การประเมินคุณภาพชายหาดโดยใช้สัตว์หน้าดินขนาดใหญ่
บริเวณชายฝั่งทะเลอันดามันตอนล่างของประเทศไทย

นางสาวขวัญตา ตันติกำธน

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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BEACH QUALITY ASSESSMENT USING BENTHIC MACROFAUNA ALONG THE SOUTHERN ANDAMAN SEA COAST OF THAILAND

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A Thesis Submitted in Partial Fulfillment of the Requirements for the

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BEACH QUALITY ASSESSMENT USING BENTHIC MACROFAUNA ALONG THE SOUTHERN ANDAMAN SEA COAST OF THAILAND

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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ขวัญตา ตันติกำธน : การประเมินคุณภาพชายหาดโดยใช้สัตว์หน้าดินขนาดใหญ่บริเวณชายฝั่งทะเลอันดามันตอนล่างของประเทศไทย (BEACH QUALITY ASSESSMENT USING BENTHIC MACROFAUNA ALONG THE SOUTHERN ANDAMAN SEA COAST OF THAILAND) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.ณัฐวุฒิ ธานี, 227 หน้า.

การประเมินคุณภาพชายหาดโดยใช้สัตว์หน้าดินขนาดใหญ่บริเวณชายฝั่งทะเลอันดามันตอนล่างของประเทศไทย ดำเนินการในจังหวัดกระบี่ ตรัง และสตูล พื้นที่ 8 ชายหาด โดยมีสถานีศึกษาทั้งหมด 30 สถานี ทำการตรวจวัดคุณภาพน้ำ 8 ดัชนี คุณภาพดิน 4 ดัชนี และร้อยละของอนุภาคดิน 6 ขนาด ในช่วงฤดูมรสุมตะวันตกเฉียงใต้ ฤดูมรสุมตะวันออกเฉียงเหนือ และฤดูร้อน ระหว่างเดือนกันยายน 2555 ถึงเดือนเมษายน 2556 พบว่าคุณภาพน้ำส่วนใหญ่ยกเว้นความเป็นกรด-เบสและออกซิเจนละลายอยู่ในเกณฑ์มาตรฐานคุณภาพน้ำทะเลของประเทศไทย คุณภาพดินของชายหาดมีสภาพเป็นกลางถึงเป็นกรด โดยมีปริมาณอินทรียวัตถุและธาตุอาหารแตกต่างกัน ขนาดของอนุภาคดินมีความแตกต่างกันในแต่ละชายหาด โดยมีอัตราส่วนของขนาดที่พบมากตั้งแต่ทรายละเอียดมากจนถึงขนาดกลาง การเก็บตัวอย่างสัตว์หน้าดินขนาดใหญ่โดยใช้กรอบตารางสุ่มขนาดพื้นที่ 2.25 ตร.ม. ในเขตน้ำขึ้นน้ำลง พบตัวอย่างสัตว์หน้าดินขนาดใหญ่ทั้งหมด 116 ชนิด จาก 51 วงศ์ 20 อันดับ 5 ชั้น และ 4 ไฟลัม กลุ่มที่พบจำนวนชนิดมากที่สุดคือโพลีคีต รองลงมาคือมอลลัสก์ ครัสตาเชียน และบราชิโอพอด ความหนาแน่นโดยเฉลี่ย 23 – 935 ตัว/2.25 ตร.ม. โดยชนิดสัตว์พื้นฐาน 20 ชนิด ประกอบด้วย *Glycera alba*, *Goniadopsis incerta*, *Scoloplos* (*Scoloplos*) *tumidus*, *Prionospio* (*Prionospio*) *steenstrupi*, *Axiothella obockensis*, *Lumbrineris* sp. 2, *Scoletoma* sp. 3, *Glycera natalensis*, *Paraprionospio* sp., *Mediomastus* sp., *Dendronereis arborifera*, *Donax incarnatus*, *Donax faba*, *Umbonium vestiarium*, *Pitar* sp., *Matuta victor*, *Dotilla intermedia*, *Diogenes dubius*, *Diogenes klassi* และ *Ocypode macrocera* การวิเคราะห์การจัดกลุ่มและความคล้ายคลึงของดัชนีทางนิเวศ และความคล้ายคลึงของความชุกชุมของสัตว์หน้าดินขนาดใหญ่พบว่า ดัชนีทางนิเวศของแต่ละสถานีมีความคล้ายคลึงกันสูงที่ร้อยละ 83 ในขณะที่ความชุกชุมของสัตว์หน้าดินขนาดใหญ่มีความคล้ายคลึงกันปานกลางที่ร้อยละ 21 จากการคำนวณหาดัชนีทางชีวภาพได้แก่ดัชนีความมากชนิดของมาร์กาเลฟ (D) ดัชนีความหลากหลายของแชนนอนวีเนอร์ (H) ดัชนีความเท่าเทียมกันของชนิดหรือความสม่ำเสมอ (J) และดัชนีความเด่นของชนิด (C) การวิเคราะห์องค์ประกอบหลักและหาความสัมพันธ์ของดัชนีทางนิเวศและดัชนีทางชีวภาพโดยใช้สมการการถดถอยแบบหลายตัวแปรพบว่าปริมาณฟอสเฟตและไนเตรตในน้ำ ความเค็ม ออกซิเจน

