predator of hammer oyster is drilling predator, especially gastropods (Chattopadhyay & Baumiller, 2009). The predators of spiny oysters include the gastropod, spiny lobster, rays, porcupine fish, stomatopod (Feifarek, 1987). Hammer oyster and spiny oyster were caught by crab gillnets and shrimp trammel net.

Four unidentified species of sea pens (marine cnidarians in the order Pennatulacea) were caught as discarded bycatch in crab trap and shrimp trammel net. Sea pens have root-like structure to stick themselves in sandy or muddy seafloor. They are filter feeders feed on plankton (Williams, 2011). They are an important food source on various marine species, particularly nudibranchs and sea stars. Sea pens provide important shelter and feeding ground for diverse marine fauna such as shrimps and brittle stars (ophiuroids) (De Clippele et al., 2015). Starfishes (Asteroidea) was also caught by shrimp trammel net and all of them were discarded. Generally, juvenile sea stars were fed by fish while the adult ones are active predators. They feed on marine invertebrates such as bivalves (Mah, 2013).

Ecological function and pray-predator relationship of those discarded bycatch illustrates the more ecological importance. Most of them are in the lower trophic level which means they are significant as a sources of food for other marine species in the higher level. Minimizing discards may enhance marine biodiversity and ecosystem integrity. Indeed, more research and studies are needed to generate understanding their ecological roles, particularly an endemic species whether they are a supporter for other fisheries resources. This study indicate the importance of bycatch study to support ecosystem approach to fisheries in Thailand.


Anemone crab (*Dorippoides* sp.)


Spider crab (Family Majoidae)


Long-eyed swimming crab

(*Podophthalmus vigil*)

Spine murex

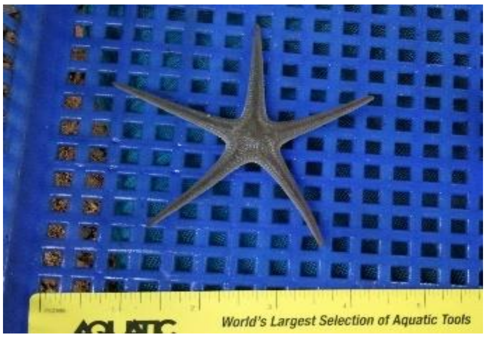
(*Murex* sp., Family Muricidae)


*Hammer oyster*

*(Malleus albus,* Family Malleidae*)*


Spiny oysters

*(Spondylus sp,* Family Spondylida*)*




Starfishes (Asteroidea)

Sea pens (Pennatulacea)

## 4.3 An in-situ study of impacts of fish traps on coral reefs in Ko Kut and Ko Mak, Trat Province

Knowing gear-habitat interaction is important for analyzing the impact of fishing activities on sensitive natural habitats. In this study, an in-situ study on fish traps in Ko Kut and Ko Mak, Trat Province was conducted to investigate the possible impacts on coral reefs. The main findings show that there are two main impacts: direct impact on corals, impacts of reef fish exploitation. Besides, other possible impacts observed during the study were found e.g. the impacts on macrobenthos, fish, and an issue on marine debris.

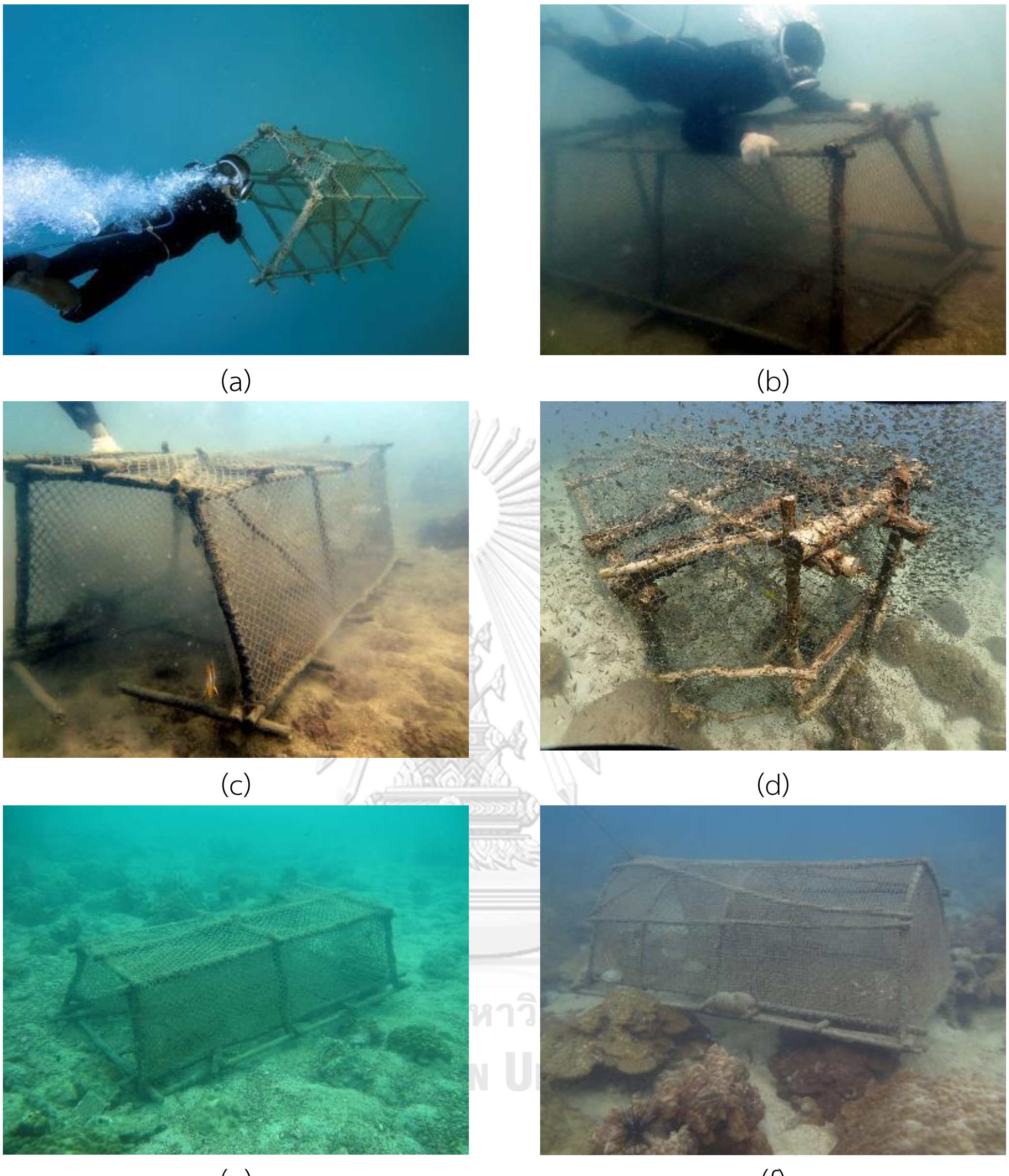
### 4.3.1 Impacts on corals

The underwater observation of fish trap fisheries revealed that most of the fish traps were laid on sandy substrate near coral colonies or rocks and sometimes on reefs (Figure 19). About 24% of the fish traps studied touched juvenile corals and coral communities, such as mushroom corals *Fungia* spp., stony corals, *Porites* sp. Pebble corals *Astreopora* sp., Moon brain corals *Favia* spp., resulting in breakage and injury of some touched corals. A total of 20 out of 82 traps touch different species of corals. High possibility of touch fall on *Fungia* sp. (15%) followed by *Porites* sp. (10%) (Table 10).



Sheridan et al. (2005) reported that fish trap sets in shallow water (<30 m) actually contact hard corals gorgonians, or sponges and the damage is patchy (Sheridan et al., 2003). Physical damage to corals have been concerned as a directed fishing impacts as reported from several studies (Mangi & Roberts, 2006; Uhrin et al., 2014). Physical damage and injury may lead to negative impact of coral health. Lamb et al. (2014) reported that skeletal eroding band disease is strongly linked with coral damage and injuries.

Sediment dispersion generated during setting and moving of traps was also observed, as another factor that could obstruct growth of corals (Erftemeijer et al., 2012). Sediments generated during trawling or dredging near coral reefs also contribute to coral reef deterioration (Sudara, 1999) and affect coral growth  (Chansaeng et al. 1992).



(a) (b) (c) (d) (e) (f)

**Figure 19** Illustrations of fish trap operation and the environmental characteristics of placement location in Ko Kut and Ko Mak, Trat, Thailand

**Table 9** Percentage of fish traps that touch each coral species

(n=82)

| Coral species | Probability of coral species touched by fish traps | |
|---|---|---|
| | Frequency | Percent |
| *Fungia* sp. | 13 | 15.85 |
| *Favia* sp. | 6 | 7.32 |
| *Porites* sp. | 9 | 10.98 |
| *Astreopora* sp. | 3 | 3.66 |

4.3.2 Harvesting reef fishes

Based on the 82 fish traps investigated, the CPUEs of fish traps varied considerably ranging from 0 – 2.56 kg/trap/day with its mean of 1.49 kg/trap/day. The average CPUE observed in rainy season was 1.32±0.21 kg/trap/day (n=24) while the one observed in dry season was 1.71±0.16 kg/trap/day (n=58). No significant difference in the CPUEs between rainy and dry season was found ($U = 511$, $p>0.05$). About 60% of total catch were target species including groupers (Family Serranidae) and snappers (Family Lutjanidae) while another 40% of them were bycatch. About 5 – 15% of the bycatch were discarded at sea and 85-95% were retained for household consumption and used as baited fish.

Of seven species of target species, three of them i.e. Duskytail groupers (*Epinephelus bleekeri*), Leopard grouper (*Plectropomus leopardus*) and Orange-spotted grouper (*Epinephelus coioides*) were categorized as “Nearly threatened” while three of them i.e. Blue line grouper (*Cephalopholis formosa*), Blacktip grouper (*Epinephelus fasciatus*), and Longfin grouper (*Epinephelus quoyanus*), were categorized as “Least concern” and one species, John’s snapper (*Lutjanus johnii*), has not yet evaluated according to the IUCN status. This reflects that these species are being exploited worldwide because of high market value and likely to become endangered in the near future. Disappearance of groupers and other top predatory fish by overfishing might affect ecosystem food web especially the predator-prey relationship and changes in fish community as reported in the Caribbean Sea (Chiappone et al., 2000).

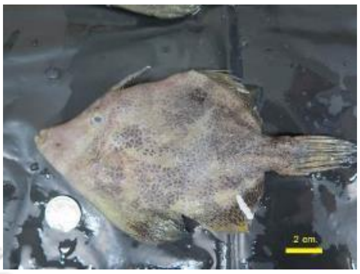
In terms of bycatch diversity, as many as 22 species of bycatch were found including 17 species of fish, 4 species of crustaceans and one species of sea cucumber as listed in Appendix E. Of which, 13 species of fish were retained for household consumption or sold as fresh fish while another 9 species were discarded at sea including 4 species of fish (*Diodon liturosus, Acanthostracion polygonius, Chelmon rostratus, Cantherhines pardalis*), 4 species of crabs (*Charybdis hellerii, Atergatis integerrimus, Myomenippe hardwickii, Dardanus megistos*) and a species of unidentified sea cucumber. Most bycatch (9 species) were carnivorous fish while five of them were herbivore fish (Figure 20).

The intensities seen in this study, trap fisheries cause serious overfishing, reduce biodiversity, and alter ecosystem structure (Hawkin et al. 2007). Disappearance of groupers and other top predatory fish by overfishing might affect ecosystem food web especially the predator-prey relationship and changes in fish community as reported in the Caribbean Sea (Chiappone et al., 2000). Extensive studies reported that removing herbivore fish from the coral reef ecosystem may also alter coral reef and may further link to reef resilience. For example, coral recruitment process is benefited by these herbivorous fish as they help reduce macroalgal cover providing more substrates for coral larvae to recruit and also prevent coral–macroalgal phase shift (Cheal et al., 2010). This can be used as one of the bioindicators for resilience-based monitoring (Heenan & Williams, 2013).


*Diodon liturosus*


*Acanthostracion polygonius*


*Chelmon rostratus*


*Cantherhines pardalis*


*Myripristis hexagona*


*Charybdis hellerii*


*Myomenippe hardwickii*


*Atergatis integerrimus*


*Dardanus megistos*


Sea cucumber

**Figure 20** *Illustrations of some bycatch species caught by fish traps, Trat Province*

4.3.3 Other possible impacts

1. Impact on marine benthic invertebrates

In this study, impacts marine benthic invertebrates were observed during trap movement and arrangement. Several studies mentioned that the impacts on macrobenthic invertebrates caused by trap movement has also been concerned. In case of lobster fisheries, the movement of the trap, particularity by wind and storm, causes scraped, fragmented, and dislodged sessile fauna, leading to significant impacts on stony coral, octocoral, and sponges (Uhrin et al., 2014).

2. Ghost fishing impacts and marine debris

Abandoned fish traps have been concerned as a cause of fish mortality through unintentional fishing or ghost fishing (Gabrielle et al. 2014; Matsuoka et al., 2005). A study of ghost fishing in Oman reveals that ghost fishing by fish trap causes fish mortality of about 1.34 kg/trap per day, decreasing over time. An exponential model trap ghost fishing mortality predicted that a mortality rate reaches to 67.27 and 78.36kg/trap during 3 and 6 months, respectively (Al-Masroori et al., 2004). Beside mortality, skin abrasions were observed with the entrapped fish (Gabrielle et al., 2014). According to Clark et al. (2012). About 5% of all trapped fish were observed with skin wounds or abrasions, while 20% of those that died had abrasions. Ballesteros et al. (2018) reported that coral which is covered by the fishing gears in Ko Tao showed several damage, particularly tissue loss. Since most of the fish traps are made of plastics which is non-biodegradable, the issues on marine debris and plastic pollution have been concerned (Ballesterosa et al., 2018; APEC Fisheries Working Group, 2004).

## 4.4 Impacts of trawl, push net and dredge fisheries on macrobenthic communities in the Strait of Ko Chang, Trat Province

### 4.4.1 Abundance of macrobenthic invertebrates

Macrobenthic communities are used as an ecological indicator to assess fishing impacts in the Strait of Ko Chang, where two different intensiveness of trawling and dredging are found, consisting of 1) the zone where trawling, push net fisheries, dredging are prohibited all year round (Station A to F), and 2) the zone where such fisheries are allowed to operate for 6 months (Station G to J).

The results showed that the dominant groups of macrobenthos found in every sampling station included polycheates, bivalves, decapods, amphipods, ophiuroids etc. In an overall picture, the average abundances of benthic species in permanent closure zone (265.55 ind./$m^2$) of trawling and dredging was significantly higher than those observed in a six-month closure zone (153.70 ind./$m^2$) in wet season ($p<0.05$), while the surveys in dry season exhibited a significant lower abundance in six-month closure zone (125.93 ind./$m^2$) compared to the permanent closure zone (252.11 ind./$m^2$) ($p<0.05$). However, the spatial variation among stations were also detected (One-way ANOVA). The two-way ANOVA testing on the effect of zone and season on the abundance revealed only an effect of zone on their abundance was observed ($F=43.31$, $p<0.01$) and no interaction between factors was found ($F = 0.44$, $p=0.83$) (Figure 21).



In an overall picture, the average abundance of macrobenthos in permanent closure zone (265.55 ind./$m^2$) was significantly higher than those observed in a six-month closure zone (153.70 ind./$m^2$). Those are higher than the previous studies by Jualaong (2007) reported that the average abundance of macrobenthos in Mu Ko Chang was 144.8 ind./$m^2$ dominated by polycheates.

According to the study of Putchakarn (2005), the average abundance of macrobenthos along the eastern gulf of Thailand (from Chonburi to Trat) was 554.47 ind./$m^2$ dominated by polycheates, crustaceans, bivalves, gastropods, and echinoderms.

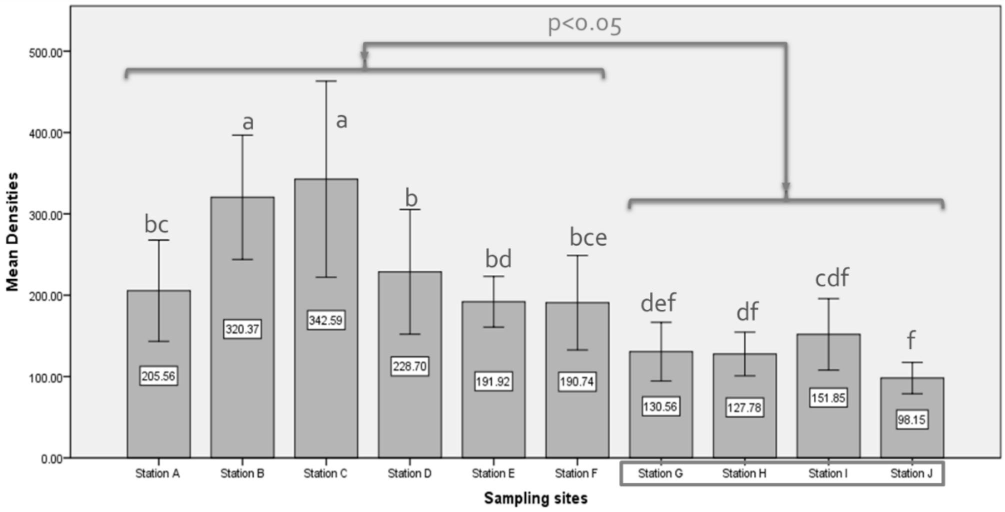



**Figure 21** Mean total density of macrobenthos (ind/m$^2$) at each study sites

Remark: Means sharing the same letter are not significantly statistical different (Tukey's HSD test, p<0.05)

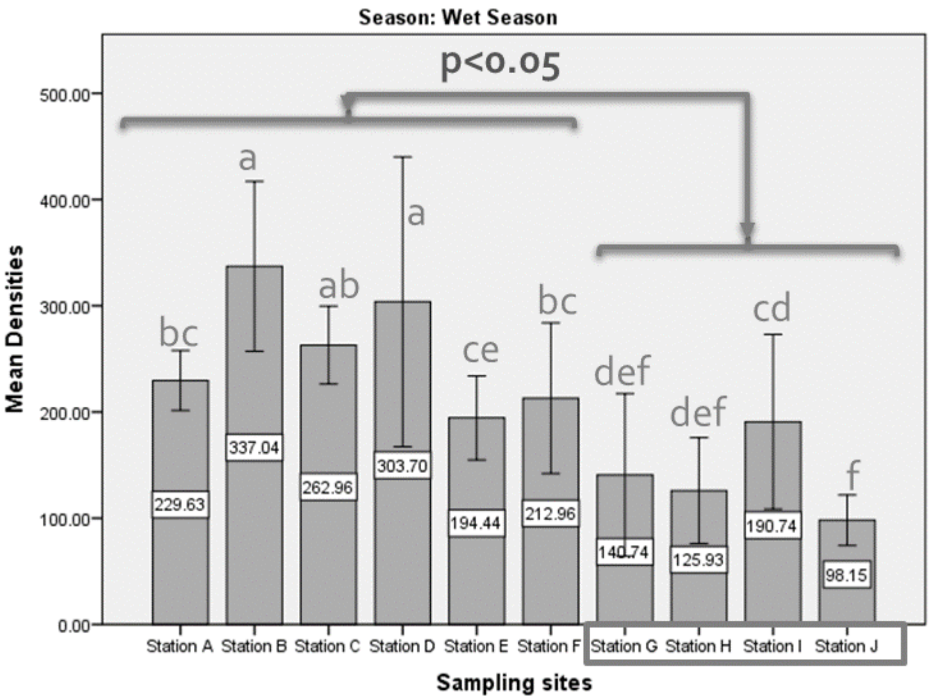



**Figure 22** Mean total density of macrobenthos (ind/m$^2$) at each study sites in wet season

Remark: Means sharing the same letter are not significantly statistical different (Tukey's HSD test, p<0.05)

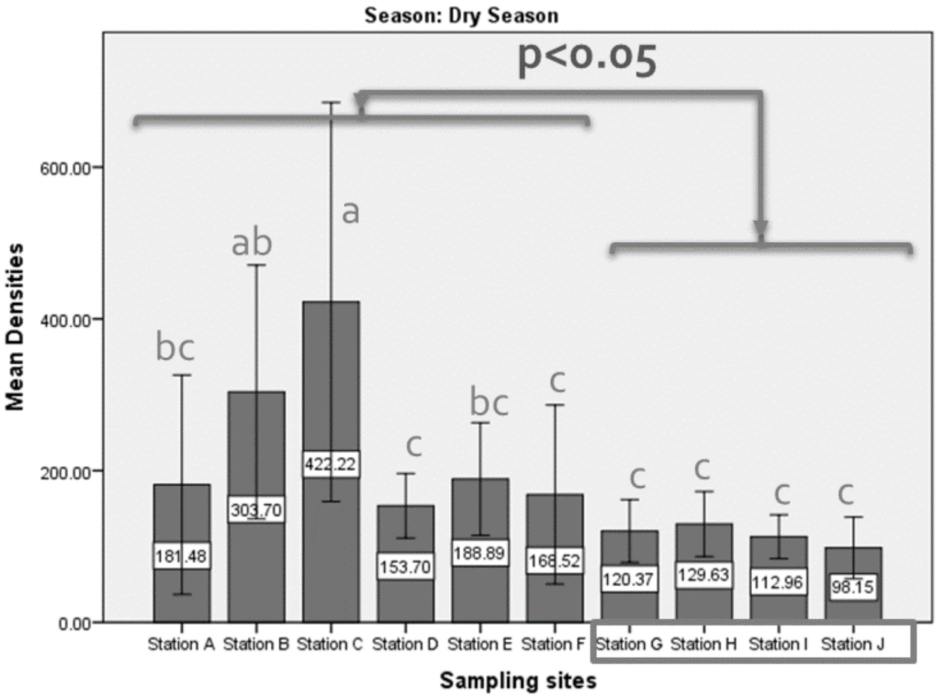



**Figure 23** Mean total density of macrobenthos (ind/$m^2$) at each study sites in dry season

Remark: Means sharing the same letter are not significantly statistical different (Tukey's HSD test, $p<0.05$)

4.4.1 Diversity of macrobenthic invertebrates

In this study, a total of 72 taxa in 10 phyla was observed. In overall, higher diversity was observed in the permanent closure zone with as many of 20.66 taxa than that observed in the six-month closure zone (16.2 taxa). The statistical test showed statistical differences in terms of number of taxa, between permanent closure zone (n=12) and six-month closure zone (n=8) (Mann-Whitney U = 7.500; $p<0.01$).