ละลาย อุณหภูมิ ความขุ่น ปริมาณฟอสเฟตและไนเตรตในดิน ความเป็นกรด-เบสของดิน และอนุภาคดินขนาด 0.71 มม. 0.3 มม. และ 0.075 มม. มีความสัมพันธ์กับดัชนีทางชีวภาพ ($p<0.05$) นอกจากนี้การประยุกต์ใช้โปรแกรม AMBI เพื่อประเมินคุณภาพชายหาดพบว่าชายหาดทั้งหมดอยู่ในสภาพธรรมชาติ (กลุ่ม 1) หรืออยู่ในสภาพถูกรบกวนเพียงเล็กน้อย (กลุ่ม 2)

สาขาวิชาชีววิทยา — ลายมือชื่อนักศึกษา____________

ปีการศึกษา 2557 — ลายมือชื่ออาจารย์ที่ปรึกษา____________

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม____________

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม____________

KHWANTA TANTIKAMTON : BEACH QUALITY ASSESSMENT USING BENTHIC MACROFAUNA ALONG THE SOUTHERN ANDAMAN SEA COAST OF THAILAND. THESIS ADVISOR : ASST. PROF. NATHAWUT THANEE, Ph.D. 227 PP.

BEACH QUALITY, BENTHIC MACROFAUNA, ANDAMAN SEA COAST, ECOLOGICAL SENSITIVITY

The beach quality assessment using benthic macrofauna along the southern Andaman Sea coast of Thailand was conducted in Krabi, Trang and Satun provinces. The survey included 30 sampling stations of 8 beaches. Of these stations, 8 water variables, 4 sediment variables and 6 sediment particle size percentages were measured during the Southwest monsoon, the Northeast monsoon and the summer during September 2012 to April 2013. Most water variables did not exceed the Thailand Marine Water Quality Standard except pH and DO. The sediment qualities of sampling beaches were neutral to acidic with variation of nutrients and organic matter content. Sediment particle sizes also varied among the beaches with the main particle sizes ranged from very fine sand to medium sand. Benthic macrofauna were also collected by the quadrate sampling technique (2.25 m^2) at the intertidal zones. Overall, 116 species were accounted belonging to 51 families, 20 orders, 5 classes of 4 phyla (Polychaeta, Mollusca, Arthropoda and Brachiopoda). The highest number of species was polychaetes followed by mollusks, crustaceans and brachiopods, respectively. The mean densities of benthic macrofauna were in the range of 23-935 individuals/2.25 m^2. Common benthic macrofauna species consisted of 20 species including *Glycera alba*, *Goniadopsis incerta*, *Scoloplos (Scoloplos) tumidus*, *Prionospio (Prionospio) steenstrupi*, *Axiothella obockensis*, *Lumbrineris* sp. 2, *Scoletoma* sp. 3, *Glycera natalensis*, *Paraprionospio* sp., *Mediomastus* sp., *Dendronereis arborifera*, *Donax incarnates*, *Donax faba*, *Umbonium vestiarium*, *Pitar* sp., *Matuta victor*, *Dotilla intermedia*, *Diogenes dubius*, *Diogenes klassi* and *Ocypode macrocera*. Cluster analysis and multidimensional scaling (MDS) were used to compare similarity of all sampling stations based on ecological variables and benthic macrofauna abundances. In the case of similarity based on ecological variable data, the results exhibited high similarity at 83% whereas moderate similarity at 21% was based on benthic macrofauna abundances. Four biological indices: Margalef richness index (D), Shannon-Wiener diversity index (H), Species equitability or Evenness index (J) and Species dominance index (C) were calculated. The major variables were investigated by Principal Component Analysis (PCA). The stepwise multiple linear regression was used to determine the correlation between the ecological variables and the biological indices. The phosphate and nitrate concentration in water, salinity, dissolved oxygen, temperature, turbidity, phosphate and nitrate concentration in sediment, sediment pH, sediment particle sizes 0.71 mm, 0.3 mm and 0.075 mm correlated to the biological indices ($p<0.05$). Moreover, the AMBI software which was applied to interpret the beach health manifested that all sampling stations were defined into undisturbed (Group I) and slightly disturbed (Group II) beach status.