The species richness, Pielou's eveness, and Shannon diversity index observed in the permanent were 2.73, 0.83, 1.08, and 2.25, 0.85, 1.02 for the six-month closure zone, respectively. The highest diversity was found at station D which is closed to Ko Chang exhibiting the species richness and Shannon diversity indices of 4.22 and 1.03 in dry season (Table 10).

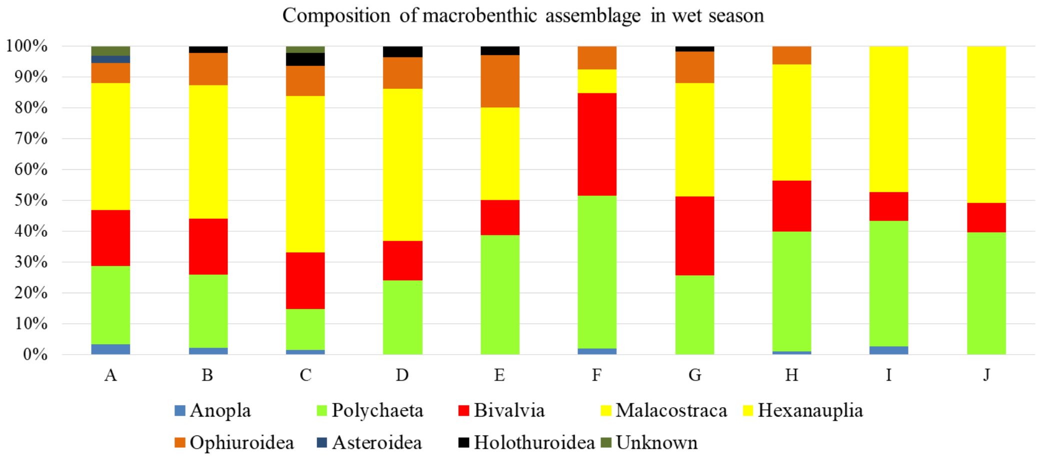
Besides, all diversity indices were different significantly between wet and dry season. However, when the observed data from every samplings were pooled, more taxa were found in dry season (12 - 35 taxa) than wet season (15 - 22 taxa) (Figure 18-19).

The diversity of macrobenthos observed in this study is relatively low compared with the study of Jualaong (2007) which reported that the diversity index of macrobenthos in Mu Ko Chang was 1.3. Study of Putchakarn (2005) also shows the higher diversity of macrobenthos (H’=1.76) along the eastern Gulf of Thailand.

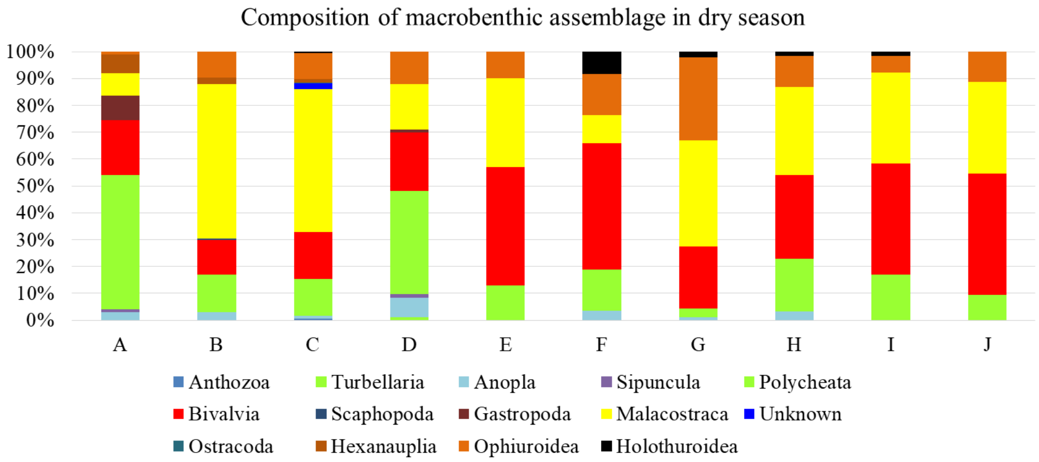
**Table 10** total taxa, richness, eveness, and diversity of macrobenthos at each site and season

| Sites | Dry season | | | | | Wet season | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S | N | d | J' | H' | S | N | d | J' | H' |
| A | 17 | 1,089 | 2.29 | 0.86 | 1.06 | 20 | 1,333 | 2.64 | 0.91 | 1.19 |
| B | 20 | 1,822 | 2.53 | 0.68 | 0.89 | 22 | 2,022 | 2.76 | 0.86 | 1.16 |
| C | 35 | 2,533 | 4.34 | 0.66 | 1.02 | 16 | 1,544 | 2.04 | 0.80 | 0.97 |
| D | 30 | 922 | 4.25 | 0.91 | 1.35 | 20 | 1,822 | 2.53 | 0.87 | 1.13 |
| E | 20 | 944 | 2.77 | 0.79 | 1.03 | 19 | 1,167 | 2.55 | 0.85 | 1.09 |
| F | 16 | 1,011 | 2.17 | 0.76 | 0.92 | 22 | 1,278 | 2.94 | 0.88 | 1.18 |
| G | 14 | 722 | 1.98 | 0.82 | 0.94 | 18 | 844 | 2.52 | 0.87 | 1.09 |
| H | 14 | 778 | 1.95 | 0.90 | 1.03 | 15 | 756 | 2.11 | 0.92 | 1.09 |
| I | 13 | 678 | 1.84 | 0.89 | 0.99 | 19 | 1,144 | 2.56 | 0.89 | 1.14 |
| J | 12 | 589 | 1.73 | 0.82 | 0.88 | 16 | 589 | 2.35 | 0.87 | 1.05 |
| Average | 19.1 | 1,109 | 2.58 | 0.81 | 1.01 | 18.7 | 1,250 | 2.50 | 0.87 | 1.11 |

Notes: S, d, J', and H' denote total taxa, species richness (Margalef), Pielou’s eveness, and Shannon-Wiener Index, respectively.



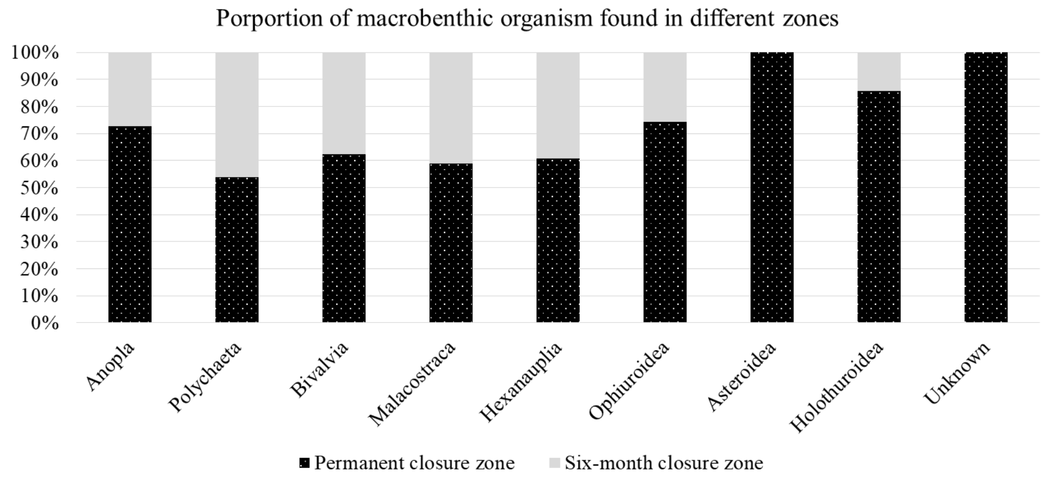

wet



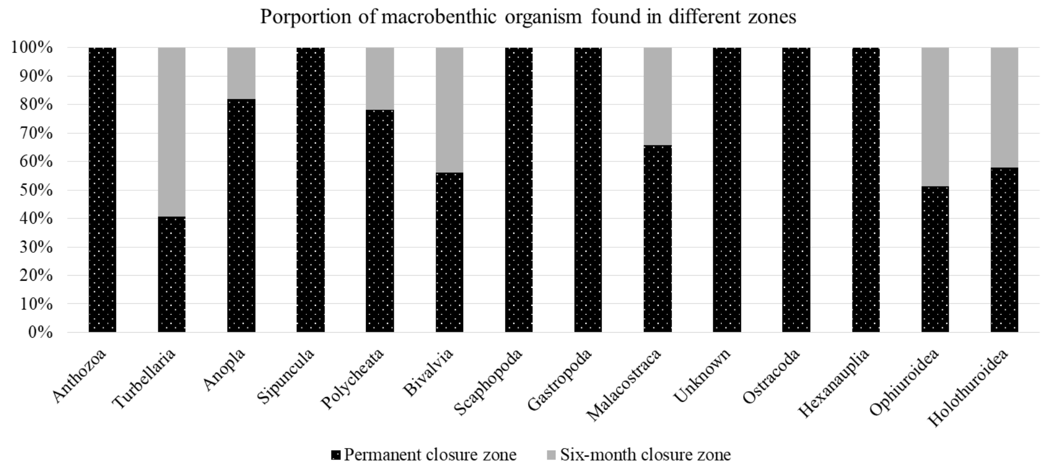



Dry

Figure 24 Species composition of macrobenthos at each zone during wet season



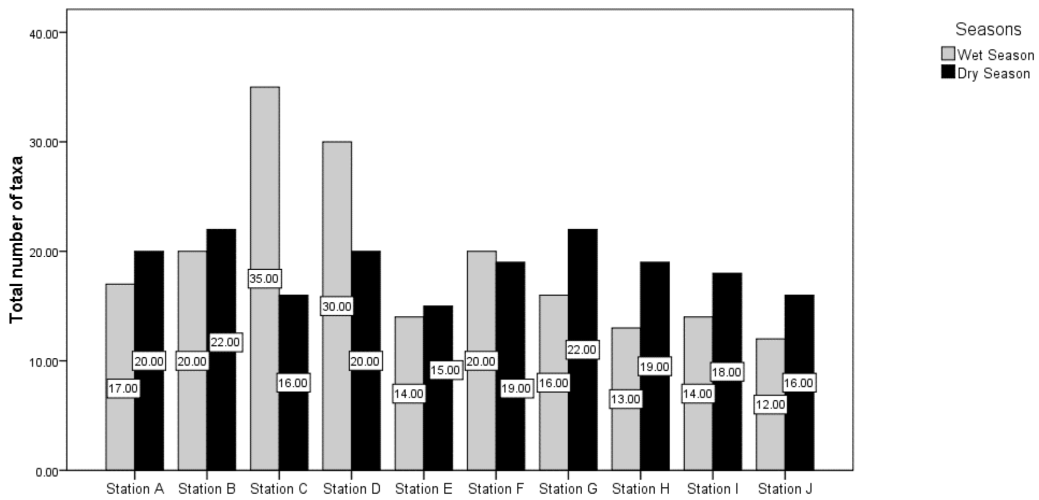

Wet season



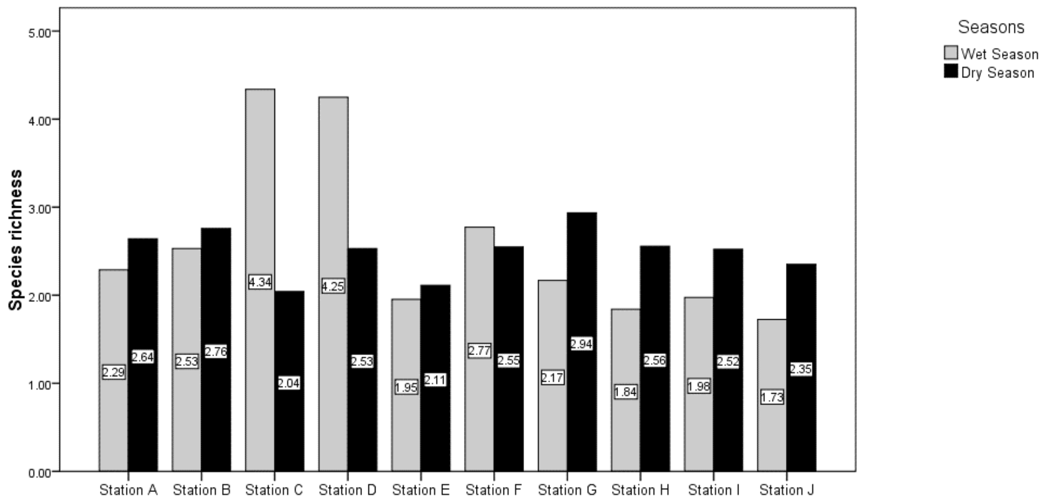

Dry season



**Figure 25** Relative abundance of macrobenthos at each zone during dry season



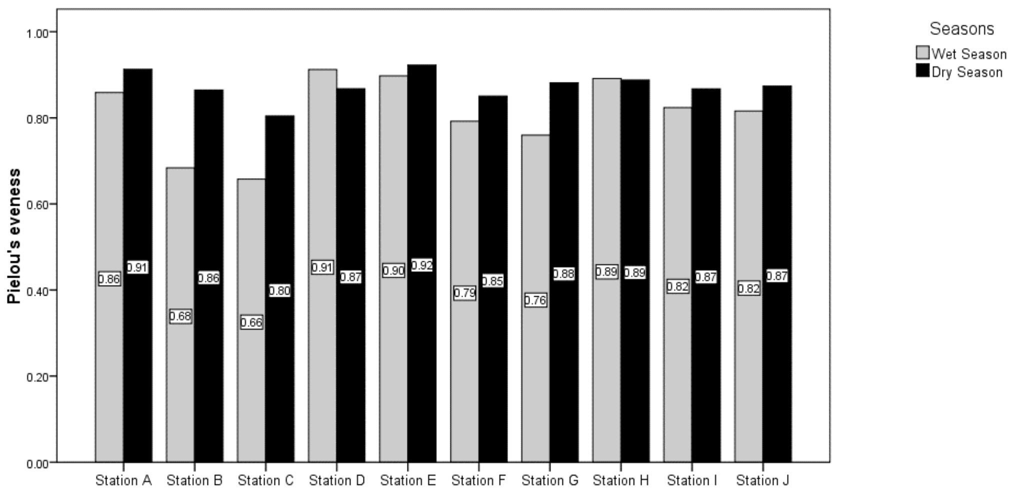

(a)



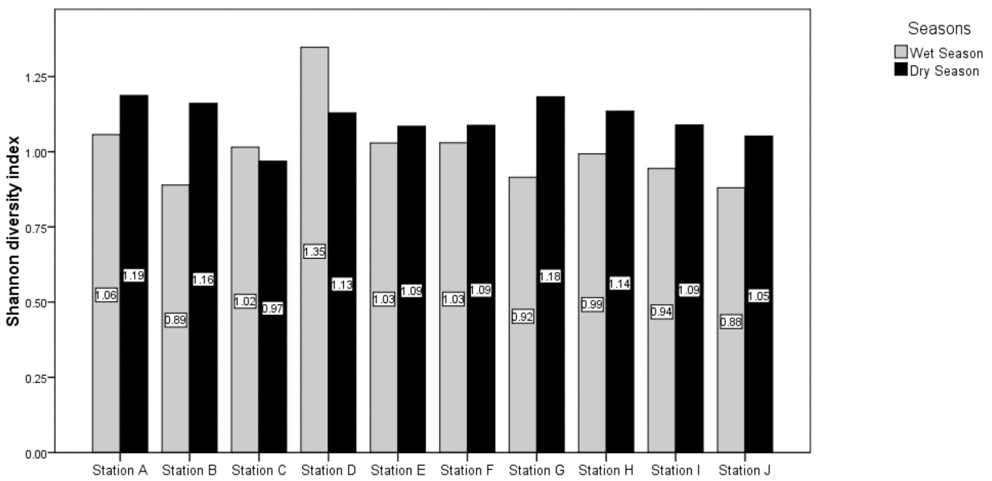

(b)



**Figure 26** Total number of taxa and Shannon diversity index of macrobenthos in each sampling site




(a)






(b)

**Figure 27** Species richness and eveness of macrobenthos in each sampling site


Amphipoda


Alpheidae

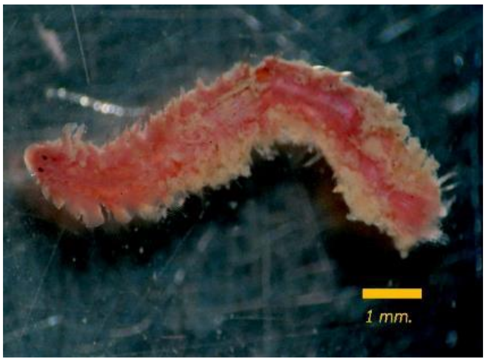

*Anadara* sp.


*Antigona* sp.


Cossuridae


Nephtyidae

**Figure 28** Illustrations of some macrobenthic species in the Strate of Ko Chang




Spionidae


Sternaspidae


*Scalopidia spinosipes*


Sea pen


Ophiuroidea


*Paracaudina* sp.