School of Biology	Student's Signature________
Academic Year 2014	Advisor's Signature________
	Co-advisor's Signature________
	Co-advisor's Signature________

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Khwanta Tantikamton

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CHAPTER I

INTRODUCTION

1.1 General introduction

The Andaman Sea coast of Thailand presents high levels of complexity, diverse habitats and supports a high level of biodiversity such as mangrove areas, coral reefs, seagrass beds and fishery resources (Nootmorn, Chayakun, and Chullasorn, 2003). These provide goods and services that support different uses which can be fishery activities, aquaculture, industrial functions and tourism. The activities cause the coastal area to face increasing and significant impacts, which include physical and chemical transformation, habitat destructions and changes in biodiversity (Defeo et al., 2009; Ellis, 2005; Svanberg, 1996). The Pollution Control Department (2012) reported environmental status of the coast of Andaman which indicated water quality problems caused by suspended solid (SS), phosphate (PO_4^{3-}), ammonia (NH_3) and total coliform bacteria (TCB).

A large proportion of the human population inhabits in coastal areas and human density is expected to increase in the coming years. Consequently, coastal ecosystems are particularly exposed to human pressures, and some of them are among the most disturbed parts of the biosphere. Society and managers require tools based on sound scientific knowledge to properly monitor, manage and protect such sensitive areas (Martinez-Crego, Alcoverro, and Romeo, 2010).

Beach environmental quality is most often expressed in terms of physical and chemical parameters. This is conceptually linked to point sources of pollution. However, non-point sources of pollution have been increasingly recognized as being responsible for many environmental quality problems. The interconnection between ecosystem services and human welfare incorporates biological and ecological criteria. The ecological integrity of beach environment under human pressure has been defined as the ability of the aquatic ecosystem to support and maintain key ecological processes and community of organisms with a species compositions, diversity and functional organization similar to that of undisturbed habitats within the region. Finding the causes of reduced aquatic system integrity, and developing and implementing adequate remedial actions are now key components of environmental management (Defeo et al., 2009; Ellis, 2005; Martinez-Crego et al., 2010; Svanberg, 1996).

A bioindicator is an organism, a part of an organism, or a set of organisms that contains information on the quality of the environment. Bioindicators can be obtained from any level of the biological organization, ranging from the biochemistry or metabolism of a single organism to emergent properties of complex community (Franzle, 2006; Martinez-Crego et al., 2010) and can be illustrated in Figure 1.1.

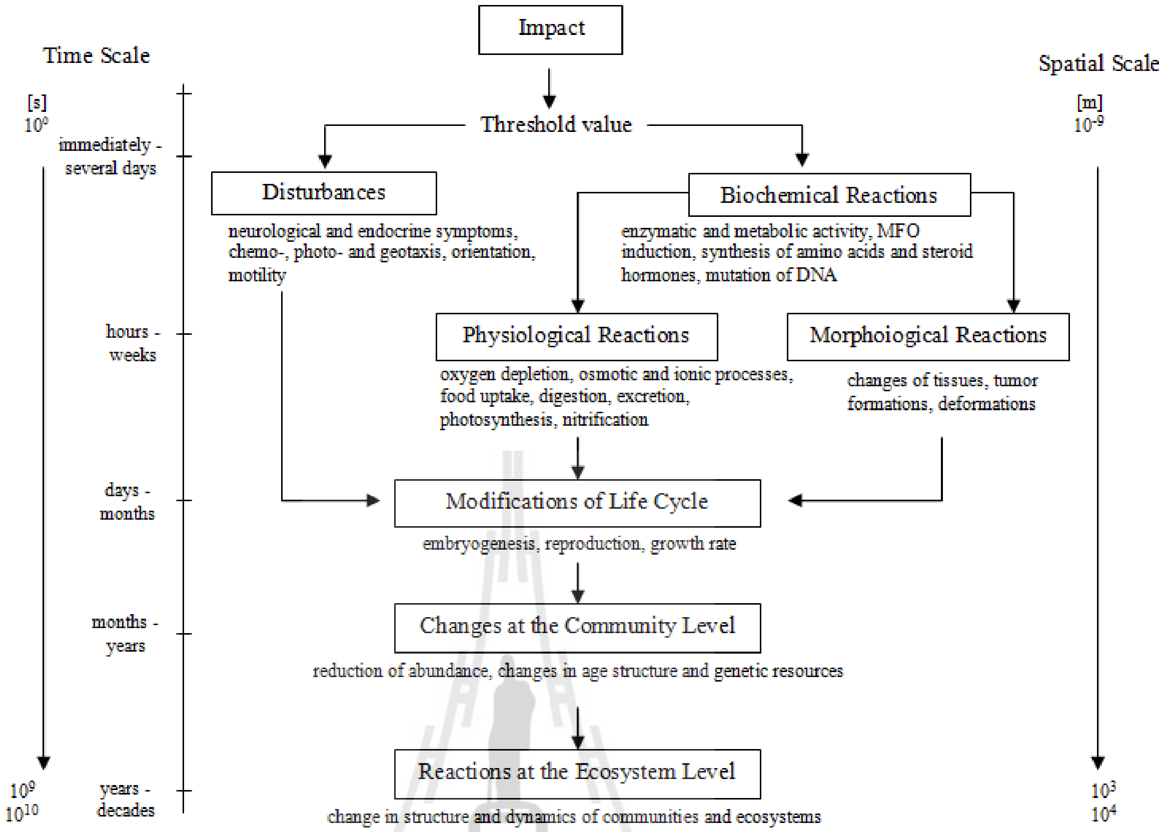


Figure 1.1 Average stress response times of biotic systems as related to size and structural complexity (Franzle, 2006).