**Figure 29** Illustrations of some macrobenthic species in the Strate of Ko Chang (continued)

Based on a Bray-Curtis Similarity, Permutational Multivariate Analysis of Variance (PERMANOVA) indicated the statistically significant differences of benthic community composition between zones (Pseudo-F = 8.9813, p(perm)= 0.001) and season (Pseudo-F = 10.267, p(perm)= 0.001). The Similarity Percentage (SIMPER) was performed to identify which taxa are responsible for major contribution to similarity or it could help identify the taxa that are generally found in a certain group. In the permanent closure zone, polycheates, bivalves, ophiuroids, and amphipods contribute 73% of a total similarity, while most similarity found in six-month closure zone were contributed mostly (80%) by bivalves, polycheates, amphipods and decapods.

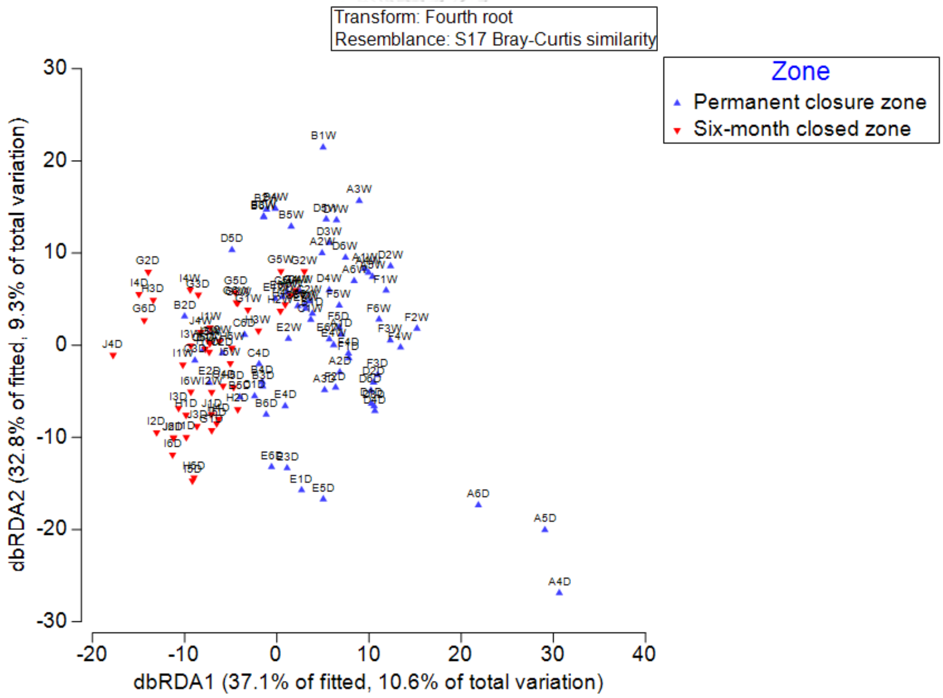



**Figure 30** dbRAD plot based on the fourth-rooth transformed data (number of individuals) showing the similarity of specie composition of each samples

**Table 11** The Similarity Percentage (SIMPER) showing the contribution of major macrobenthic invertebrates between zone groups and season groups.

| Examines Zone groups | | | Examines Season groups | | |
|---|---|---|---|---|---|
| Group Permanent closure zone | | | Group Dry | | |
| Average similarity: 66.13 | | | Average similarity: 63.26 | | |
| Species | Contrib% | Cum.% | Species | Contrib% | Cum.% |
| Polychaeta | 26.58 | 26.58 | Bivalvia | 26.62 | 26.62 |
| Bivalvia | 21.94 | 48.52 | Polycheata | 21.69 | 48.31 |
| Ophiuroidea | 13.39 | 61.91 | Amphipoda | 17.67 | 65.99 |
| Amphipoda | 12.01 | 73.92 | Ophiuroidea | 11.01 | 77 |
| Group Six-month closure zone | | | Group Wet | | |
| Average similarity: 70.93 | | | Average similarity: 71.80 | | |
| Species | Contrib% | Cum.% | Species | Contrib% | Cum.% |
| Bivalvia | 21.43 | 21.43 | Polycheata | 27.61 | 27.61 |
| Polycheata | 21.41 | 42.85 | Bivalvia | 17.67 | 45.28 |
| Amphipoda | 20.7 | 63.55 | decapoda | 17.36 | 62.64 |
| decapoda | 16.97 | 80.52 | Amphipoda | 12.44 | 75.08 |



4.4.3 Environmental factors

Environmental parameters played important role in shaping community structure and their abundance. As observed, most environmental parameters between two zones were not statistically different except the percentage of sand and depth ($p<0.05$). The percentage of sand in permanent and six-month closure zones were 22.68% and 14.45% and the average depth between two zones were 4.48 and 7.7 meters, respectively (Figure 31).

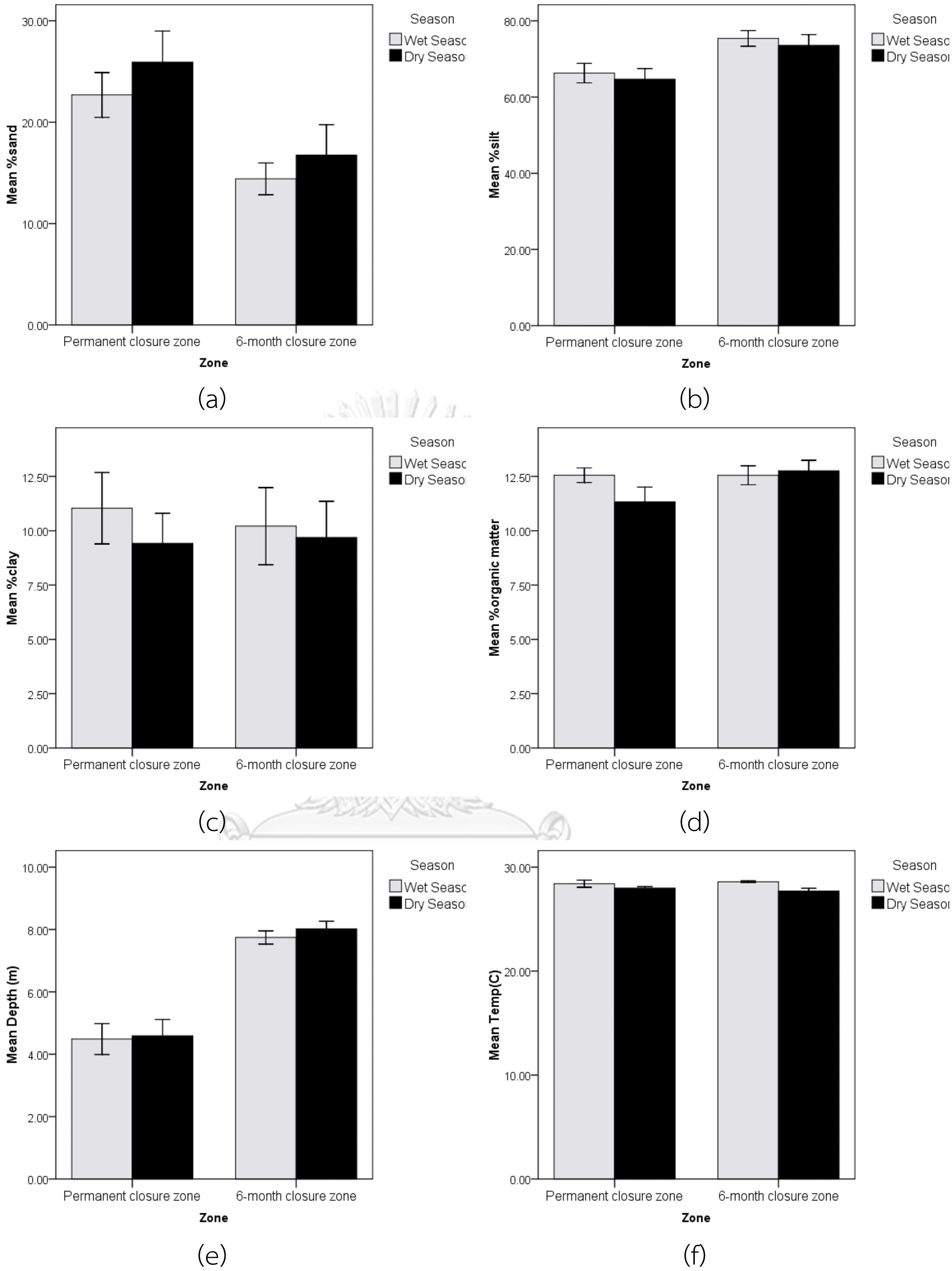



**Figure 31** Some environmental data recorded during sampling in two zones and two periods

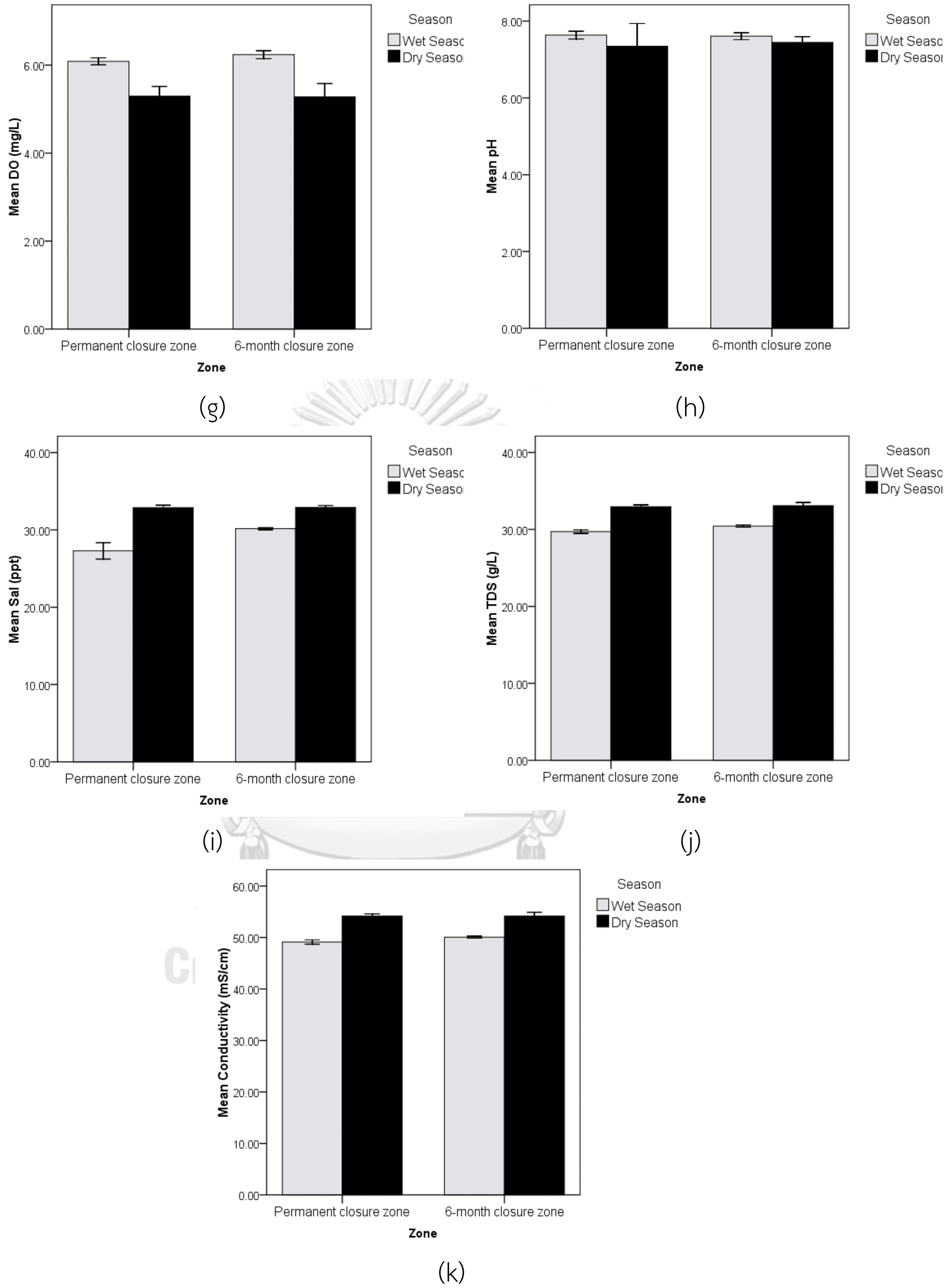



**Figure 31** Some environmental data recorded during sampling in two zones and two periods

The PCA ordination reveals the similarity of environmental condition at each sampling site. A slightly separation between two zones was driven by the percentage of sand, silt, and depth. The DISTLM revealed that some parameters that can be used as predictors include %silt, %clay, %Organic matter, depth, temperature, dissolved oxygen, pH, and salinity. The dbRDA ordination plot explained with the first two axes explained 37.1% of the fitted variation and 10.6% of the total variation. The pattern of the macrofaunal samples in each station suggested two gradients of variation. The first gradient was driven by variable “depth” explaining that the benthic composition on the left of the quadrant, most of stations in the six-month closure zone, were more influenced by depth. The second gradient was driven by the variable “salinity”, clustering the sampling stations in the lower quadrant explaining that those sampling station are influenced more with salinity, especially during dry season (Figure 33).

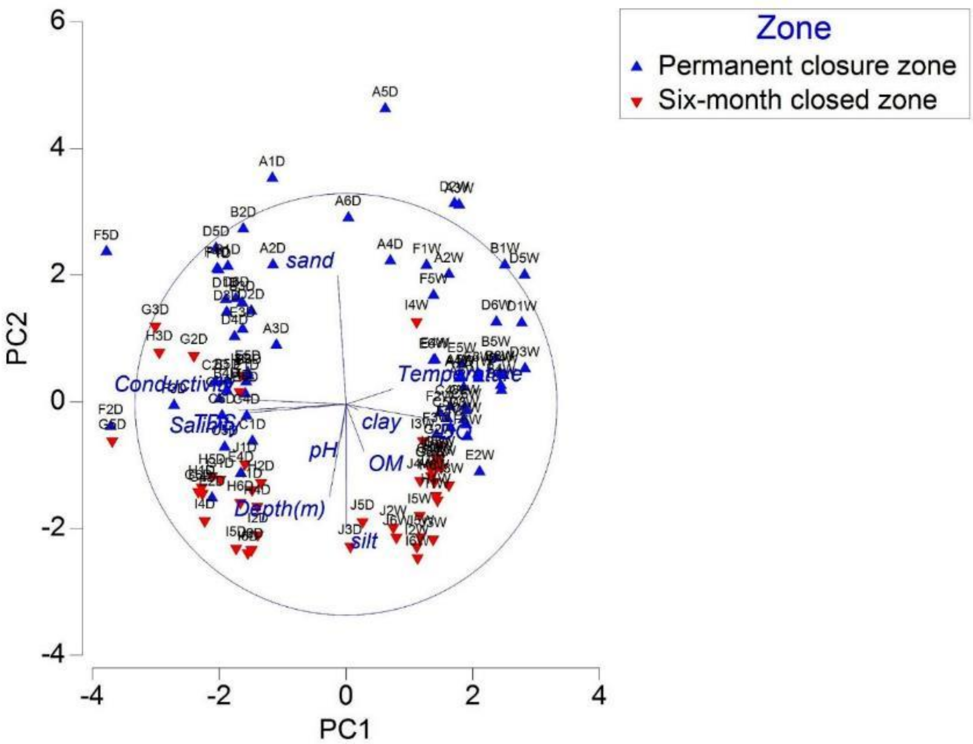



**Figure 32** PCA plot showing the similarity of environmental condition of each samples

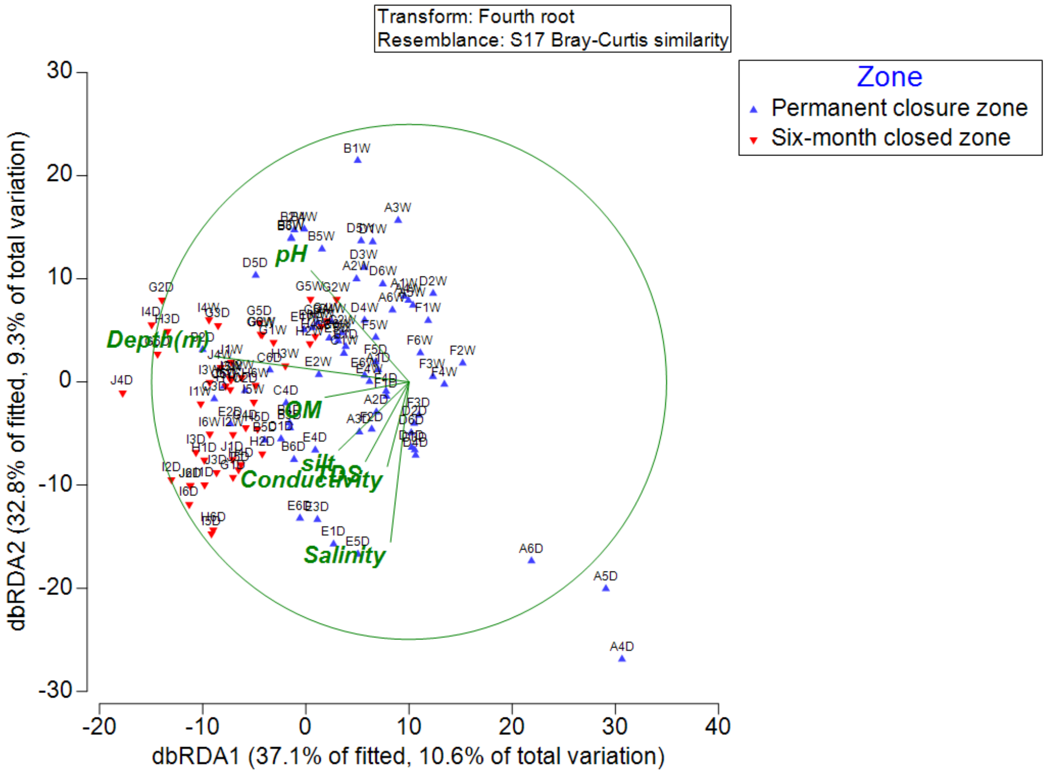



**Figure 33** The relationships between the environmental parameters and the abundance of the benthic communities were examined using a distance-based linear model (DISTLM) and distance-based redundancy analysis ordination (dbRDA).

**Table 12** The results from distance-based linear model (DISTLM) showing the fitted explanatory environmental variables

| Variable | $R^2$ | SS(trace) | Pseudo-F | p-value |
|---|---|---|---|---|
| Sand | 0.02 | 1,705.30 | 2.38 | 0.042* |
| Silt | 0.04 | 1,917.50 | 2.72 | 0.023* |
| Clay | 0.05 | 612.74 | 0.87 | 0.421 |
| Organic matter | 0.08 | 2,328.40 | 3.36 | 0.010* |
| Depth | 0.13 | 4,823.20 | 7.35 | 0.001* |
| Temperature | 0.16 | 2,582.40 | 4.04 | 0.002* |
| Dissolved oxygen | 0.18 | 1,573.60 | 2.50 | 0.050* |
| pH | 0.21 | 2,772.30 | 4.54 | 0.010* |
| Salinity | 0.27 | 5,014.40 | 8.79 | 0.001* |
| TDS | 0.28 | 456.97 | 0.80 | 0.553 |
| Conductivity | 0.28 | 564.24 | 0.99 | 0.454 |

Our finding revealed that although there was no seasonal variability on the mean total density, the composition of macrobenthos varied seasonally. Generally macrobenthic communities are dynamic and seasonally changed within a year. It also relates to the recruitment process and predator-pray relationship (Lamptey & Armah, 2008).