Biological criteria are considered important components of water quality because they are direct measures of condition of the biota. They may cover problems undetected or underestimated by other methods, and such criteria provide measurements of the progress of restoration efforts (Borja, Franco, and Perez, 2000). Benthic communities are used in monitoring effects of marine pollution as organisms are mostly sessile and integrate effects of pollutants overtime. Various studies have demonstrated that benthic macrofauna responds relatively rapidly to anthropic and natural stress (Borja et al., 2000; Dauvin, Bellan, and Bellan-Santini, 2010; Teixeira et al., 2010). River ecology has an established long tradition in applying benthic macrofauna as bioindicators (Kudthalang and Thanee, 2010). Some attempts provided useful bioindiactors to measure ecological quality in the marine environment. Macrobenthic animals are relatively sedentary and cannot avoid deteriorating environmental quality conditions. They have relatively long life-spans making them suitable to be used to indicate environmental quality with time. Macrobenthic animal comprise a large number of species that exhibit different tolerance to stress.

Pollutants put to the sea can be accumulated and have direct effects on benthic communities. Pollution induced changes of relative crude, total number of species, diversity and occurrence of opportunistic species (Borja et al., 2000; Gray, Clarke, Warwick, and Hobbs, 1990). Dauvin et al. (2010) defined benthic fauna by difference in their responses to the environmental quality levels as sensitive to tolerant. Previous studies on the ecological characteristics of benthic macroinvertebrates concern their certain habitat types and the environmental variables which are used to determine the basis for distribution patterns of them and to evaluate the beach environments by the presence or absence of the invertebrates. Because of the varying sensitivities of species, it should be possible to identify subtle effects of pollutant reflected in changes in community structure. Then the benthic macrofauna species or communities can be used as indicators for environmental pollution which best act to indicate the health of coastal areas.

This research studied on species, communities and distribution of benthic macrofauna along the southern Andaman Sea coast. The selected provinces were Krabi, Trang and Satun. The sampling areas were categorized into both anthropogenic and non-anthropogenic impact areas to determine the correlation between environmental factors and macrobenthic communities. These data provide important knowledge for coastal environmental management to solve problems and prevent adverse effects to the coastal zone.

1.2 Research objectives

The objectives in the study of beach quality assessment using benthic macrofauna along the southern Andaman Sea coast of Thailand were:

(i) To study the benthic macrofauna communities that were associated with human pressures in the southern Andaman Sea coast of Thailand, which are Krabi, Trang, and Satun provinces.

(ii) To utilize environmental data and benthic macrofauna assemblages to characterize the present conditions along beaches of the southern Andaman Sea coast of Thailand.

(iii) To evaluate the biotic indices and indicators of benthic macrofauna to assess coastal ecosystem health.

1.3 Scope and limitation of the study

The study of beach quality assessment using benthic macrofauna along the southern Andaman Sea coast of Thailand was conducted in anthropogenic and non-anthropogenic impacted coastal areas which are the same coast of Krabi, Trang and Satun provinces. The samples were collected in 3 periods of one year. The sampling periods covered the time during the Northeast monsoon (mid October to mid February), dry season (mid February to mid May) and during the Southwest monsoon (mid May to mid October).

CHAPTER II

LITERATURE REVIEW

2.1 The Andaman Sea coast of Thailand

The Andaman Sea has been identified as one of the world's large marine ecosystems. It is a non-enclosed area with narrow continental shelf and well exposed to the deep oceanic waters in the northern part while the southern part has many large areas of mangrove forests and runoff. In the southern region, a great number of run-off rivers are located: suspended solids appeared to be a prominent factor of environmental properties (Janekarn and Chullasorn, 1997). As the favorable environmental conditions, the coastal and marine living resources in this sea are abundant. The most important components of the ecosystems are mangrove forests, seagrass beds, coral reefs and fishery resources (Nootmorn et al., 2003).

The provinces of Ranong, Pang-nga, Phuket, Krabi, Trang and Satun face the Andaman Sea and have a total about 732 km coastline. The coastline length of each province is 69 km in Ranong, 239.3 km in Pang-nga, 160 km in Krabi, 119 km in Trang and 144.8 km in Satun (Office of the Strategy Management of Andaman, 2011; Office of the Strategy Management of South-border, 2011). The sea of the Ranong, Phang-nga, Krabi, Trang and Satun provinces is influenced by semi-diurnal tides of approximately 3 m in spring and 1 m in neap tide (Pornpinatepong, 2005). The coastal area has a tropical climate that is characterized by two monsoonal winds. The

Southwest monsoon from May through October brings moderate to heavy rains. The Southwest winds mainly generate moderate waves along the Andaman Sea coast. The retreat of the Southwest monsoon in September and October is frequently accompanied by peak wind and wave intensity caused by the passing of cyclones generated in South China Sea. During the Northeast monsoon, the winds generate wave along the east coast of the southern peninsular of Thailand. The water circulation is tidally dominated by a major flow in a northeasterly direction. During the Northeast monsoon, which prevails from November to April, the surface and subsurface flow in the nearshore areas appears to more northwards at a speed of 2-4 cm/sec. During the Southwest monsoon that prevails from May to October, the surface flows southwards of 2-5 cm/sec (Limpsaichol, 1992).

2.2 Coastal water quality and beach quality in the Andaman coast of Thailand

Changes in the size, composition and distribution of human populations affect coastal regions by changing land use and land cover. Fishing or harvesting, the destruction of mangrove, pollution and sedimentation from human activities all can affect the coastal environment. Endanger Wildlife Trust (2003) defined human activities supported coastal areas are extractive industries, farming, fisheries, forestry, manufacturing, oil, gas and offshore engineering, tourism and recreation, services such as processing and disposing of wastes, transport and its related infrastructure and residential and commercial development.

The main human activities in coastal areas of the Andaman Sea are marine capture fisheries, coastal aquaculture, manufacturing, urbanization, transport, andtourism and recreation (Janekarn and Chullasorn, 1997; Jantarashote, 2003).

The sea water quality around the coast of Andaman was monitored at 65 water quality monitoring stations beginning from Ranong province to Satun province. Most of the parameters which indicated water quality problems were suspended solid, phosphate, ammonia and total coliform bacteria. Water quality of the Andaman Sea was fair and good in some areas. Many stations at Krabi, Trang and Satun were found to have good and fair water quality. None of station had deteriorated or highly deteriorated water quality (Table 2.1). Most of the areas which had good water quality were in islands or the areas that were not affected from human activities. In contrast, the areas that had fair water quality had higher human activities (Pollution Control Department, 2012).

Table 2.1 Coastal water quality in the Andaman Sea coast in 2011.

Marine Water Quality Index	Area
Excellent (>90-100)	None
Good (>80-90)	Phuket: Kata Noi beach
	Krabi: Lanta island (Laem Ta Nod)
Fair (>50-80)	Ranong: Bang Bane beach, Prapas beach
	Phang-nga: Ban Kao Pi Lai, Phrathog island, Ban Nam Khem, Bang Sak beach, Tai Muang, Klong Pak Bang (Kao Lak), Ban

Table 2.1 (Continued) Coastal water quality in the Andaman Sea coast in 2011.

Marine Water Quality Index	Area
	Bang Nieng, Ban Tub Lamu, Ban Koh Kor Kao, Ban Kuek Kak Krabi: Nopparatthara beach, Lanta island (South of Klong Kwang beach, Ban Klong Nin, Ban Sala Dan), Phi Phi island (Laem Tong, Lo Ba Kao Gulf, Lo Da Lum Gulf, Yao beach, Ton Sai beach), Ban Bo Muang Trang: Pak Meng beach, Samran beach, Chao Mai beach, Yong Ling beach, Yao beach Satun: Ban Pak Bara beach, Pak Bara pier, Ban Tung Rin, Ban Pak Bang
Deteriorated (>25-50)	None
Highly deteriorated (0-25)	None

Source: Pollution Control Department (2012)

2.3 Pollution sources and anthropogenic impacts to coastal areas

Most of the coastal areas of the world have been reported to be damaged from pollution. Human populations are over-utilizing the resources in many areas, while wholesale destruction of the forests on land, together with rapid urbanization, is landing the massive loads of sediments and pollution. In Southeast Asia, marine pollution comes from both land (e.g., via river and wind) and sea (e.g., through marine dredging, mining, dumping and shipping). Other pollutants, such as heat from industrial cooling effluents, or munitions dumping, are relatively minor (Todd, Ong, and Chou, 2010).

Jantarashote (2003) reported that threat ranks of the Andaman coastal and marine environment were land-based activities, fishing, discharges of water from shrimp farms and oil spill.

2.3.1 Land-based activities

The provinces along the Andaman Sea coast have rapidly developed in agriculture, industry and service sectors. The coastal area has a high capacity for tourism and since a few decades back gradually gained popularity. Established communities along the coastal area create several impacts to the coastal environment and the wastes from the service sector in some areas are mainly dumped into coastal area and finally transfer into the sea. Industrialization, urbanization and upland activities have also worsened the situation. The agriculture also releases chemical fertilizers and insecticides to the coastal and marine environment. Food processing industry is the main industry in this area and it discharged wastes into the coastal areas (Chongprasith and Praekuvanich, 2003; Jantarashote, 2003).

2.3.2 Fishing

The Andaman Sea of Thailand has been recognized for its high fisheries and economical potential. Fishery in the Andaman Sea is classified into small-scale and commercial fisheries and these activities have made high income for Thailand. In contrast, widespread violations of regulations, including fishing during closed periods, the use of illegal mesh sizes and the destruction of fish habitats such as mangroves, seagrass beds and coral reefs have most common happened within the coastal zone. (Panjarat, 2008). In addition, dynamite and cyanide fishing create an impact to the coastal marine environment (Jantarashote, 2003).