Our results revealed that most environmental parameters observed between two zones were not significantly different except %sand, %silt, and depth. It may because of that those sampling stations are located in the same micro-region where smaller environmental fluctuation occurs. A number of environmental variables including sediment structure, organic matter content, temperature, salinity, dissolved oxygen, nutrient concentrations, pH, turbidity, water transparency, and depth have been concerned as factors influencing on macrobenthic community (Lamptey & Armah, 2008; )

Soheil et al. (2018) mentioned that macrobenthic community was shaped by a combination of the factors and no single factor could be considered as a main influencing factor. According to the analysis, the results showed that depth, salinity, temperature, dissolved oxygen, organic matter content, pH, silt and clay content clay play important factor in the change of macrobenthic composition.

In terms of fishing impacts, the difference in abundance of macrobenthos between two zones are significantly different and it may be probably caused by the combination of fishing activities and environmental factors. However, Sea pens were only found in permanent closure zone where no fishing activity is found while none of the sea pens was found in any sampling sites in six month closure zone. Sea pens, in this case may imply that disappearance of those sea pens in the six-month closure zone may link to the physical disturbance from trawling and dredging (Williams, 2011). However, it is still difficult to confirm that the change in composition of macrobenthos between such zones because of the strong influence of environmental factors. Studies on the recovery of benthic communities showed recovery periods ranging from 3 months up to 25 years (Micheli et al., 2004).

## 4.5 Expert-based gear impacts assessment: Transdisciplinary approach

### 4.5.1 Rating gear impacts

Based on the expert judgment on the exercise A, trawlers generated impacts on forage fish, epifauna, infauna and various habitats (coral reefs, seagrass beds, soft bottom). Marine mammals and sea turtles were risky from pair trawls. In terms of artisanal fishing gears, most of the gears generate lower impacts on both bycatch and habitats. However, high impact scores of shrimp trammel nets were observed on demersal fish, forage fish, and crabs. Most judges concerned bottom longlines could affect on marine mammals and sea turtles. Among artisanal fishing gears, the impacts of crab traps on coral reefs were concerned (Figure 34).

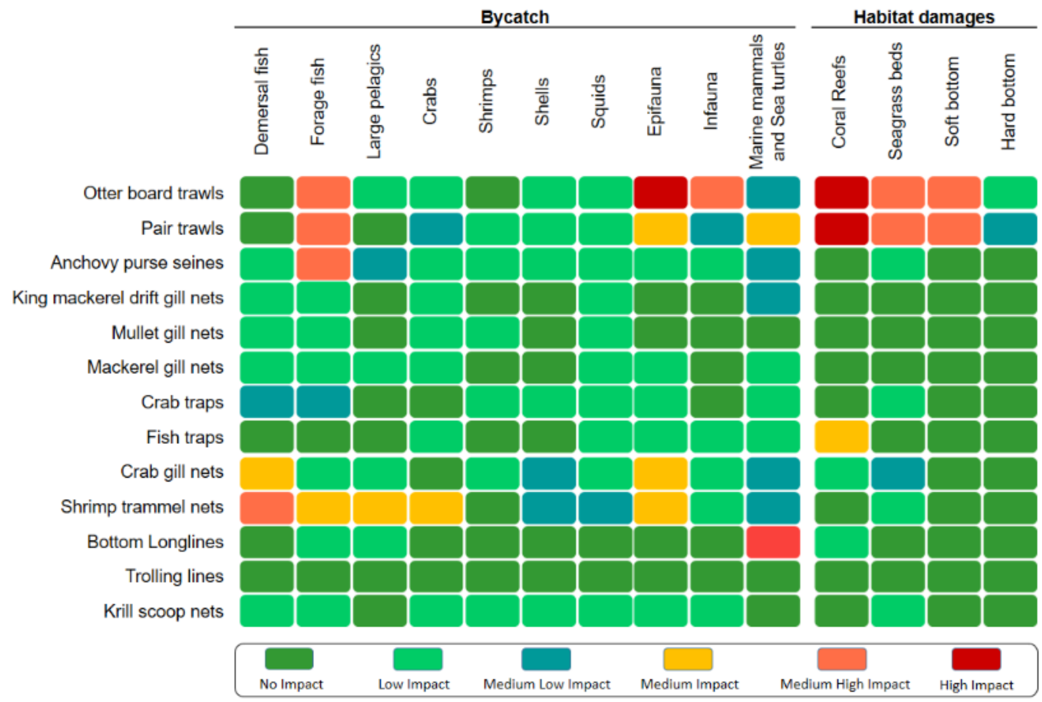



**Figure 34** Rating of fishing gear impacts on bycatch and habitat damages

### 4.5.2 Ranking gear impacts

Severity rankings were performed using the normalized score obtained from the exercise B. In overall, otter board trawls and pair trawls were ranked as the most severe. The highest impact score concerning on forage fish caught as bycatch and damages on coral reefs, seagrass beds, and soft bottom. Shrimp trammel nets were also concerned as they might cause impacts on forage fish, marine mammals, sea turtles, and seagrass beds. However, the severity scores of all observed small-scale fishing gears remain low (Figure 35-36).

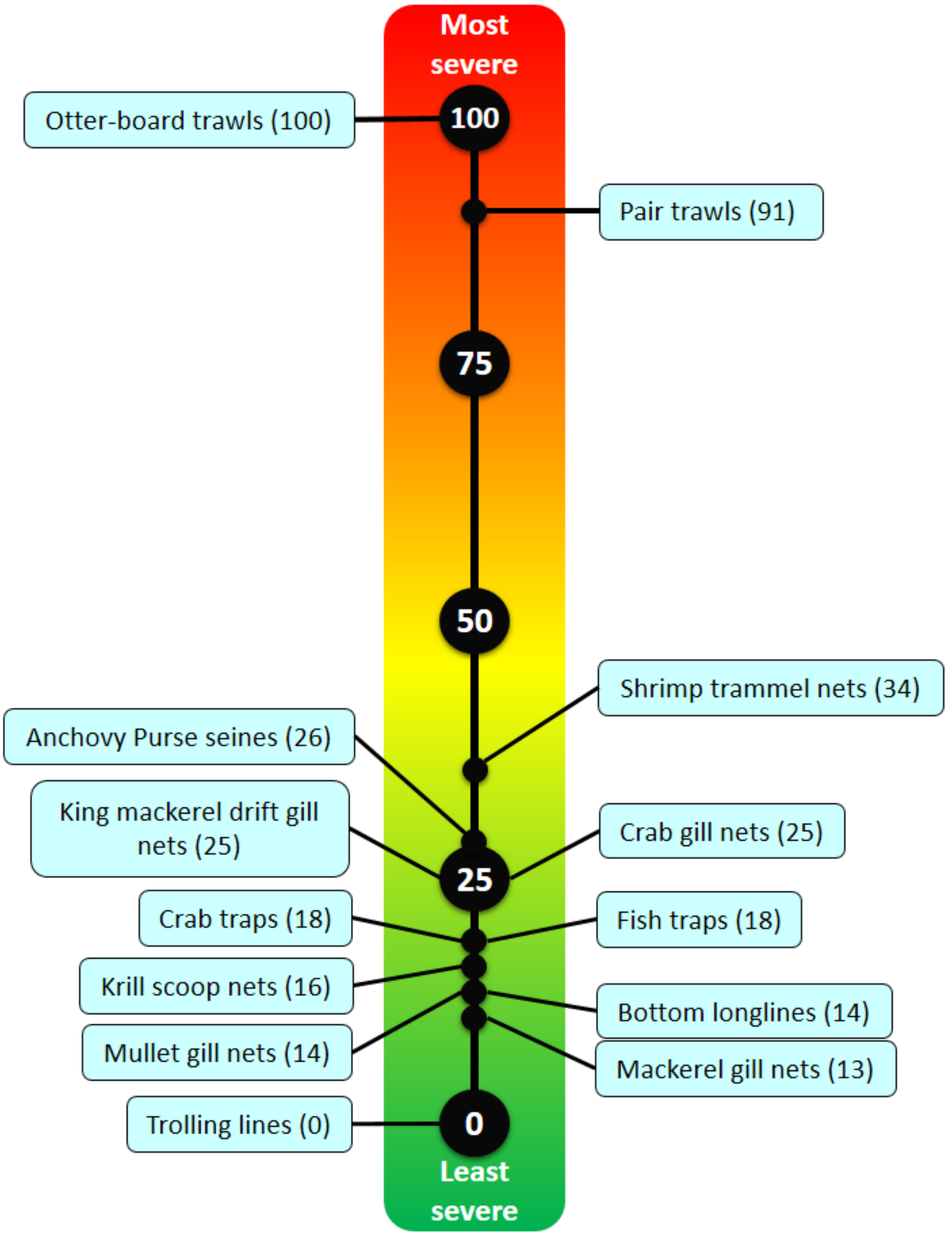



**Figure 35** Overall severity ranking of fishing gear impacts (when the score on bycatch and habitat damages are pooled)

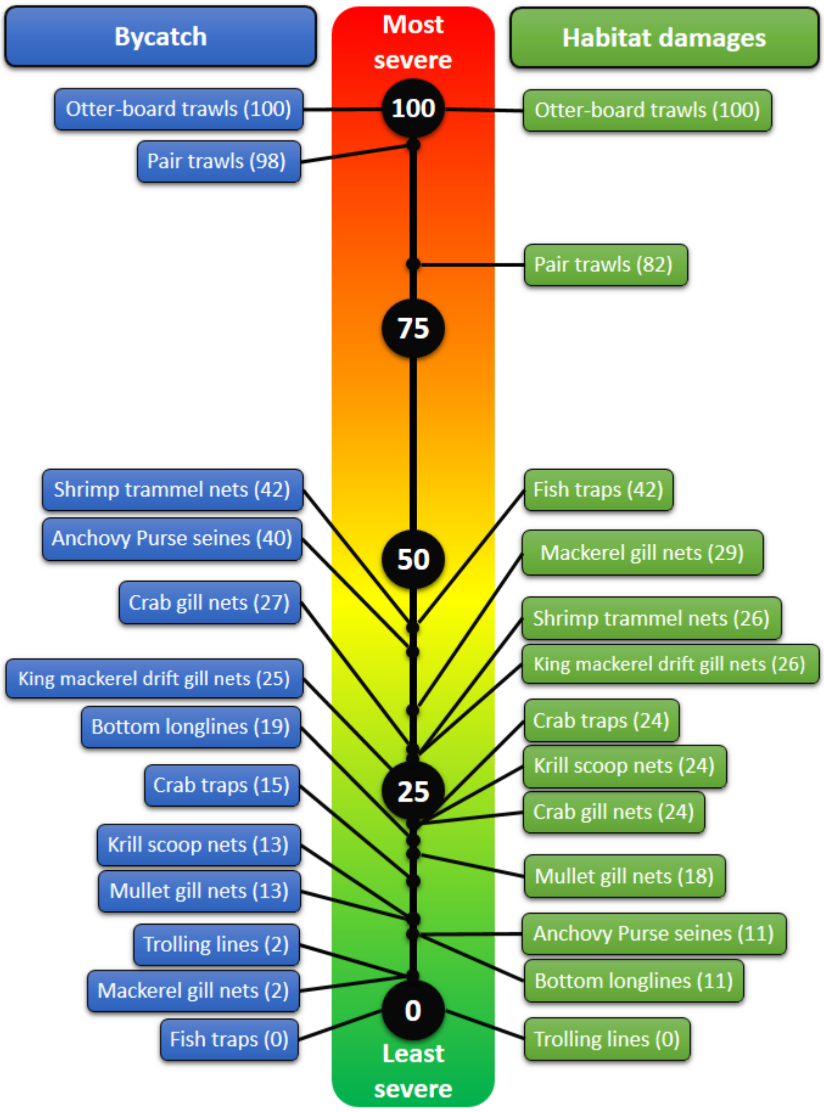



Figure 36 Overall severity ranking of fishing gear impacts and severity ranking of the impacts on bycatch and habitat damages (aggregated voting scores were normalized on a scale of 100)

Kendall's tau-b correlation coefficient ($\tau_b$) of 0.28 revealed that severity ranks of bycatch and habitat damage was not significantly correlated ($p>0.05$) although the first and second rank are similar. The result of post consultation workshop is consistant with the result from the expert workshop. Results of group discussion from three fishing communities in Ko Chang, Trat Province, Thailand regarding ecological impacts of the fishing gears are shown in Table 13.

In determining ecological impacts of fishing gears, Chuenpagdee et al. (2003) assessed collateral impacts of fishing in the US using damage schedule approach as a tool for eliciting judgement and information on the severity of fishing gear impacts from relevant stakeholders including fishers, scientists and managers. The damage schedule approach consists of integrating the knowledge, expert elicitation, and pair comparison to rank the fishing gear impacts revealing that bottom fishing gears such as bottom trawlers, gillnets, dredges, and midwater gillnets were assessed as the high impact level. The authors suggested the use of those gears in the US should be prohibited in ecologically sensitive areas.

Similarly, Fuller et al. (2008) also applied the expert elicitation in assessing ecological impact of fishing gear in Canada. Bottom trawls showed the highest severity of impacts in both west and east coasts of Canada, followed by bottom gillnets and dredges etc.

Experts highlighted that the knowledge on fishing impacts in Thailand is very limited. Experts also mentioned that the level and characteristics of fishing impacts depend on many factors such as fishing gears, operation, fishing period, seasonality, local environment. Overfishing also cause local extinction of some species. Semi-grooved venus ( *Paphia semirugata,)* has been disappeared in Trat province. There is still a concern on a rapid decline in the population of Short-neck clam (*Paphia undulate).* Indirect impact of fishing on sensitive habitats should be also considered. Intensity of fishing gear used should be concerned because it directly relates to the impact level.

This is an alternative method for assessing impacts during data limited situation. The method is not only relied on the expert judgement but also based on best available scientific information. Expert consultation workshop should be convened in the future to verify the results since the scientific information and fishing regulations are always developed while fishing gears  are also improved and replaced with the modern ones.

**Table 13** Results of group discussion of three fishing communities in Ko Chang, Trat Province, Thailand regarding ecological impacts of the fishing gears

| Gears | Bycatch | Habitat damages |
|---|---|---|
| Otter board trawl | The trawl catch many species on the seafloor. They think that dolphin and sea turtles are also threaten from this gears. | These fishing gears are able to destroy soft bottom since the trawl net will compact upper layer of soft bottom, and perhaps, the life at the seafloor. They also have conflict with other fishing gears, especially squid traps. Sometimes, pair trawls destroy artificial reefs. These trawls don't operate in coral reefs so the impacts on coral reef is low. If these trawls operate within seagrass beds, higher impacts could be occurred on seagrass and marine life living within the seagrass beds. |
| Pair trawl | | |
| Anchovy Purse seine | Small other forage fish | Less damage on habitat |
| King mackerel drift gill net | Dolphin and sea turtles | This gear can destroy other fishing gears. |
| Mullet gill nets | Forage fish | Don't have any damage on habitat because this gill nets do not touch seafloor during operation. |
| Mackerel gill nets | Forage fish | Don't know |
| Crab traps | Forage fish and gastropods, especially spine murex. Larger fishing vessel with a lot of crap traps cause reduction of crab population. At present, the blue swimming crabs with smaller size are caught. | Habitat damages were less mentioned but they concerned that multiples crab traps may destroy other fishing gears. |

Table 13 Results of group discussion of three fishing communities in Ko Chang, Trat Province, Thailand regarding ecological impacts of the fishing gears

| Gears | Bycatch | Habitat damages |
|---|---|---|
| Fish traps | Other non-target fish can be consumed so they don’t think that these gears cause bycatch impacts. Other small fish and other non-fish species can be caught but only a small amounts. | Less damages on habitats |
| Crab gill nets | | |
| Shrimp trammel nets | | |
| Bottom Longline | Less bycatch but sea turtle was caught in the past. | |
| Trolling line | Less bycatch. Other non-target fish can be consumed so they don’t think that this gear cause bycatch impacts | Trolling lines do not to touch seafloor during operation. |
| Acetes push net | Acetes push net contributes less bycatch, nothing to concern. Other caught fish can be household consumed. | Don’t have any damage on habitat because fishers prefer not to touch seafloor during operation. |

# CHAPTER V

# CONCLUSIONS AND SUGGESTIONS

## 5.1 Conclusions

According to the study on ecological impacts of fishing gears in Ko Chang, Trat Province, Thailand, general conclusions are the followings:

5.1.1 Existing knowledge and gap

1. A major gap of knowledge on the ecological impacts of fishing gears in Thailand was found, particularly the data on bycatch (retained and discarded) and habitat damages.
2. The onboard surveys of bycatch for nine small-scale fishing gears in Ko Chang reveal some bycatch issues in small-scale fisheries. Some of the gears, particularly trammel nets, crab traps, and gillnets, produced the higher number of bycatch in terms of biomass and species richness.
3. A study on the impacts of fish traps on coral reefs revealed various possible impacts including physical damages on corals, impacts from sediment dispersion, ecosystem imbalance due to an exploitation of reef fish, and marine debris.
4. Heavily fishing activities (in this case trawlers, push nets, and dredges), may affect on the abundance of macrobenthic communities. The difference of the mean total densities observed in trawled and untrawled areas exhibit the possible impacts of fishing activities on the abundance of macrobenthic species in the Strait of Ko Chang.
5. The results from expert consultation show that otter-board trawls and pair-trawls were rated with the highest score of bycatch and habitat impacts. In terms of small-scale fishing gears, bycatch impacts caused by shrimp trammel nets and crab gill nets were mostly concerned.
6. This dissertation enhances understandings of the ecological impacts of fishing gears on marine ecosystems in Thailand that are highly required for ecosystem-based fisheries management.

5.1.2 Bycatch in small-scale fishing gears

1. Higher catch rates are found with bottom longlines and krill push nets but low bycatch diversity. Most gears are seasonally used for examples, shrimp trammel nets, Acetes push net etc. Catch rate of each gear varies seasonally and spatially.
2. The gears that touch seafloor while operating tend to produce more bycatch.
3. Most of target catch and some retained bycatch are sold as fresh fish, while target catch from krill push nets are processed to be sold as shrimp paste.
4. Overall, gastropods and crustaceans (trash crabs) are mostly discarded.
5. Crab gillnets mullet gillnets and shrimp trammel nets produce highest diversity of bycatch.
6. Diversity of bycatch from krill push net, squid trap, and bottom longline remained low.

5.1.3 Impacts of fish trap fisheries on coral reefs

1. Physical damage: About 24% of the fish traps studied touched juvenile corals and coral communities, such as *Fungia* spp., *Porites* sp., *Astreopora* sp, *Favia* spp., resulting in breakage of some touched corals, especially *Fungia* spp.
2. Impact of fish trap fisheries on benthic organisms should also be considered.
3. Sediment dispersion generated during setting and moving of traps was also observed, as another factor that could obstruct growth of corals.
4. Taking out some reef fish, especially the herbivorous fish may alter the dynamics of reef ecosystems, particularly algal-coral dynamics.
5. Fish traps fisheries are also risky to be as ghost fishing and marine debris.

5.1.4 Impacts of commercial fishing on macrobenthic community

1. A total of 35 taxa in 7 phyla of macrobenthic organisms were found in dry season while lower number of taxa was found in wet season (22 taxa in 5 phyla).

2. In an overall picture, the average abundances of macrobenthos in permanent closure zone (265.55 ind./$m^2$) was significantly higher than those observed in a six-month closure zone (153.70 ind./$m^2$) in wet season ($p<0.05$).

3. Similarly, the surveys in dry season exhibited the higher abundance in the permanent closure zone (252.11 ind./$m^2$) compared to what observed in six-month closure zone (125.93 ind./$m^2$).

4. The abundance of macrobenthos varied spatially while seasonal variability of its abundance is not detected. Species composition of macrobenthos was influenced by season and zone.

5. The difference in abundance of macrobenthos between two zones are significantly different and it may be probably caused by the impacts of fishing activities.

6. It is still difficult to confirm that the change in composition of macrobenthos between such zones because of the high seasonal and spatial variation as well as the different environmental condition between two zones.

5.2.5 Expert-based gear impacts assessment: Transdisciplinary approach

1. Trawl fisheries are mostly concerned on the bycatch (especially forage fish and macrobenthic species) and habitat damage such as coral reefs, seagrass, and soft bottom.