2.3.3 Discharges of water from shrimp farms

Shrimp farms in the Andaman Sea coast are most intensive farms that produce high quantity of shrimp by using various types of chemical for growth rate acceleration and disease protection. Wasteload from shrimp culture activities is mainly occurred and affects the water quality in some coastal areas. The intensive culture causes very turbid water (TSS 106 mg/L) that exceeds the threshold value. The TSS consists of a high organic fraction (OF), and is mainly derived from the remainder of the meal (Tookwinas and Ruangpan, 1992).

2.3.4 Oil spill

Along the Andaman Sea coast there are many piers for fishing vessels and tour boats, and harbors for cargo vessels and navy base. These cause oil spills in the coastal areas by (1) boat accidents, crashes, or sinking, (2) oil transfer from ships to small boats in the open sea and from ships to ports and (3) the illegal discharge of wastewater contaminated with oil from ships into the sea (Singkran, 2013). Some oil and fuel are distributed into coastal areas and considered to be a serious environmental problem and often have long-term impacts on wildlife, fisheries, coastal habitats, socioeconomics, and human activities in affected areas, where environmental recovery may take several years (Pollution Control Department, 2010).

2.4 Importance of benthic macrofauna to coastal areas

The community of organisms that live on, or in, the bottom of a water body is known as “benthos”. The term “benthos” was introduced by the eminent German naturalist and artist Ernst Haeckel (1834-1919), who also introduced the term “ecology”. The benthic community is complex. It includes a wide range of organisms from bacteria to plants (phytobenthos) and animals (zoobenthos) and from the different levels of the food web. Benthic animals are generally classified according to size as microfauna (microbenthos) <0.063 mm, meiofauna (meiobenthos) 0.063-1.0 (or 0.5) mm, macrofauna (macrobenthos) >1.0 (or 0.5) mm and, sometimes, megafauna (megabenthos) > 10.0 mm. Epifauna live on the surface and infauna bury within the sediment. (Taggliapietra and Sigorini, 2010). Macrofauna are multicellular animals retained on a 1.0 mm sieve except nematodes and copepods. Nematodes and copepods are the major component of meiofauna and only a small proportion is retained on the 1.0 mm sieve (Borja and Dauer, 2008).

Taggliapietra and Sigorini (2010) considered that well-known groups of macrobenthic animals are worms such as polychaetes and oligochaetes, mollusks such as bivalves and gastropods, and crustaceans such as amphipods and decapods. The benthic invertebrates can be differentiated by the position and occupy on or in bottom sediments as above.

According to their feeding types, benthic macrofauna mainly constitute three modes of feeding such as filter feeders (bivalves, sponges, ascidians, worms, barnacles, etc), browsers (amphipods, isopods, gastropods, etc) and deposit feeders (annelids, bivalves, gastropods, holothurians, crustaceans, etc) (Govindan, 2002).

Beaches provide habitats and support a great variety of living organisms. They are key ecosystems that link the sand dunes with the surf zone through a constant interchange of sand, organic matter and nutrients. The surf zones of beaches are an important nursery and recruitment area for fish that rely on the smaller invertebrates as a supply of food. For example, prey organisms (e.g. invertebrates) that live in the intertidal zone support fish populations. Beaches are also home to a variety of shorebirds and the essential nesting habitat for turtles. These areas are considerable biological diversity which plays a major role in the life cycles of economic important species. However, during recent decades, these habitats in the Andaman Sea present in a critical state (Janekarn and Chullasorn, 1997).

Beach fauna are one of very important components of the ecosystem. They provide a critical link between microorganisms, e.g. bacteria and macrofauna such as ecologically and commercially important fish species. A large percentage of fish production can be directly linked to this food chain with fish feeding directly on beach fauna. The energy source starts with beach wrack, dead plants and animals that wash on to the beach, and primary producers such as phytoplankton. Bacteria, fungi, meiofauna and macrofauna all feed on these items and pass the energy along the food chain, eventually reaching fish and birds (Griffith Center form Coastal Management, 2011). Moreover, they play a vital role in the recycling of essential life sustaining elements such as C, N, and P in the marine ecosystem. Macrofaunal activities on sediment nutrient dynamics can also result in a higher N : P ratio of the sediments efflux compared with sediments without macrofauna (Karlson, Bonsdroff, and Rosenberg, 2007). The sedimental organic matter from the water column is effectively consumed into invertebrate benthic biomass and converted to dissolved organic matter and inorganic nutrients by benthic organisms. The nutrients released from the sediments due to bacteria degradation of organic matter, diffuse and disperse into overlaying water and influence the primary production which in turn triggers the zooplankton production in the marine environment (Mermillod-Blondin, Francois-Carcaillet, and Rosenberg, 2005). Another important function of the sandy beach fauna is that they clean up the beaches. Beach fauna numbering in the millions are feeding on beach wrack and are in fact cleaning the grains of sand on the beach (Gage, 2001).