2. Pair trawl and bottom longlines show significant impacts on marine mammals and sea turtles.

3. Small-scale fishing gears such as crab gill nets and shrimp trammel nets illustrate the higher concerns of their impacts on ecosystems especially demersal fish, forage fish etc.

4. This method could be the alternative method to assess impacts of fishing gears on ecosystem in other areas.

## 5.2 Suggestions

### 5.2.1 Bridging the gap

The huge knowledge gap on bycatch (especially discard information) and habitat damage caused by small-scale fishing gears, illustrated by the study, will certainly pose difficulty in fisheries sustainability, given their importance. This study shows a significant gap in research and knowledge on the ecological impacts of fishing gears in Thailand. In-depth research is required on various topics related to both small- and large-scale fisheries including, but not limited to: (a) a detailed study on catch composition consisting of target species, retained and discarded bycatch, as well as the use of these data as a baseline for gear impact assessment; (b) a study on interactions of fishing gear and natural habitats such as coral reefs, seagrass beds, seafloor etc.; (c) modification of fishing gears and methods to minimise bycatch and damage to the natural habitats by incorporating local knowledge and local fishers in the research; and (d) bycatch and discards should be involved in the category in fisheries statistics or promoting monitoring program on monitoring fishing impacts.

### 5.2.2 Governing fishing impacts

Fishing impacts, particularly bycatch and habitat damage, have been mentioned in a global discourse making society to pay attention to. Bycatch issues have been mentioned since the Code of Conduct for Responsible Fisheries. In the Sustainable Development Goals also involve marine environment as one of the goals, SDG 14.4. where fishing impacts are highly concerned including "*effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics.*" Not limit to just these, some other international conventions and agreements also link to the human impacts on ocean. Fishing impacts are highly needed to be governed. Minimizing the impacts, however, is not simple as that.

Governing this problem must consider all related dimensions with integrated approach. Not just only the environmental dimension, but also the impacts of policy implication on socio-economic dimension and local livelihoods. Additionally, all parties should be also participated when transdisciplinary approach will be useful. In order to minimize the impact of fishing gears in terms of bycatch and habitat damage, policies should falls on the following principles

1) Reducing fishing impacts by modifying and developing fishing gears to minimize bycatch as well as finding the fishing techniques or season or period of time to increase selectivity and avoiding fishing during spawning season; promoting 'zero discards' as well as enhancing fishers to discard bycatch species at sea to increase survivability and less mortality.

2) Effectively reserve fragile natural habitat that are sensitive or prone to having impacts from certain fishing gears.

3) Effective use of bycatch, especially discarded bycatch, for examples Chitosan may be extracted from discarded trash crab, other value-added products from these discarded bycatch should be promoted.

4) Promoting local stewardship by local fishers for sustainable fisheries along with maintaining marine biodiversity. Along with that, enhancing effective communication between local fishers and academicians, practitioners or even policy makers to exchange and integrate scientific and knowledge. Furthermore, Building up stewardship network in local level and scale up into provincial, regional, and international should be initiated.

While more research on these topics is required in order to implement EAF in Thailand, public awareness about the ecological impacts of fishing gears should also be raised. As the responsible governing body in fisheries, the DOF should add research strategies and development plans into its implementation strategies and policy planning process. Also, a new information system and data collection process could be developed to help obtain systematic and regular data on bycatch and habitat impacts. Lastly, research collaboration among DOF and research and academic Institution , as well as funding agencies, should be promoted to increase capacity.

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APPENDIX

**Appendix A:** Quantity of retained bycatch caught from each fishing gear

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Quantity of retained bycatch (kg) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BL | CG | CT | FT | PN | MG | TN | SQ | TL | Total |
| Bivalves | Pectinidae | *Amusium pleuronectes* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.10 | 0.00 | 0.00 | 7.10 |
| | | Total | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.10 | 0.00 | 0.00 | 7.10 |
| Crabs | Portunidae | *Charybdis affinis* | 0.00 | 0.00 | 6.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.00 |
| | | *Charybdis feriatus* | 0.00 | 0.00 | 0.60 | 0.00 | 0.00 | 0.00 | 0.00 | 6.00 | 0.00 | 6.60 |
| | | *Podophthalmus vigil* | 0.00 | 0.00 | 8.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.60 |
| | | *Portunus sanguinolentus* | 0.00 | 0.00 | 2.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.30 |
| | | *Scylla serrata* | 0.00 | 0.30 | 1.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.90 |
| | | *Sphaerosius* sp. | 0.00 | 0.00 | 3.70 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.95 |
| | | *Square shell crab* | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | | *Thalamita crenata* | 0.00 | 0.50 | 5.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.10 |
| | | Total | 0.00 | 0.80 | 28.60 | 0.25 | 0.00 | 0.00 | 0.00 | 6.00 | 0.00 | 35.65 |
| Demersal fish | Ariidae | *Arius* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 0.00 | 0.00 | 0.40 |
| | Caesionidae | *Caesio cuning* | 0.00 | 0.00 | 0.00 | 4.50 | 0.00 | 0.10 | 0.00 | 0.00 | 2.10 | 6.70 |
| | Cynoglossidae | *Cynoglossus* sp. 1 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | | *Cynoglossus* sp. 2 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 |
| | Drepaneidae | *Drepane punctata* | 0.00 | 1.50 | 0.00 | 0.00 | 0.00 | 1.90 | 0.00 | 0.00 | 0.00 | 3.40 |
| | Ephippidae | *Platax teira* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 | 0.00 | 0.70 |
| | Gerreidae | *Gerres erythrourus* | 0.00 | 0.00 | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 |
| | Haemulidae | *Diagramma pictum* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 | 0.00 | 0.80 |
| | | *Pomadasys maculatus* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 |
| | Lethrinidae | *Lethrinus crocineus* | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.40 |
| | | *Lethrinus lentjan* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.80 | 0.00 | 0.00 | 0.00 | 4.80 |

**Appendix A:** Quantity of retained bycatch caught from each fishing gear (Continued)

| Group | Family | Species | Quantity of retained bycatch (kg) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BL | CG | CT | FT | PN | MG | TN | SQ | TL | Total |
| Demersal fish | Lobotidae | *Lobotes surinamensis* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 0.00 | 0.00 | 0.40 |
| | Lutjanidae | *Lutjanus argentimaculatus* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.90 | 0.00 | 0.00 | 0.00 | 3.90 |
| | | *Lutjanus russellii* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.10 |
| | | *Lutjanus vitta* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 | 0.00 | 0.00 | 0.00 | 0.80 |
| | Monacanthidae | *Paramonacanthus* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.20 |
| | Nemipteridae | *Nemipterus hexodon* | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 7.20 | 0.00 | 0.00 | 7.50 |
| | Ophichthidae | Unidentified eel | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.10 |
| | Platycephalidae | *Platycephalus indicus* | 0.00 | 5.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 5.40 |
| | Plotosidae | *Plotosus anguillaris* | 0.00 | 0.00 | 0.50 | 13.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.70 |
| | | *Plotosus canius* | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 1.30 | 0.00 | 0.00 | 1.40 |
| | Polynemidae | *Eleutheronema* sp. | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | Psettodidae | *Psettodes erumei* | 0.00 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 |
| | Sciaenidae | *Otolithes ruber* | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 |
| | Serranidae | *Cephalopholis Formosa* | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 |
| | | *Epinephelus quoyanus* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 | 0.00 | 3.10 | 0.00 | 3.80 |
| | | *Plectropomus leopardus* | 0.00 | 0.00 | 0.00 | 0.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.45 |
| | Siganidae | *Siganus javus* | 0.00 | 0.00 | 0.00 | 0.70 | 0.00 | 0.00 | 0.00 | 1.70 | 0.00 | 2.40 |
| | Sillaginidae | *Sillago sihama* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 0.00 | 0.40 |
| | | Unidentified fish sp1 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 |
| | | Unidentified fish sp2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 |
| | | Unidentified fish sp3 | 0.00 | 0.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.50 | 0.00 | 0.00 | 3.50 |
| | | Unidentified fish sp4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.10 |
| | | Total | 1.00 | 7.70 | 1.15 | 22.45 | 0.40 | 13.20 | 10.70 | 6.60 | 3.10 | 66.30 |

**Appendix A:** Quantity of retained bycatch caught from each fishing gear (Continued)

| Group | Family | Species | Quantity of retained bycatch (kg) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BL | CG | CT | FT | PN | MG | TN | SQ | TL | Total |
| Gastropods | Volutidae | *Cymbiola* sp. | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | | *Melo melo* | 0.00 | 7.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.20 |
| | | Total | 0.00 | 7.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.40 |
| Large pelagics | Belonidae | *Tylosurus crocodilus* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.50 | 2.50 |
| | Carangidae | *Alectis indica* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 7.50 | 7.80 |
| | Chirocentridae | *Chirocentrus dorab* | 0.00 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 |
| | Coryphaenidae | *Coryphaena hippurus* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.40 | 6.40 |
| | Polynemidae | *Eleutheronema tetradactylum* | 1.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.60 |
| | Sphyraenidae | *Sphyraena forsteri* | 0.00 | 2.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.20 |
| | Sphyraenidae | *Sphyraena obtusata* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.50 | 0.70 |
| | | *Sphyraena qenie* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.30 | 15.30 |
| | | *Sphyraena flavicauda* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.20 | 0.00 | 0.00 | 0.00 | 1.20 |
| | | *Sphyraena sp1* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.90 | 0.00 | 0.00 | 0.00 | 0.90 |
| | | Total | 1.60 | 3.00 | 0.00 | 0.00 | 0.00 | 2.40 | 0.20 | 0.00 | 32.20 | 39.40 |
| Sharks and rays | Carcharhinidae | *Carcharhinus sorrah* | 23.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 23.40 |
| | Dasyatidae | *Dasyatis gerrardi* | 18.90 | 3.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.00 |
| | | *Dasyatis imbricatus* | 25.00 | 7.80 | 0.00 | 0.00 | 0.00 | 0.00 | 1.20 | 0.00 | 0.00 | 34.00 |
| | | *Himantura bleekeri* | 22.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.40 |
| | | *Himantura* sp. | 0.30 | 0.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.50 | 0.00 | 0.00 | 1.40 |
| | | *Pastinachus* sp. | 0.00 | 0.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.60 |
| | Hemiscylliidae | *Chiloscyllium punctatum* | 0.00 | 1.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.20 |
| | | Total | 90.00 | 13.30 | 0.00 | 0.00 | 0.00 | 0.00 | 1.70 | 0.00 | 0.00 | 105.00 |

**Appendix A:** Quantity of retained bycatch caught from each fishing gear (Continued)

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Quantity of retained bycatch (kg) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BL | CG | CT | FT | PN | MG | TN | SQ | TL | Total |
| Shrimps | Penaeidae | Unidentified Shrimp | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 |
| | Squillidae | *Harpiosquilla raphidea* | 0.00 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 |
| | | *Oratosquilla* sp. *1* | 0.00 | 1.50 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 0.00 | 0.00 | 5.20 |
| | | *Oratosquilla* sp. *2* | 0.00 | 0.00 | 0.24 | 0.00 | 0.00 | 0.00 | 1.90 | 0.00 | 0.00 | 2.14 |
| | | *Oratosquilla* sp. *2* | 0.00 | 0.00 | 0.76 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.76 |
| | | Total | 0.00 | 1.90 | 1.00 | 0.00 | 0.10 | 0.00 | 5.60 | 0.00 | 0.00 | 8.60 |
| Small pelagics | Carangidae | *Atule mate* | 0.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.90 | 0.00 | 0.00 | 0.00 | 1.50 |
| | | *Carangoides hedlandensis* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.60 | 2.60 |
| | | *Carangoides* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.50 | 1.50 |
| | | *Megalaspis cordyla* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.20 | 0.00 | 0.00 | 1.20 |
| | | *Scomberoides lysan* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.90 | 0.00 | 0.00 | 1.20 | 2.10 |
| | | *Selar boops* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 1.50 | 1.80 |
| | | *Selar crumenophthalmus* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 | 0.00 | 0.00 | 0.00 | 0.70 |
| | | *Selaroides leptolepis* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.20 | 5.20 |
| | | *Selaroides* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 |
| | | *Atule mate* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.02 |
| | Leiognathidae | *Gazza minuta* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.20 | 0.00 | 0.00 | 2.20 |
| | | *Leiognathus equulus* | 0.00 | 1.00 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.40 |

**Appendix A:** Quantity of retained bycatch caught from each fishing gear (Continued)

| Group | Family | Species | Quantity of retained bycatch (kg) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BL | CG | CT | FT | PN | MG | TN | SQ | TL | Total |
| Small pelagics | Leiognathidae | *Leiognathus fasciatus* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.10 |
| | | *Leiognathus* sp. | 0.00 | 1.40 | 0.00 | 0.00 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 | 1.80 |
| | Mugilidae | *Valamugil buchanani* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 3.00 |
| | Scombridae | *Rastrelliger brachysoma* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 2.50 | 2.70 |
| | | *Rastrelliger kanagurta* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 | 0.00 | 0.00 | 0.00 | 0.70 |
| | Stromateidae | *Pampus argenteus* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 0.30 |
| | | Unidentified fish5 | 0.00 | 0.00 | 0.00 | 5.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 |
| | | Total | 0.60 | 3.40 | 0.40 | 5.00 | 0.40 | 6.32 | 3.90 | 0.30 | 13.60 | 33.92 |
| Squid & Cuttlefish | Loliginidae | *Uroteuthis duvaucelii* | 1.00 | 0.00 | 0.00 | 0.00 | 0.70 | 0.00 | 0.00 | 0.00 | 0.00 | 1.70 |
| | Octopodidae | *Octopus* sp. | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 1.30 | 0.00 | 0.00 | 1.60 |
| | Sepiidae | *Sepia* sp.1 | 0.00 | 0.00 | 0.25 | 0.00 | 0.20 | 0.00 | 1.40 | 0.00 | 0.00 | 1.85 |
| | | *Sepia* sp.2 | 0.00 | 1.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.60 |
| | | Total | 1.00 | 1.60 | 0.55 | 0.00 | 0.90 | 0.00 | 2.70 | 0.00 | 0.00 | 6.75 |
| Total | | | 94.20 | 39.10 | 31.70 | 27.70 | 1.80 | 21.92 | 31.90 | 13.81 | 48.90 | 311.03 |

**Appendix B:** Number of individuals of retained bycatch found in each gear

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets,  ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Number of individuals of retained bycatch | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BL | CG | CT | FT | PN | MG | TN | SQ | TL | Total |
| Bivalves | Pectinidae | *Amusium pleuronectes* | 0 | 0 | 0 | 0 | 0 | 0 | 122 | 0 | 0 | 122 |
| | | Total | 0 | 0 | 0 | 0 | 0 | 0 | 122 | 0 | 0 | 122 |
| Crabs | Portunidae | *Charybdis affinis* | 0 | 0 | 215 | 0 | 0 | 0 | 0 | 0 | 0 | 215 |
| | | *Charybdis feriatus* | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 6 | 0 | 11 |
| | | *Podophthalmus vigil* | 0 | 0 | 139 | 0 | 0 | 0 | 0 | 0 | 0 | 139 |
| | | *Portunus sanguinolentus* | 0 | 0 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 29 |
| | | *Scylla serrata* | 0 | 1 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| | | *Sphaerosius* sp. | 0 | 0 | 29 | 2 | 0 | 0 | 0 | 0 | 0 | 31 |
| | | *Square shell crab* | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| | | *Thalamita crenata* | 0 | 6 | 75 | 0 | 0 | 0 | 0 | 0 | 0 | 81 |
| | | Total | 0 | 7 | 504 | 2 | 0 | 0 | 0 | 6 | 0 | 519 |
| Demersal fish | Ariidae | *Arius* sp. | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 5 |
| | Caesionidae | *Caesio cuning* | 0 | 0 | 0 | 11 | 0 | 1 | 0 | 0 | 23 | 35 |
| | Cynoglossidae | *Cynoglossus* sp. 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | *Cynoglossus* sp. 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | Drepaneidae | *Drepane punctata* | 0 | 3 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 11 |
| | Ephippidae | *Platax teira* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 4 |
| | Gerreidae | *Gerres erythrourus* | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | Haemulidae | *Diagramma pictum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| | | *Pomadasys maculatus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |

**Appendix B:** Number of individuals of retained bycatch found in each gear (Continued)

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Number of individuals of retained bycatch | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BL | CG | CT | FT | PN | MG | TN | SQ | TL | Total |
| Demersal fish | Lethrinidae | *Lethrinus crocineus* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 2 |
| | | *Lethrinus lentjan* | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 6 |
| | Lobotidae | *Lobotes surinamensis* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | Lutjanidae | *Lutjanus argentimaculatus* | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| | | *Lutjanus russellii* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | | *Lutjanus vitta* | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 |
| | Monacanthidae | *Paramonacanthus* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| | Nemipteridae | *Nemipterus hexodon* | 0 | 1 | 0 | 0 | 0 | 0 | 56 | 0 | 0 | 57 |
| | Ophichthidae | *Unidentified eel* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| | Platycephalidae | *Platycephalus indicus* | 0 | 11 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 13 |
| | Plotosidae | *Plotosus anguillaris* | 0 | 0 | 3 | 25 | 0 | 0 | 0 | 0 | 0 | 28 |
| | | *Plotosus canius* | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 2 |
| | Polynemidae | *Eleutheronema* sp. | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Psettodidae | *Psettodes erumei* | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| | Sciaenidae | *Otolithes ruber* | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 9 |
| | Serranidae | *Cephalopholis Formosa* | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 6 |
| | | *Epinephelus quoyanus* | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 5 | 0 | 11 |
| | | *Plectropomus leopardus* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Siganidae | *Siganus javus* | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 27 | 0 | 36 |
| | Sillaginidae | *Sillago sihama* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 |

**Appendix B:** Number of individuals of retained bycatch found in each gear (Continued)

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Number of individuals of retained bycatch | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BL | CG | CT | FT | PN | MG | TN | SQ | TL | Total |
| Demersal fish | | Unidentified fish sp1 | 52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 52 |
| | | Unidentified fish sp2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 |
| | | Unidentified fish sp3 | 0 | 0 | 0 | 62 | 0 | 0 | 36 | 0 | 0 | 98 |
| | | Unidentified fish sp4 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 |
| | | Total | 52 | 21 | 8 | 115 | 9 | 37 | 99 | 39 | 29 | 409 |
| Gastropods | Volutidae | *Cymbiola* sp. | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | *Melo melo* | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| | | Total | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| Large pelagics | Belonidae | *Tylosurus crocodilus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | Carangidae | *Alectis indica* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 5 | 6 |
| | Chirocentridae | *Chirocentrus dorab* | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| | Coryphaenidae | *Coryphaena hippurus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| | Polynemidae | *Eleutheronema tetradactylum* | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| | Sphyraenidae | *Sphyraena forsteri* | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| | | *Sphyraena obtusata* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 2 |
| | | *Sphyraena qenie* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| | | *Sphyraena flavicauda* | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| | | *Sphyraena sp1* | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 9 |
| | | Total | 8 | 11 | 0 | 0 | 0 | 12 | 1 | 0 | 13 | 46 |