Benthic macrofauna create bioturbation during their movements and feeding activities which condition the sediments for meiofauna and microfauna and as a stimulant of nutrient regeneration. Many deposit feeders ingest anaerobic sediments and transfer them to surface layer where they become oxidized zone. This also helps transfer of bacteria and organic matter from deeper reduced layer to surface oxidized zone. Simultaneously, this also transport of well oxygenate water from the surface to deeper zone (Govindan, 2002).

Some benthic macrofauna are known as habitat engineers e.g. the polychaete *Lanice conchilega*, which structures the environment by building tubes or burrows. Such structures increase a habitat complexity and provide the habitat suitable for other species. *L. conchilega* positively influences macrofaunal density, species richness and community composition (Rabaut, Guilini, Hoey, Vincx, and Degraer, 2007). Additionally, the bioirrigation activities of habitat engineers bring organic matter, as well as oxygen, to the deeper sediment layers, which would otherwise be anoxic. A species *Callianassa subterranean* constructs a complex burrow wall. Sediment expelled from the burrow increases the total oxygen uptake relative to the surrounding sediment surface. *L. conchilega* acts as a piston when moving in its tube: this mechanism associate with oxygen transport (Foster and Graf, 1995).

Species of *Arenicola marina* and *Corophium arenarium* produce changing in bed properties. They modify shear-wave propagation through the bed by changing bed rigidity, by increasing open burrows and also modification of sediment texture and bed properties (Jones and Jago, 1993).

2.5 Impacts of environmental changing on benthic fauna

Variability in environmental factors and ecological relationships cause variability in states of populations, communities and ecosystems. Many human pressures cause deviations from these natural states of the ecosystem. The main environmental parameters in the benthic environment are salinity, littoral or sublittoral height/depth and morphology, nutrients, water flow velocity and turbulence, soft substrate composition (mud content, organic matter content, median grain size), soft and hard substrate elements, temperature and pH. In the case of human pressures, Boon, Gittenberger, and van Loon (2011) considered that in the Dutch transitional and coastal waters are affecting to the benthos by eutrophication that are leading to surplus deposition of organic matter and oxygen lack, pollution by metals and organics, coastal reconstruction and dredging, sand extraction, bottom-distribution fisheries, dumping and coastal nourishment. These are affecting morphology, currents, substrate composition and adding hard substrate. Additionally, climate change affects temperature and pH.

Large, sudden deposits of sediments, from either natural or anthropogenic events, are likely to bury and kill most benthic organisms and severely change the bottom habitats. Beach nourishments could have more serious effects on native habitats and assemblages. Structures of assemblages are related to nourishment of beaches: assemblages of macrofauna on high enrichment beaches are less heterogeneous than the assemblages with no effects from nourishments. The assemblages are characterized by high abundances of a few taxa typical of high organic load beaches. The species such as *Ampelisca diadema* (amphipod) and *Capitomastus minimus* (round worm) found almost exclusively in areas with high enrichments. *Spio decoratus* and *Prionospio caspersi* (polychaetes) occasionally occurred at both high and low nourishment beaches but low abundances. *Tellina tenuis, Lentidium mediterranium, Donax semistriatus*, *Chamelea gallina* (bivalves) and *Cyclope neritea* (gastropod) are highly correlated with nourishments. But *Orbinidae* sp., *Glycera tridactyla* (polychaete) and *Balthyporela guilliamasoniana* (amphipod) are highly abundant when no effect from nourishments (Colosio, Abbiati, and Airoldi, 2007).

Aggregate dredging has an impact on community composition of the benthic macrofauna within the boundaries and intensively-dredged sites. Dredging at a site is associated with a significant suppression of population density and biomass of benthic macrofauna. The community is dominated by one species within the boundaries of the dredged site. In contrast, there is little evidence of an impact on community structure outside the immediate boundaries of the intensive dredged sites. Macrofaunal communities have a relatively low dominance by one or a few species, and a more uniform species composition typical of undisturbed environments (Newell, Seiderer, Simpson, and Robinson, 2004). The benthic macrofauna was used in order to assess impacts of man-made pollution in port areas which are industrialized, tourism and aquaculture sources. The very high dominances where high abundances are found, the dominances of polychaetes and mollusks and very low numbers and frequencies of crustaceans and echinoderms, pointed to an unbalanced or stressed situation for the local benthic macrofauna. The dominant species is *Corbula gibba* followed by *Pectinaria koreni*. The analysis of a macrofauna pattern showed declining along a gradient of environmental stress (Solis-Weiss et al., 2004). Kumar, Katti, Moorthy, and D'Souza (2004) considered that benthic macrofauna related to sediment characteristics in the coastal zone. On the basis of comparison made, changes in the textual characteristics of the sediment and the higher level of organic carbon might be responsible for reducing the frequency of occurrence and abundance of benthic macrofauna especially at stations located near effluent outfall to the stations located far away from discharge point. Species richness and evenness of distribution have indicated that the disturbance of the environment, mainly from pollution, resulting in changes of sensitive and tolerant benthic communities (Belan, 2003).