**Appendix B:** Number of individuals of retained bycatch found in each gear (Continued)

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Number of individuals of retained bycatch | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BL | CG | CT | FT | PN | MG | TN | SQ | TL | Total |
| Sharks and rays | Carcharhinidae | *Carcharhinus sorrah* | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 |
| | Dasyatidae | *Dasyatis gerrardi* | 25 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33 |
| | | *Dasyatis imbricatus* | 1 | 26 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 30 |
| | | *Himantura bleekeri* | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 |
| | | *Himantura* sp. | 2 | 4 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 9 |
| | | *Pastinachus* sp. | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | Hemiscylliidae | *Chiloscyllium punctatum* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | Total | 65 | 41 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 112 |
| Shrimps | Penaeidae | Unidentified Shrimp | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| | Squillidae | *Harpiosquilla raphidea* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | *Oratosquilla* sp. | 0 | 26 | 0 | 0 | 0 | 0 | 62 | 0 | 0 | 88 |
| | | *Oratosquilla* sp. *1* | 0 | 0 | 3 | 0 | 0 | 0 | 29 | 0 | 0 | 32 |
| | | *Oratosquilla* sp. *2* | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| | | Total | 0 | 27 | 15 | 0 | 2 | 0 | 91 | 0 | 0 | 135 |
| Small pelagics | Carangidae | *Atule mate* | 10 | 0 | 0 | 0 | 0 | 24 | 0 | 0 | 0 | 34 |
| | | *Carangoides hedlandensis* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| | | *Carangoides* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 20 |
| | | *Megalaspis cordyla* | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 |
| | | *Scomberoides lysan* | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 10 | 30 |

**Appendix B:** Number of individuals of retained bycatch found in each gear (Continued)

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Number of individuals of retained bycatch | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BL | CG | CT | FT | PN | MG | TN | SQ | TL | Total |
| Small pelagics | Carangidae | *Selar boops* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 23 | 26 |
| | | *Selar crumenophthalmus* | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 12 |
| | | *Selaroides leptolepis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 | 60 |
| | | *Selaroides* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | Caranginae | *Atule mate* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | Leiognathidae | *Gazza minuta* | 0 | 0 | 0 | 0 | 0 | 0 | 239 | 0 | 0 | 239 |
| | | *Leiognathus equulus* | 0 | 33 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 49 |
| | | *Leiognathus fasciatus* | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 0 | 0 | 19 |
| | | *Leiognathus* sp. | 0 | 2 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 22 |
| | Mugilidae | *Valamugil buchanani* | 0 | 0 | 0 | 0 | 0 | 30 | 0 | 0 | 0 | 30 |
| | Scombridae | *Rastrelliger brachysoma* | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 30 | 33 |
| | | *Rastrelliger kanagurta* | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 6 |
| | Stromateidae | *Pampus argenteus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| | unidentified fish | Unidentified fish5 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 10 |
| | | Total | 10 | 36 | 16 | 10 | 20 | 112 | 246 | 3 | 146 | 599 |
| Squid & Cuttlefish | Loliginidae | *Uroteuthis duvaucelii* | 32 | 0 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 57 |
| | Octopodidae | *Octopus* sp. | 0 | 0 | 5 | 0 | 0 | 0 | 24 | 0 | 0 | 29 |
| | Sepiidae | *Sepia* sp.1 | 0 | 0 | 3 | 0 | 1 | 0 | 7 | 0 | 0 | 11 |
| | | *Sepia* sp.2 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| | | Total | 32 | 6 | 8 | 0 | 26 | 0 | 31 | 0 | 0 | 103 |
| Total | | | 167 | 157 | 551 | 127 | 57 | 162 | 596 | 48 | 188 | 2053 |

**Appendix C:** Quantity of discarded bycatch caught from each fishing gear

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Quantity of discarded bycatch (kg) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | CG | CT | FT | PN | MG | TN | Total |
| Anthozoans | Pennatulacea | Unidentified sea pen sp1 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| | | Unidentified sea pen sp2 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 |
| | | Unidentified sea pen sp3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 |
| | | Unidentified sea pen sp4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.05 |
| | | Total | 0.00 | 0.11 | 0.00 | 0.00 | 0.00 | 0.07 | 0.18 |
| Bivalves | Malleidae | *Malleus albus* | 4.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 |
| | Pinnidae | *Atrina* sp. | 0.70 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 |
| | Spondylidae | *Spondylus* sp. | 2.60 | 0.00 | 0.00 | 0.00 | 0.00 | 1.20 | 3.80 |
| | | Total | 7.30 | 0.00 | 0.00 | 0.00 | 0.00 | 1.20 | 8.50 |
| Crabs | Calappidae | *Matuta victor* | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 | 0.05 | 0.20 |
| | Diogenidae | *Hermit crab* | 0.00 | 3.60 | 0.70 | 0.00 | 0.00 | 0.30 | 4.60 |
| | Dorippidae | *Dorippoides facchino* | 1.80 | 0.00 | 0.00 | 0.00 | 0.00 | 1.80 | 3.60 |
| | Galeninae | *Galene bispinosa* | 1.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.30 |
| | Leucosiidae | *Seulocia* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.05 |
| | Limulidae | *Carcinoscorpius rotundicauda* | 2.10 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 2.90 |
| | Majoidea | Unidentified spider crab | 8.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.90 |
| | Paguridae | *Dradanus negistos* | 2.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.60 |
| | Portunidae | *Charybdis affinis* | 1.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.50 |
| | | *Charybdis* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.45 | 0.45 |
| | | *Podophthalmus vigil* | 15.10 | 0.00 | 0.00 | 0.00 | 0.15 | 0.00 | 15.25 |

**Appendix C:** Quantity of discarded bycatch caught from each fishing gear (Continued)

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Quantity of discarded bycatch (kg) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | CG | CT | FT | PN | MG | TN | Total |
| Crabs | Portunidae | *Portunus gladiator* | 3.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.60 |
| | | *Portunus pelagicus* | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.05 |
| | | *Sphaerosius* sp. | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.05 |
| | | Unidentified shell crab sp1 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 |
| | Xanthidae | *Demania scaberrima* | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 |
| | | Total | 37.15 | 4.40 | 0.80 | 0.00 | 0.30 | 2.65 | 45.30 |
| Demersal fish | Batrachoididae | *Allenbatrachus grunniens* | 0.00 | 0.05 | 0.00 | 0.00 | 0.10 | 0.30 | 0.45 |
| | Gobiidae | Unidentified goby sp1 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.05 |
| | | Unidentified goby sp2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.05 |
| | Lethrinidae | *Lethrinus crocineus* | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.05 |
| | Lutjanidae | *Lutjanus russellii* | 0.00 | 0.10 | 0.00 | 0.05 | 0.00 | 0.00 | 0.15 |
| | | *Lutjanus vitta* | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 0.40 |
| | Paralichthyidae | *Pseudorhombus arsius* | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.20 | 0.50 |
| | Platycephalidae | *Platycephalus indicus* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 |
| | Psettodidae | *Psettodes erumei* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.90 |
| | Sciaenidae | *Otolithes ruber* | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.10 | 0.15 |
| | Scorpaenidae | *Pterois milea* | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 |
| | Siganidae | *Siganus guttatus* | 0.00 | 0.00 | 2.50 | 0.00 | 0.00 | 0.00 | 2.50 |
| | Soleidae | Unidentified flatfish sp1 | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 |

**Appendix C:** Quantity of discarded bycatch caught from each fishing gear (Continued)

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Quantity of discarded bycatch (kg) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | CG | CT | FT | PN | MG | TN | Total |
| Demersal fish | Terapontidae | *Terapon jarbua* | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.20 |
| | | *Terapon theraps* | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.30 |
| | Triacanthidae | *Triacanthus* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 |
| | Pempheridae | *Parapriacanthus* sp. | 0.00 | 0.00 | 0.00 | 5.00 | 0.00 | 0.00 | 5.00 |
| | | Total | 2.35 | 0.20 | 2.55 | 5.10 | 1.30 | 0.85 | 12.35 |
| Echinoderms | Asteroidea | Unidentified starfish sp1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.30 |
| | | Unidentified starfish sp2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 | 0.40 |
| | Holothuriidae | *Holothuria impatiens* | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 |
| | | Unidentified sea cucumber sp1 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 |
| | | Unidentified sea cucumber sp2 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 |
| | | Total | 0.00 | 0.25 | 0.00 | 0.00 | 0.00 | 0.70 | 0.95 |
| Gastropods | Muricidae | *Murex* sp. | 10.70 | 1.24 | 0.00 | 0.00 | 0.00 | 12.10 | 24.04 |
| | | Unidentified gastropod sp1 | 2.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.50 |
| | | Unidentified gastropod sp2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.30 | 1.30 |
| | Volutidae | *Melo melo* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 |
| | | Total | 13.60 | 1.24 | 0.00 | 0.00 | 0.00 | 13.40 | 28.24 |
| Seahorse | Syngnathidae | Unidendified seahorse sp1 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 |
| | | Total | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 |

**Appendix C:** Quantity of discarded bycatch caught from each fishing gear (Continued)

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Quantity of discarded bycatch (kg) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | CG | CT | FT | PN | MG | TN | Total |
| Small pelagics | Leiognathidae | *Eubleekeria jonesi* | 0.00 | 0.00 | 0.00 | 0.90 | 0.00 | 2.60 | 3.50 |
| | | *Gazza minuta* | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.30 |
| | | *Leiognathus equulus* | 0.60 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.70 |
| | Tetraodontidae | *Lagocephalus lunaris* | 0.40 | 0.00 | 0.00 | 0.00 | 0.45 | 0.80 | 1.65 |
| | | Total | 1.00 | 0.00 | 0.00 | 1.00 | 0.75 | 3.40 | 6.15 |
| **Total** | | | 61.50 | 6.20 | 3.35 | 6.10 | 2.35 | 22.27 | 101.77 |

**Appendix D:** Number of individuals of discarded bycatch

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Number of individuals of discarded bycatch | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | CG | CT | FT | PN | MG | TN | Total |
| Anthozoans | Pennatulacea | Unidentified sea pen sp1 | 0 | 7 | 0 | 0 | 0 | 0 | 7 |
| | | Unidentified sea pen sp2 | 0 | 35 | 0 | 0 | 0 | 0 | 35 |
| | | Unidentified sea pen sp3 | 0 | 0 | 0 | 0 | 0 | 10 | 10 |
| | | Unidentified sea pen sp4 | 0 | 0 | 0 | 0 | 0 | 29 | 29 |
| | | Total | 0 | 42 | 0 | 0 | 0 | 39 | 81 |
| Bivalves | Malleidae | *Malleus albus* | 88 | 0 | 0 | 0 | 0 | 0 | 88 |
| | Pinnidae | *Atrina* sp. | 5 | 0 | 0 | 0 | 0 | 0 | 5 |
| | Spondylidae | *Spondylus* sp. | 60 | 0 | 0 | 0 | 0 | 80 | 140 |
| | | Total | 153 | 0 | 0 | 0 | 0 | 80 | 233 |
| Crabs | Calappidae | *Matuta victor* | 0 | 0 | 0 | 0 | 12 | 3 | 15 |
| | Diogenidae | *Hermit crab* | 0 | 50 | 9 | 0 | 0 | 4 | 63 |
| | Dorippidae | *Dorippoides facchino* | 140 | 0 | 0 | 0 | 0 | 198 | 338 |
| | Galeninae | *Galene bispinosa* | 20 | 0 | 0 | 0 | 0 | 0 | 20 |
| | Leucosiidae | *Seulocia* sp. | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| | Limulidae | *Carcinoscorpius rotundicauda* | 9 | 4 | 0 | 0 | 0 | 0 | 13 |
| | Majoidea | Unidentified spider crab | 199 | 0 | 0 | 0 | 0 | 0 | 199 |
| | Paguridae | *Dradanus negistos* | 30 | 0 | 0 | 0 | 0 | 0 | 30 |
| | Portunidae | *Charybdis affinis* | 34 | 0 | 0 | 0 | 0 | 0 | 34 |
| | | *Charybdis* sp. | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| | | *Podophthalmus vigil* | 184 | 0 | 0 | 0 | 1 | 0 | 185 |

**Appendix D:** Number of individuals of discarded bycatch caught from each fishing gear (Continued)

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Quantity of discarded bycatch (kg) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | CG | CT | FT | PN | MG | TN | Total |
| Crabs | Portunidae | *Portunus gladiator* | 96 | 0 | 0 | 0 | 0 | 0 | 96 |
| | | *Portunus pelagicus* | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | | *Sphaerosius* sp. | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| | | Unidentified shell crab sp1 | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| | Xanthidae | *Demania scaberrima* | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | Total | 715 | 54 | 13 | 0 | 13 | 210 | 1005 |
| Demersal fish | Batrachoididae | *Allenbatrachus grunniens* | 0 | 1 | 0 | 0 | 2 | 2 | 5 |
| | Gobiidae | Unidentified goby sp1 | 0 | 0 | 0 | 28 | 0 | 0 | 28 |
| | | Unidentified goby sp2 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| | Lethrinidae | *Lethrinus crocineus* | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | Lutjanidae | *Lutjanus russellii* | 0 | 1 | 0 | 61 | 0 | 0 | 62 |
| | | *Lutjanus vitta* | 0 | 0 | 0 | 0 | 9 | 0 | 9 |
| | Paralichthyidae | *Pseudorhombus arsius* | 0 | 0 | 0 | 0 | 3 | 1 | 4 |
| | Platycephalidae | *Platycephalus indicus* | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | Psettodidae | *Psettodes erumei* | 6 | 0 | 0 | 0 | 0 | 0 | 6 |
| | Sciaenidae | *Otolithes ruber* | 0 | 1 | 0 | 0 | 0 | 1 | 2 |
| | Scorpaenidae | *Pterois milea* | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Siganidae | *Siganus guttatus* | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| | Soleidae | Unidentified flatfish sp1 | 3 | 0 | 0 | 0 | 0 | 0 | 3 |

**Appendix D:** Number of individuals of discarded bycatch caught from each fishing gear (Continued)

Note: BL = Bottom longlines, CG = Crab gillnets, CT = Crab traps, FT = Fish traps, PN = Acetes push net, MG = Mullet gillnets, TN = Shrimp trammel nets, ST = Squid traps, TL = Trolling lines

| Group | Family | Species | Number of individuals of discarded bycatch | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | CG | CT | FT | PN | MG | TN | Total |
| Demersal fish | Terapontidae | *Terapon jarbua* | 0 | 0 | 0 | 0 | 4 | 0 | 4 |
| | | *Terapon theraps* | 0 | 0 | 0 | 0 | 9 | 0 | 9 |
| | Triacanthidae | *Triacanthus* sp. | 0 | 0 | 0 | 0 | 0 | 4 | 4 |
| | Pempheridae | *Parapriacanthus* sp. | 0 | 0 | 0 | 170 | 0 | 0 | 170 |
| | | Total | 10 | 3 | 4 | 259 | 27 | 12 | 315 |
| Echinoderms | Asteroidea | Unidentified starfish sp1 | 0 | 0 | 0 | 0 | 0 | 7 | 7 |
| | | Unidentified starfish sp2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | Holothuriidae | *Holothuria impatiens* | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| | | Unidentified sea cucumber sp1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| | | Unidentified sea cucumber sp2 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| | | Total | 0 | 4 | 0 | 0 | 0 | 8 | 12 |
| Gastropods | Muricidae | *Murex* sp. | 327 | 28 | 0 | 0 | 0 | 410 | 765 |
| | | Unidentified gastropods sp1 | 40 | 0 | 0 | 0 | 0 | 0 | 40 |
| | | Unidentified gastropods sp2 | 0 | 0 | 0 | 0 | 0 | 45 | 45 |
| | Volutidae | *Melo melo* | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| | | Total | 369 | 28 | 0 | 0 | 0 | 455 | 852 |
| Seahorse | Syngnathidae | Unidentified seahorse sp1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | Total | 1 | 0 | 0 | 0 | 0 | 0 | 1 |

**Appendix E:** A list of target and bycatch species caught by fish traps in Ko Kut and Ko Mak

| Common name | Scientific name | Family | IUCN status[c] | Consumption classification[d] | Trophic level/vulnerability/price category[d] |
|---|---|---|---|---|---|
| Duskytail grouper[a] | *Epinephelus bleekeri* | Serranidae | Near Threatened | Carnivore, feed on fish and crustaceans. | Trophic Level: 3.9 ±0.6 SE; based on size and trophs of closest relatives<br>Resilience: Low<br>Vulnerability: High vulnerability (60 of 100)<br>Price category: Very high. |
| Leopard grouper[a] | *Plectropomus leopardus* | Serranidae | Near Threatened | Carnivore, adults feed mainly on fish. Juveniles feed on small fish and invertebrates such as crustaceans and squid. | Trophic Level: 4.4 ±0.7 SE; Based on diet studies.<br>Resilience: Medium<br>Vulnerability: Moderate to high vulnerability (51 of 100)<br>Price category: Very high. |
| Orange-spotted grouper[a] | *Epinephelus coioides* | Serranidae | Near Threatened | Carnivore, feed on small fishes, shrimps, and crabs. | Trophic Level: 4.0 ±0.0 SE; Based on diet studies.<br>Resilience: Low<br>Vulnerability: High vulnerability (58 of 100)<br>Price category: High |
| Blue line grouper[a] | *Cephalopholis formosa* | Serranidae | Least Concern | Carnivore, feed on small fish, squid, and crustaceans. | Trophic Level: 4.1 ±0.7 SE; Based on size and trophs of closest relatives<br>Resilience: Medium<br>Vulnerability: Low to moderate vulnerability (34 of 100)<br>Price category: Very high |

[a]Target species; [b]Bycatch, [c]IUCN Redlist (www.iucn.org); [d]FishBase (www.fishbase.org)

**Appendix E:** A list of target and bycatch species caught by fish traps in Ko Kut and Ko Mak (Continued)

| Common name | Scientific name | Family | IUCN status[c] | Consumption classification[d] | Trophic level/vulnerability/price category[d] |
|---|---|---|---|---|---|
| Blacktip grouper[a] | *Epinephelus fasciatus* | Serranidae | Least Concern | Carnivore, feed on crabs, stomatopods, fishes, ophiuroids, octopus, and fish. | Trophic Level: 3.7 ±0.4 SE; Based on diet studies.<br>Resilience: Low<br>Vulnerability: Moderate to high vulnerability (53 of 100)<br>Price category: High |
| Longfin grouper[a] | *Epinephelus quoyanus* | Serranidae | Least Concern | Carnivore, feeds on shrimps, small fishes, worms and crabs | Trophic Level: 4.0 ±0.5 SE; Based on diet studies.<br>Resilience: Medium<br>Vulnerability: Moderate vulnerability (36 of 100).<br>Price category: Very high. |
| John's snapper[a] | *Lutjanus johnii* | Lutjanidae | Not Evaluated | Carnivore, feed on fishes and benthic invertebrates including shrimps, crabs and cephalopods. | Trophic Level: 4.2 ±0.6 SE; Based on diet studies.<br>Resilience: Medium<br>Vulnerability: High vulnerability (60 of 100).<br>Price category: High. |
| Black-blotched porcupinefish | *Diodon liturosus* | Diodontidae | Least Concern | Carnivore, feed on hard-shelled benthic invertebrates which are crushed with powerful jaws. | Trophic Level: 3.5 ±0.37 SE; Based on food items.<br>Resilience: Not evaluate<br>Vulnerability: Low to moderate vulnerability (30 of 100)<br>Price category: Unknown |
| Boxfish | *Acanthostracion polygonius* | Ostraciidae | Least Concern | Carnivore, feed on marine invertebrates including shrimp, tunicates, and sponges. | Trophic Level: 2.0 ±0.0 se; Based on diet studies.<br>Resilience: High<br>Vulnerability: Low to moderate vulnerability (26 of 100)<br>Price category: High |

[a]Target species; [b]Bycatch, [c]IUCN Redlist (www.iucn.org); [d]FishBase (www.fishbase.org)

**Appendix E:** A list of target and bycatch species caught by fish traps in Ko Kut and Ko Mak (Continued)

| Common name | Scientific name | Family | IUCN status[c] | Consumption classification[d] | Trophic level/vulnerability/price category[d] |
|---|---|---|---|---|---|
| Bluebarred parrotfish | *Scarus ghobban* | Scaridae | Least Concern | Herbivore, feed on algae | Trophic Level: 2.0 ±0.0 se; Based on diet studies.<br>Resilience: Medium<br>Vulnerability: Moderate vulnerability (37 of 100)<br>Price category: High. |
| Two-banded soapfish | *Diploprion bifasciatum* | Serranidae | Not Evaluated | Carnivore, feed mainly on fishes. | Trophic Level: 4.0 ±0.65 SE; Based on food items.<br>Resilience: Medium<br>Vulnerability: Low to moderate vulnerability (29 of 100)<br>Price category: Unknown |
| Copperbanded butterflyfish | *Chelmon rostratus* | Chaetodontidae | Not Evaluated | Carnivore | Trophic Level: 3.5 ±0.37 SE; Based on food items.<br>Resilience: High<br>Vulnerability: Low vulnerability (15 of 100)<br>Price category: Unknown |
| Tripletail wrasse | *Cheilinus trilobatus* | Labridae | Least Concern | Carnivore, feed on hard shell invertebrates | Trophic Level: 3.9 ±0.2 SE; Based on diet studies.<br>Resilience: Medium<br>Vulnerability: Moderate vulnerability (43 of 100).<br>Price category: Very high. |
| Doubletooth soldierfish | *Myripristis hexagona* | Holocentridae | Least Concern | Carnivore, feed on plankton such as crab larvae | Trophic Level: 3.1 ±0.30 SE; Based on food items.<br>Resilience: High,<br>Vulnerability: Low vulnerability (23 of 100)<br>Price category: Medium |

[a]Target species; [b]Bycatch, [c]IUCN Redlist (www.iucn.org); [d]FishBase (www.fishbase.org)

**Appendix E:** A list of target and bycatch species caught by fish traps in Ko Kut and Ko Mak (Continued)

| Common name | Scientific name | Family | IUCN status[c] | Consumption classification[d] | Trophic level/vulnerability/price category[d] |
|---|---|---|---|---|---|
| Redcoat | *Sargocentron rubrum* | Holocentridae | Least Concern | Carnivore, feed mainly on benthic crabs and shrimps | Trophic Level: 3.6 ±0.3 SE; Based on diet studies.<br>Resilience: High<br>Vulnerability: Low vulnerability (24 of 100)<br>Price category: Medium |
| Whitecheek monocle bream | *Scolopsis vosmeri* | Nemipteridae | Not Evaluated | Carnivore, feed on invertebrates and zoobenthos | Trophic Level: 3.5 ±0.37 SE; Based on food items.<br>Resilience: High<br>Vulnerability: Low vulnerability (24 of 100)<br>Price category: Low |
| Yellowspotted rabbitfish | *Siganus guttatus* | Siganidae | Not Evaluated | Herbivore feeding on benthic algae but becomes an omnivore when held under captivity. | Trophic Level: 2.7 ±0.30 SE; Based on food items.<br>Resilience: High<br>Vulnerability: Low vulnerability (19 of 100)<br>Price category: High |
| Whitespotted rabbitfish | *Siganus canaliculatus* | Siganidae | Not Evaluated | Herbivore, feed on benthic algae and to some extent on seagrass. | Trophic Level: 2.8 ±0.31 SE; Based on food items.<br>Resilience: Medium<br>Vulnerability: Low vulnerability (15 of 100)<br>Price category: High |
| Yellow-spot Goatfish | *Parupeneus indicus* | Mullidae | Not Evaluated | Carnivore, feed on benthic invertebrates; including small crabs, amphipods, shrimps, small octopuses, polychaete worms, and small fishes | Trophic Level: 3.5 ±0.37 SE; Based on food items.<br>Resilience: Medium<br>Vulnerability: Moderate vulnerability (36 of 100)<br>Price category: Medium |

[a]Target species; [b]Bycatch, [c]IUCN Redlist (www.iucn.org); [d]FishBase (www.fishbase.org)

**Appendix E:** A list of target and bycatch species caught by fish traps in Ko Kut and Ko Mak (Continued)

| Common name | Scientific name | Family | IUCN status[c] | Consumption classification[d] | Trophic level/vulnerability/price category[d] |
|---|---|---|---|---|---|
| Pearly monocle bream | *Scolopsis margaritifera* | Nemipteridae | Not Evaluated | Carnivore,<br>feeds mainly on small benthic invertebrates and small fishes | Trophic Level: 3.6 ±0.52 SE; Based on food items.<br>Resilience: High<br>Vulnerability: Low to moderate vulnerability (26 of 100)<br>Price category: Low |
| Red-bellied fusilier | *Caesio cuning* | Caesionidae | Not Evaluated | Carnivore, feeds on zooplankton. | Trophic Level: 3.4 ±0.45 SE; Based on food items.<br>Resilience: Medium<br>Vulnerability: Moderate vulnerability (35 of 100)<br>Price category: Medium |
| Fan-bellied leatherjacket | *Monacanthus chinensis* | Monacanthidae | Least Concern | Omnivore, feeds on algae, seagrass, and small invertebrates. | Trophic Level: 2.4 ±0.1 SE; Based on diet studies.<br>Resilience: Medium<br>Vulnerability: Moderate vulnerability (37 of 100)<br>Price category: Unknown |
| Double-barred rabbitfish | *Siganus virgatus* | Siganidae | Not Evaluated | Herbivore, feed on benthic seaweeds. | Trophic Level: 2.7 ±0.31 SE; Based on food items.<br>Resilience: High<br>Vulnerability: Low vulnerability (19 of 100)<br>Price category: High |
| Java rabbitfish | *Siganus javus* | Siganidae | Not Evaluated | Herbivore, feeding mostly on algae | Trophic Level: 2.4 ±0.08 SE; Based on food items.<br>Resilience: High<br>Vulnerability: Low to moderate vulnerability (29 of 100)<br>Price category: High |

[a]Target species; [b]Bycatch, [c]IUCN Redlist (www.iucn.org); [d]FishBase (www.fishbase.org)

**Appendix E:** A list of target and bycatch species caught by fish traps in Ko Kut and Ko Mak (Continued)

| Common name | Scientific name | Family | IUCN status[c] | Consumption classification[d] | Trophic level/vulnerability/price category[d] |
|---|---|---|---|---|---|
| Swimming crabs | *Charybdis hellerii* | Portunidae | Not Evaluated | Omnivore, feed on crustaceans, mulluscs and algae | NA |
| Stone crab | *Myomenippe hardwickii* | Menippidae | Not Evaluated | Omnivore, feed on crustaceans, mulluscs and algae | NA |
| Spotted hermit crab | *Dardanus megistos* | Diogenidae | Not Evaluated | Omnivore, feed on crustaceans, mulluscs and algae | NA |
| Red egg crab | *Atergatis integerrimus* | Xanthidae | Not Evaluated | Omnivore, feed on crustaceans, mulluscs and algae | NA |
| Sea cucumber | Unidentified sea cucumber | *Unidentified sea cucumber* | NA | Scavengers, feeding on organic matter in the seafloor | NA |

[a]Target species; [b]Bycatch, [c]IUCN Redlist (www.iucn.org); [d]FishBase (www.fishbase.org)

## Appendix F: Abundance of macrobenthos found in wet season at site A to E

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | | B | | C | | D | | E | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **Phylum Nemertinea** | | | | | | | | | | | | | |
| Anopla | | | | 7.41 | 9.07 | 9.26 | 8.36 | 3.70 | 5.74 | 0.00 | 0.00 | 3.70 | 5.74 |
| **Phylum Annelida** | | | | | | | | | | | | | |
| Polychaeta | Capitellida | Capitellidae | | 0.00 | 0.00 | 18.52 | 11.48 | 0.00 | 0.00 | 18.52 | 11.48 | 22.22 | 12.17 |
| | Cossurida | Cossuridae | | 0.00 | 0.00 | 7.41 | 9.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Eunicida | Lumbrineridae | | 0.00 | 0.00 | 3.70 | 9.07 | 3.70 | 5.74 | 18.52 | 9.07 | 18.52 | 11.48 |
| | Maldanida | Maldanidae | | 0.00 | 0.00 | 0.00 | 0.00 | 18.52 | 9.07 | 0.00 | 0.00 | 3.70 | 5.74 |
| | Nephtyida | Nephtyidae | | 9.26 | 8.36 | 3.70 | 5.74 | 0.00 | 0.00 | 22.22 | 7.03 | 33.33 | 15.71 |
| | Orbiniida | Orbiniidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 |
| | Phyllodocida | Hesionidae | | 1.85 | 4.54 | 1.85 | 4.54 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 |
| | | Phyllodocidae | | 0.00 | 0.00 | 16.67 | 15.32 | 0.00 | 0.00 | 0.00 | 0.00 | 7.41 | 9.07 |
| | Spionida | Spionidae | | 11.11 | 14.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Syllida | Syllidae | | 0.00 | 0.00 | 3.70 | 5.74 | 3.70 | 5.74 | 7.41 | 9.07 | 0.00 | 0.00 |
| | Sabellida | Sabellidae | | 3.70 | 5.74 | 12.96 | 8.36 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 |
| | | Oweniidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Terebellida | Sternaspidae | | 11.11 | 7.03 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Cirratulidae | | 22.22 | 7.03 | 11.11 | 9.94 | 5.56 | 9.30 | 3.70 | 5.74 | 3.70 | 5.74 |
| | Unidentified polychaete sp1 | | | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Unidentified polychaete sp2 | | | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Unidentified polychaete sp3 | | | 7.41 | 9.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Appendix F:** Abundance of macrobenthos found in wet season at site A to E (Continued)

| Class | Order | Family | Species | Density (individuals/$m^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | | B | | C | | D | | E | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **Phylum Mollusca** | | | | | | | | | | | | | |
| Bivalvia | | Mesoclesmatidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Myida | Corbulidae | *Corbula* sp. | 3.70 | 5.74 | 7.41 | 9.07 | 0.00 | 0.00 | 11.11 | 14.05 | 1.85 | 4.54 |
| | Nuculanida | Nuculanidae | *Nuculana* sp. | 5.56 | 9.30 | 27.78 | 15.32 | 0.00 | 0.00 | 3.70 | 5.74 | 40.74 | 31.16 |
| | Cardiida | Tellinidae | *Tellina* sp. | 11.11 | 14.05 | 11.11 | 14.05 | 25.93 | 16.73 | 14.81 | 9.07 | 3.70 | 5.74 |
| | | Tellinidae | *Macomas* sp. | 9.26 | 10.92 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.41 | 9.07 |
| | Venerida | Veneridae | *Phaphia undulata* | 5.56 | 9.30 | 14.81 | 11.48 | 18.52 | 9.07 | 9.26 | 8.36 | 7.41 | 5.74 |
| | Arcida | Arcidae | *Anadara* sp. | 7.41 | 5.74 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Unidentified bivalve sp1 | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 |
| **Phylum Arthropoda** | | | | | | | | | | | | | |
| Malacostraca | Stomatopoda | Squillidae | | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 |
| | Decapoda | Unidentified decapod sp1 | | 0.00 | 0.00 | 7.41 | 11.48 | 0.00 | 0.00 | 18.52 | 9.07 | 1.85 | 4.54 |
| | | Unidentified decapod sp2 | | 5.56 | 9.30 | 0.00 | 0.00 | 3.70 | 9.07 | 0.00 | 0.00 | 3.70 | 5.74 |
| | | Scalopididae | *Scalopida spinosipes* | 31.48 | 19.14 | 25.93 | 11.48 | 61.11 | 27.89 | 37.04 | 19.46 | 0.00 | 0.00 |
| | | Pilumnidae | *Typhlocarcinops canaliculata* | 0.00 | 0.00 | 7.41 | 9.07 | 0.00 | 0.00 | 22.22 | 15.71 | 0.00 | 0.00 |
| | Amphipoda | | | 29.63 | 19.46 | 85.19 | 73.59 | 61.11 | 15.32 | 62.96 | 133.09 | 0.00 | 0.00 |
| | Tanaidacea | | | 5.56 | 9.30 | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 |

**Appendix F:** Abundance of macrobenthos found in wet season at site A to E (Continued)

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | | B | | C | | D | | E | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Malacostraca | Copepoda | | | 16.67 | 26.06 | 20.37 | 17.43 | 7.4 | 14.81 | 1.85 | 4.54 | 9.26 | 18.37 |
| | Cumacea | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Phylum Echinodermata** | | | | | | | | | | | | | |
| Ophiuroidea | Ophiurae | Ophiotrichidae | *Ophiotrix* sp. | 14.81 | 9.07 | 35.19 | 16.36 | 25.93 | 20.69 | 31.48 | 8.36 | 14.81 | 13.46 |
| Asteroidea | Paxillosida | Astropectinidae | *Astropecten* sp. | 5.56 | 9.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Holothuroidea | | | | 0.00 | 0.00 | 7.41 | 9.07 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 |
| Holothuroidea | Molpadida | Caudinidae | *Acaudina molpadioides* | 0.00 | 0.00 | 0.00 | 0.00 | 11.11 | 12.17 | 7.41 | 9.07 | 0.00 | 0.00 |

**Appendix G:** Abundance of macrobenthos found in wet season at site F to J

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | F | | G | | H | | I | | J | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **Phylum Nemertinea** | | | | | | | | | | | | | |
| Anopla | | | | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 |
| **Phylum Annelida** | | | | | | | | | | | | | |
| Polychaeta | Cossurida | Cossuridae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.41 | 18.14 | 0.00 | 0.00 |
| | Capitellida | Capitellidae | | 0.00 | 0.00 | 7.41 | 13.46 | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 |
| | Eunicida | Lumbrineridae | | 5.56 | 6.09 | 0.00 | 0.00 | 7.41 | 9.07 | 0.00 | 0.00 | 3.70 | 9.07 |
| | Maldanida | Maldanidae | | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 | 9.26 | 8.36 | 5.56 | 6.09 |
| | Nephtyida | Nephtyidae | | 12.96 | 8.36 | 7.41 | 11.48 | 0.00 | 0.00 | 22.22 | 17.21 | 5.56 | 6.09 |
| | Orbiniida | Orbiniidae | | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 1.85 | 4.54 | 1.85 | 4.54 |
| | Phyllodocida | Hesionidae | | 0.00 | 0.00 | 11.11 | 9.94 | 9.26 | 8.36 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Phyllodocidae | | 0.00 | 0.00 | 3.70 | 9.07 | 0.00 | 0.00 | 5.56 | 13.61 | 0.00 | 0.00 |
| | Sabellida | Sabellidae | | 12.96 | 14.77 | 1.85 | 4.54 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 |
| | | Oweniidae | | 0.00 | 0.00 | 14.81 | 11.48 | 0.00 | 0.00 | 1.85 | 4.54 | 11.11 | 7.03 |
| | Spionida | Spionidae | | 0.00 | 0.00 | 3.70 | 9.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Syllida | Syllidae | | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 3.70 | 5.74 |
| | Terebellida | Cirratulidae | | 11.11 | 9.94 | 7.41 | 9.07 | 16.67 | 9.30 | 16.67 | 20.79 | 3.70 | 9.07 |
| | | Sternaspidae | | 5.56 | 13.61 | 0.00 | 0.00 | 12.96 | 10.92 | 1.85 | 4.54 | 1.85 | 4.54 |
| | Unidentified polycheates sp1 | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Unidentified polycheates sp2 | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Unidentified polycheates sp3 | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Appendix G** Abundance of macrobenthos found in wet season at site F to J (Continued)

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | F | | G | | H | | I | | J | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **Phylum Mollusca** | | | | | | | | | | | | | |
| Bivalvia | | Mesoclesmatidae | | 11.11 | 12.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Myida | Corbulidae | *Corbula* sp. | 5.56 | 6.09 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 1.85 | 4.54 |
| | Nuculanida | Nuculanidae | *Nuculana* sp. | 29.63 | 36.29 | 7.41 | 9.07 | 7.41 | 9.07 | 16.67 | 20.79 | 1.85 | 4.54 |
| | Cardiida | Tellinidae | *Tellina* sp. | 0.00 | 0.00 | 3.70 | 5.74 | 7.41 | 11.48 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Tellinidae | *Macomas* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Venerida | Veneridae | *Phaphia undulata* | 9.26 | 12.99 | 1.85 | 4.54 | 0.00 | 0.00 | 11.11 | 12.17 | 5.56 | 6.09 |
| | Arcida | Arcidae | *Anadara* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Unidentified bivalve sp1 | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Phylum Arthropoda** | | | | | | | | | | | | | |
| Malacostraca | Stomatopoda | Squillidae | | 3.70 | 5.74 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Decapoda | *Unidentified Decapod1* | | 1.85 | 4.54 | 7.41 | 11.48 | 7.41 | 11.48 | 0.00 | 0.00 | 14.81 | 11.48 |
| | | *Unidentified Decapod2* | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 |
| | | Scalopididae | *Scalopida spinosipes* | 35.19 | 24.76 | 14.81 | 11.48 | 3.70 | 9.07 | 31.48 | 21.56 | 11.11 | 9.94 |
| | | Pilumnidae | *Typhlocarcinops canaliculata* | 1.85 | 4.54 | 1.85 | 4.54 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Amphipoda | | | 18.52 | 18.14 | 37.04 | 36.29 | 14.81 | 11.48 | 25.93 | 16.73 | 22.22 | 12.17 |
| | Tanaidacea | | | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 | 7.41 | 9.07 | 0.00 | 0.00 |

**Appendix G:** Abundance of macrobenthos found in wet season at site F to J (Continued)

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | F | | G | | H | | I | | J | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| | Copepoda | | | 11.11 | 18.15 | 5.55 | 10.28 | 0.00 | 0.00 | 7.41 | 9.07 | 0.00 | 0.00 |
| | Cumacea | | | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Phylum Echinodermata** | | | | | | | | | | | | | |
| Ophiuroidea | Ophiurae | Ophiotrichidae | *Ophiotrix* sp. | 22.22 | 23.31 | 0.00 | 0.00 | 22.22 | 12.17 | 11.11 | 14.05 | 0.00 | 0.00 |
| Asteroidea | Paxillosida | Astropectinidae | *Astropecten* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Holothuroidea | | | *Unidentified sea cucumber sp1* | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 |
| Holothuroidea | Molpadida | Caudinidae | *Acaudina molpadioides* | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## Appendix H: Abundance of macrobenthos found in dry season at site A to E

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | | B | | C | | D | | E | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **Phylum Cnidaria** | | | | | | | | | | | | | |
| Anthozoa | Pennatulacea | Pennatulidae | | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Phylum Platyhelminthes** | | | | | | | | | | | | | |
| Turbellaria | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.76 | 1.85 |
| **Phylum Nemertinea** | | | | | | | | | | | | | |
| Anopla | | | | 5.56 | 9.30 | 9.26 | 10.92 | 5.56 | 6.09 | 11.11 | 14.05 | 7.90 | 9.39 |
| **Phylum Sipunculida** | | | | | | | | | | | | | |
| Sipuncula | | | | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.76 | 1.85 |
| **Phylum Annelida** | | | | | | | | | | | | | |
| Polychaeta | Orbiniida | Orbiniidae | | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 1.85 | 4.54 |
| | Cossurida | Cossuridae | | 38.89 | 41.43 | 0.00 | 0.00 | 5.56 | 13.61 | 3.70 | 9.07 | 1.51 | 3.70 |
| | Terebellida | Cirratulidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.56 | 9.30 | 7.10 | 8.95 |
| | Capitellida | Capitellidae | | 0.00 | 0.00 | 0.00 | 0.00 | 5.56 | 13.61 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Maldanida | Maldanidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.26 | 12.99 | 5.87 | 9.55 |
| | Phyllodocida | Hesionidae | | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 3.70 | 5.74 | 0.96 | 2.34 |
| | Phyllodocida | Nephtyidae | | 11.11 | 27.22 | 22.22 | 15.71 | 12.96 | 12.99 | 1.85 | 4.54 | 2.61 | 4.54 |
| | Spionida | Spionidae | | 0.00 | 0.00 | 5.56 | 13.61 | 7.41 | 13.46 | 5.56 | 6.09 | 2.87 | 4.72 |
| | Phyllodocida | Phyllodocidae | | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 1.85 | 4.54 | 0.76 | 1.85 |
| | Eunicida | Lumbrineridae | | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 5.56 | 9.30 | 1.55 | 3.80 |
| | Phyllodocida | Sigalionidae | | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 1.85 | 4.54 | 0.76 | 1.85 |
| | Terebellida | Sternaspidae | | 0.00 | 0.00 | 9.26 | 17.80 | 0.00 | 0.00 | 1.85 | 4.54 | 8.16 | 8.50 |
| | Sabellida | Oweniidae | | 0.00 | 0.00 | 0.00 | 0.00 | 7.41 | 13.46 | 3.70 | 9.07 | 1.51 | 3.70 |

**Appendix G:** Abundance of macrobenthos found in dry season at site A to E (Continued)

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | | B | | C | | D | | E | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Polychaeta | Phyllodocida | Pilargiidae | | 27.78 | 31.23 | 1.85 | 4.54 | 3.70 | 9.07 | 1.85 | 4.54 | 0.76 | 1.85 |
| | Terebellida | Ampharetidae | | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Phyllodocida | Goniadidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.41 | 9.07 | 1.51 | 3.70 |
| | Terebellida | Trichobranchidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Phyllodocida | Polynoidae | | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 3.70 | 9.07 | 1.51 | 3.70 |
| | Magelonidae | Magelonidae | | 11.11 | 14.05 | 0.00 | 0.00 | 3.70 | 5.74 | 1.85 | 4.54 | 2.61 | 4.54 |
| | Terebellida | Terebellidae | | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Phylum Mollusca** | | | | | | | | | | | | | |
| Bivalvia | Arcida | Arcidae | *Anadara* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 7.41 | 9.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Cardiida | Tellinidae | *Tellina* sp. | 0.00 | 0.00 | 5.56 | 6.09 | 0.00 | 0.00 | 3.70 | 9.07 | 1.51 | 3.70 |
| | | | *Arcopella casta* | 1.85 | 4.54 | 0.00 | 0.00 | 1.85 | 4.54 | 5.56 | 9.30 | 1.55 | 3.80 |
| | | | *Macomas* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 2.61 | 4.54 |
| | | | *Macomona philipinarum* | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Lucinida | Lucinidae | *Chavania striata* | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 1.85 | 4.54 | 13.72 | 26.30 |
| | Nuculanida | Nuculanidae | *Nuculana* sp. | 22.22 | 18.59 | 12.96 | 14.77 | 9.26 | 8.36 | 5.56 | 9.30 | 53.40 | 39.16 |
| | Myida | Corbulidae | *Corbula* sp. | 0.00 | 0.00 | 3.70 | 9.07 | 18.52 | 11.48 | 1.85 | 4.54 | 2.61 | 4.54 |
| | Venerida | Veneridae | *Phaphia undulata* | 9.26 | 14.77 | 3.70 | 5.74 | 3.70 | 5.74 | 5.56 | 9.30 | 7.10 | 5.55 |
| | Unidentified Bivalvia sp1 | | | 0.00 | 0.00 | 12.96 | 31.75 | 24.07 | 34.01 | 1.85 | 4.54 | 0.76 | 1.85 |
| | Unidentified Bivalvia sp2 | | | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 5.56 | 9.30 | 1.55 | 3.80 |
| | Unidentified Bivalvia sp3 | | | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 9.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Unidentified Bivalvia sp4 | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Appendix H:** Abundance of macrobenthos found in dry season at site A to E (Continued)

| Class | Order | Family | Species | Density (individuals/$m^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | | B | | C | | D | | E | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Scaphopoda | Arcida | Arcidae | *Dentalium* sp. | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Gastropoda | | | Unidentified Gastropoda1 | 16.67 | 15.32 | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.76 | 1.85 |
| **Phylum Arthropoda** | | | | | | | | | | | | | |
| Malacostraca | Decapoda | Unidentified decapod sp1 | | 1.85 | 4.54 | 3.70 | 5.74 | 1.85 | 4.54 | 0.00 | 0.00 | 3.70 | 5.74 |
| | | Scalopididae | *Scalopida spinosipes* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Unidentified Crab sp1 | | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Unidentified Crab sp2 | | 0.00 | 0.00 | 11.11 | 14.05 | 12.96 | 21.56 | 3.70 | 5.74 | 2.81 | 4.67 |
| | | Unidentified Crab sp3 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 |
| | | Chamocarinidae | *Chasmocarcinops gelasimides* | 0.00 | 0.00 | 0.00 | 0.00 | 5.56 | 9.30 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Pilumnidae | *Typhlocarcinops canaliculata* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Amphipoda | | | 7.41 | 18.14 | 146.30 | 97.48 | 196.30 | 141.01 | 18.52 | 30.36 | 14.32 | 16.10 |
| | Lucifer | | | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Isopoda | | | 5.56 | 9.30 | 11.11 | 18.59 | 5.56 | 13.61 | 3.70 | 9.07 | 1.51 | 3.70 |
| | Cumacea | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Ostracoda | Ostracoda | | | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 |
| Hexanauplia | Copepoda | | | 12.96 | 22.68 | 7.41 | 9.07 | 5.55 | 10.28 | 0.00 | 0.00 | 0.00 | 0.00 |
| Unidentified Arthropod sp1 | | | | 0.00 | 0.00 | 0.00 | 0.00 | 9.26 | 14.77 | 0.00 | 0.00 | 0.00 | 0.00 |

**Appendix H:** Abundance of macrobenthos found in dry season at site A to E (Continued)

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | | B | | C | | D | | E | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **Phylum Echinodermata** | | | | | | | | | | | | | |
| Ophiuroidea | Amphilepidida | Ophiotrichidae | *Ophiotrix* sp. | 1.85 | 4.54 | 29.63 | 28.69 | 40.74 | 43.70 | 18.52 | 15.18 | 26.60 | 17.55 |
| Holothuroidea | Molpadida | Caudinidae | *Acaudina molpadioides* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.26 | 10.92 |
| Holothuroidea | Unidentified sea cucumber sp1 | | | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 3.70 | 5.74 |

**Appendix I:** Abundance of macrobenthos found in dry season site F to J

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | F | | G | | H | | I | | J | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **Phylum Cnidaria** | | | | | | | | | | | | | |
| Anthozoa | Pennatulacea | Pennatulidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Phylum Platyhelminthes** | | | | | | | | | | | | | |
| Turbellaria | | | | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Phylum Nemertinea** | | | | | | | | | | | | | |
| Anopla | | | | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 |
| **Phylum Sipunculida** | | | | | | | | | | | | | |
| Sipuncula | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Phylum Annelida** | | | | | | | | | | | | | |
| Polychaeta | Orbiniida | Orbiniidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Cossurida | Cossuridae | | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Terebellida | Cirratulidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Capitellida | Capitellidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.56 | 13.61 | 0.00 | 0.00 |
| | Maldanida | Maldanidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Phyllodocida | Hesionidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Phyllodocida | Nephtyidae | | 3.70 | 5.74 | 14.81 | 11.48 | 9.26 | 10.92 | 9.26 | 8.36 | 7.41 | 9.07 |
| | Spionida | Spionidae | | 0.00 | 0.00 | 3.70 | 5.74 | 5.56 | 6.09 | 5.56 | 13.61 | 1.85 | 4.54 |
| | Phyllodocida | Phyllodocidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Eunicida | Lumbrineridae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Phyllodocida | Sigalionidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Terebellida | Sternaspidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Appendix I:** Abundance of macrobenthos found in dry season site F to J (Continued)

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | F | | G | | H | | I | | J | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Polychaeta | Sabellida | Oweniidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Phyllodocida | Pilargiidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Terebellida | Ampharetidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Phyllodocida | Goniadidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Terebellida | Trichobranchidae | | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 |
| | Phyllodocida | Polynoidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Magelonida | Magelonidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Terebellida | Terebellidae | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Phylum Mollusca** | | | | | | | | | | | | | |
| Bivalvia | Arcida | Arcidae | *Anadara* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 9.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Cardiida | Tellinidae | *Tellina* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | *Arcopella casta* | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | *Macomas* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | *Macomona philipinarum* | 7.41 | 13.46 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 9.07 | 1.85 | 4.54 |
| | Lucinida | Lucinidae | *Chavania striata* | 1.85 | 4.54 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 | 1.85 | 4.54 |
| | Myida | Corbulidae | *Corbula* sp. | 1.85 | 4.54 | 3.70 | 5.74 | 7.41 | 9.07 | 0.00 | 0.00 | 1.85 | 4.54 |
| | Nuculanida | Nuculanidae | *Nuculana* sp. | 18.52 | 22.95 | 24.07 | 10.92 | 18.52 | 13.46 | 24.07 | 10.92 | 22.22 | 9.94 |
| | Venerida | Veneridae | *Phaphia undulata* | 1.85 | 4.54 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Unidentified Bivalvia sp1 | | | 0.00 | 0.00 | 0.00 | 0.00 | 9.26 | 12.99 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Unidentified Bivalvia sp2 | | | 7.41 | 18.14 | 12.96 | 12.99 | 11.11 | 17.21 | 7.41 | 11.48 | 14.81 | 16.73 |
| | Unidentified Bivalvia sp3 | | | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Unidentified Bivalvia sp4 | | | 0.00 | 0.00 | 5.56 | 13.61 | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 4.54 |

**Appendix I:** Abundance of macrobenthos found in dry season site F to J (Continued)

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | F | | G | | H | | I | | J | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Scaphopoda | Arcida | Arcidae | *Dentalium* sp. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Gastropoda | Unidentified Gastropoda1 | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Phylum Arthropoda** | | | | | | | | | | | | | |
| Malacostraca | Decapoda | Unidentified decapod sp1 | | 3.70 | 5.74 | 3.70 | 9.07 | 0.00 | 0.00 | 0.00 | 0.00 | 5.56 | 13.61 |
| | | Scalopididae | *Scalopida spinosipes* | 3.70 | 9.07 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 5.74 | 0.00 | 0.00 |
| | | Unidentified Crab sp1 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Unidentified Crab sp2 | | 22.22 | 35.14 | 3.70 | 5.74 | 3.70 | 5.74 | 12.96 | 8.36 | 1.85 | 4.54 |
| | | Unidentified Crab sp3 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Chamocarinidae | *Chasmocarcinops gelasimides* | 0.00 | 0.00 | 0.00 | 0.00 | 7.41 | 9.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Pilumnidae | *Typhlocarcinops canaliculata* | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Amphipoda | | | 35.19 | 30.97 | 33.33 | 22.22 | 31.48 | 14.77 | 20.37 | 14.77 | 25.93 | 16.73 |
| | Lucifer | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Isopoda | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Cumacea | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Ostracoda | Ostracoda | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Hexanauplia | Copepoda | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Unidentified Arthropod sp1 | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Appendix I:** Abundance of macrobenthos found in dry season site F to J (Continued)

| Class | Order | Family | Species | Density (individuals/m$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | F | | G | | H | | I | | J | |
| | | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **Phylum Echinodermata** | | | | | | | | | | | | | |
| Ophiuroidea | Amphilepidida | Ophiotrichidae | *Ophiotrix* sp. | 51.85 | 64.66 | 7.41 | 9.07 | 12.96 | 12.99 | 12.96 | 16.36 | 11.11 | 7.03 |
| Holothuroidea | Molpadida | Caudinidae | *Acaudina molpadioides* | 0.00 | 0.00 | 1.85 | 4.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Holothuroidea | Unidentified sea cucumber sp1 | | | 3.70 | 9.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Appendix J:** Environmental data recorded during macrobenthic sampling in wet season

| Sampling sites | | Sand (%) | Silt (%) | Clay (%) | Organic matter (%) | Depth (m) | Temp. (C) | DO (mg/L) | pH | Salinity (ppt) | TDS (g/L) | Conductivity (mS/cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station A | Mean | 21.19 | 62.31 | 16.51 | 13.48 | 3.55 | 28.79 | 5.75 | 7.65 | 21.28 | 30.01 | 49.55 |
| | SD | 4.33 | 8.97 | 4.87 | 0.55 | 0.08 | 0.02 | 0.01 | 0.01 | 0.68 | 0.03 | 0.01 |
| Station B | Mean | 26.01 | 63.73 | 10.26 | 13.5 | 5.61 | 28.86 | 6.23 | 7.71 | 25.55 | 30.17 | 50.21 |
| | SD | 3.58 | 7 | 3.93 | 0.18 | 0.25 | 0.07 | 0.04 | 0.35 | 0.56 | 0.41 | 0.39 |
| Station C | Mean | 18.66 | 66.4 | 14.94 | 12.25 | 6.97 | 28.7 | 6.35 | 7.48 | 29.74 | 29.79 | 49.82 |
| | SD | 0.66 | 1.33 | 0.75 | 0.18 | 0.08 | 0.15 | 0.12 | 0.14 | 0.19 | 0.09 | 0.14 |
| Station D | Mean | 28.87 | 62.89 | 8.24 | 11.81 | 3.93 | 28.6 | 6.2 | 7.96 | 28.74 | 28.98 | 47.7 |
| | SD | 6.11 | 9.3 | 4.05 | 0.89 | 0.05 | 0.05 | 0.01 | 0.36 | 0.41 | 0.5 | 1.24 |
| Station E | Mean | 22.87 | 70.48 | 6.66 | 12.13 | 4.34 | 26.69 | 6.18 | 7.27 | 28.74 | 29.25 | 47.87 |
| | SD | 4.67 | 4.92 | 0.25 | 0.31 | 0.12 | 1.7 | 0.03 | 0.09 | 1 | 1.2 | 1.44 |
| Station F | Mean | 18.5 | 71.89 | 9.61 | 12.16 | 2.54 | 28.78 | 5.81 | 7.74 | 29.66 | 30.08 | 49.61 |
| | SD | 10.24 | 7.64 | 4.37 | 1.52 | 0.08 | 0.01 | 0.04 | 0.08 | 0.46 | 0.04 | 0.03 |
| Station G | Mean | 14.57 | 74.5 | 10.94 | 11.64 | 7.13 | 28.81 | 5.91 | 7.34 | 29.87 | 30.05 | 49.57 |
| | SD | 1.95 | 3.47 | 5.1 | 0.3 | 0.2 | 0.01 | 0.01 | 0 | 0.01 | 0.01 | 0 |
| Station H | Mean | 14.29 | 72.61 | 13.09 | 12.94 | 7.43 | 28.68 | 6.28 | 7.54 | 30.02 | 30.56 | 49.78 |
| | SD | 1.55 | 3.65 | 5.2 | 0.98 | 0.09 | 0.18 | 0.12 | 0.25 | 0.07 | 0.25 | 0.17 |
| Station I | Mean | 15.98 | 74.89 | 9.13 | 13.74 | 8.18 | 28.51 | 6.43 | 7.75 | 30.66 | 30.51 | 50.43 |
| | SD | 5.99 | 6.56 | 2.83 | 0.53 | 0.11 | 0.11 | 0.01 | 0.04 | 0.26 | 0.26 | 0.32 |
| Station J | Mean | 12.77 | 79.54 | 7.69 | 11.88 | 8.23 | 28.34 | 6.33 | 7.79 | 30.06 | 30.58 | 50.45 |
| | SD | 3.87 | 3.15 | 0.72 | 0.41 | 0.1 | 0.11 | 0.1 | 0.07 | 0.05 | 0.35 | 0.45 |
| **Average** | Mean | 19.37 | 69.92 | 10.71 | 12.55 | 5.79 | 28.47 | 6.15 | 7.62 | 28.43 | 30 | 49.5 |
| | SD | 6.88 | 7.96 | 4.59 | 1 | 1.99 | 0.8 | 0.24 | 0.27 | 2.8 | 0.67 | 1.1 |

**Appendix K:** Environmental data recorded during macrobenthic sampling in dry season

| Sampling sites | | Sand (%) | Silt (%) | Clay (%) | Organic matter (%) | Depth (m) | Temp. (C) | DO (mg/L) | pH | Salinity (ppt) | TDS (g/L) | Conductivity (mS/cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station A | Mean | 34.68 | 58.43 | 6.89 | 11.54 | 3.63 | 28.66 | 5.75 | 4.91 | 30.8 | 31.77 | 53.02 |
| | SD | 8.13 | 8.09 | 0.95 | 0.17 | 0.27 | 0.31 | 0.23 | 3.53 | 0.19 | 0.69 | 0.92 |
| Station B | Mean | 30.93 | 59.65 | 9.42 | 12.82 | 5.5 | 27.68 | 5.3 | 7.81 | 33.24 | 32.88 | 54.06 |
| | SD | 7.75 | 8.59 | 4.37 | 0.35 | 0.2 | 0.53 | 0.16 | 0.11 | 0.12 | 0.32 | 0.23 |
| Station C | Mean | 20.97 | 66.52 | 12.51 | 12.38 | 7.39 | 28.05 | 5.24 | 7.85 | 33.34 | 33.13 | 54.13 |
| | SD | 3.76 | 1.17 | 3.82 | 0.75 | 0.45 | 0.08 | 0.18 | 0.13 | 0.05 | 0.15 | 0.26 |
| Station D | Mean | 27.91 | 63.38 | 8.71 | 7.63 | 3.85 | 27.92 | 5.76 | 8.15 | 33.52 | 33.13 | 54 |
| | SD | 5.21 | 8.9 | 3.81 | 0.16 | 0.06 | 0.04 | 0.02 | 0.03 | 0.07 | 0.08 | 0.51 |
| Station E | Mean | 19.22 | 70.04 | 10.74 | 13.03 | 4.43 | 27.96 | 5.55 | 7.98 | 33.51 | 33.8 | 53.75 |
| | SD | 7.6 | 6.44 | 5.19 | 1.72 | 0.31 | 0.03 | 0.65 | 0.06 | 0.41 | 0.16 | 0.6 |
| Station F | Mean | 21.8 | 69.95 | 8.25 | 10.56 | 2.77 | 27.62 | 4.17 | 7.37 | 32.77 | 32.97 | 56.06 |
| | SD | 10.87 | 8.3 | 4.14 | 0.17 | 0.14 | 0.2 | 0.6 | 0.42 | 0.24 | 0.12 | 1.91 |
| Station G | Mean | 21.87 | 70.84 | 7.28 | 12.32 | 7.47 | 27.78 | 4.51 | 7.55 | 33.03 | 33.45 | 54.94 |
| | SD | 8.45 | 6.72 | 3.12 | 0.82 | 0.29 | 0.24 | 0.68 | 0.37 | 0.41 | 0.45 | 2 |
| Station H | Mean | 15.8 | 71.75 | 12.45 | 12.33 | 7.69 | 27.49 | 5.26 | 7.34 | 32.76 | 33.24 | 54.74 |
| | SD | 4.26 | 6.22 | 4.82 | 1.64 | 0.13 | 0.38 | 0.67 | 0.35 | 0.69 | 0.29 | 0.82 |
| Station I | Mean | 16.12 | 75.39 | 8.49 | 13.73 | 8.63 | 28.5 | 5.58 | 7.74 | 33.41 | 33.61 | 54.35 |
| | SD | 8.1 | 6.7 | 2.79 | 0.64 | 0.51 | 0.55 | 0.54 | 0.27 | 0.35 | 0.24 | 0.74 |
| Station J | Mean | 13.21 | 76.25 | 10.54 | 12.65 | 8.3 | 27.01 | 5.77 | 7.13 | 32.34 | 32.01 | 52.65 |
| | SD | 5.43 | 7.33 | 3.45 | 0.86 | 0.34 | 0.01 | 0.18 | 0.05 | 0.51 | 1.55 | 2.06 |
| Average | Mean | 22.25 | 68.22 | 9.53 | 11.9 | 5.96 | 27.87 | 5.29 | 7.38 | 32.87 | 33 | 54.17 |
| | SD | 9.43 | 8.82 | 3.99 | 1.85 | 2.1 | 0.54 | 0.67 | 1.37 | 0.86 | 0.82 | 1.45 |

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