Organic pollutants are major reservoir in water column and can be accumulated through bioconcentration, in sediments and benthic organisms. From the benthos, the pollutants can be introduced into higher trophic levels through tropic transfer (Figure 2.1).

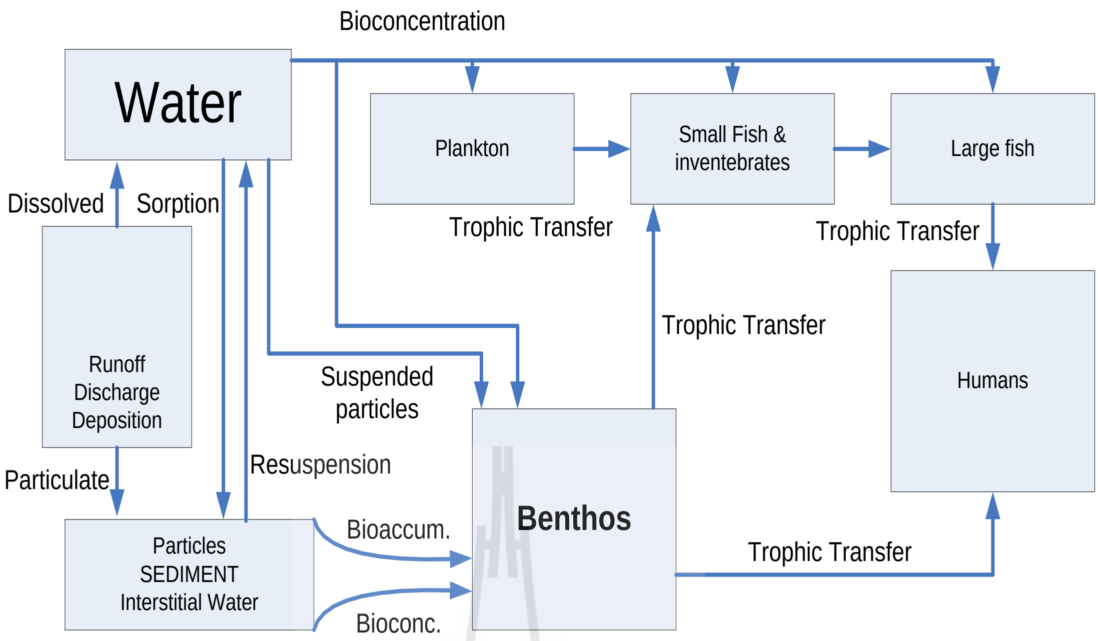


Figure 2.1 Idealized pollutant pathways in marine ecosystem (Lee, 1996).

2.6 Marine health assessment by using benthic fauna

Benthic communities are often used as biological indicators because they can provide information on environmental conditions either due to the sensitivity of single species (indicator species) or because of some general feather that makes them integrate environmental signals over a long period of time. These features are exposure to low dissolved oxygen levels (hyposia/anoxia) that often occur near the bottom surface due to organic matter degradation, limited mobility that restricts their ability to avoid adverse conditions, taxonomic and functional diversity that make them suitable for the detection of different types and levels of stress (Taggliapietra and Sigorini, 2010). Benthic animals are those associated with the bottom of seas, rivers, lakes, etc. There are advantages in using benthic animals for monitoring environment over plankton or fish that live in water column. Benthos lives essentially in a 2 dimensional dispersal. This makes sample design easier. The distribution of plankton and fish is affected by tides and diurnal cycles which are additional factors to be considered when these groups are collected. Also, because of their low mobility, benthic animals take some time to recolonize an area after a pulse or intermittent pollution event. The use of macrobenthic organisms as indicators has many advantages: they are useful for studying the local effects of physical and chemical perturbations; some of these species are long-lived; their taxonomy and their quantitative sampling are relatively easy (Borja et al., 2000).

Water quality can be determined by analyzing the chemicals present in the water (e.g. oxygen content, metallic and organic pollutants, nutrients) or using biological indicators (also called bioindicators) as surrogates to indicate the quality of the water in which they are present. Among bioindicators, there are many biological compartments such as phytoplankton, macroalgae, fish, macrozoobenthos and meiozoobenthos (Dauvin et al., 2010). The important reasons for using bioindicators are the direct determination of biological effects, the determination of synergetic and antagonistic effects of multiple pollutants on an organism, the early recognition of pollutant damage to the organisms as well as toxic dangers to humans and relatively low cost compared to technical measuring methods (Nkwoji, Igbo, Adeleye, Obienu, and Tony-Obiagwu, 2010). Most of literatures have developed water quality indicators and indices to indicate the response of the fauna to pollution gradients. It is well documented that pollution results in changes of the disappearance of sensitive species in polluted area, the increase in the abundance of certain resistant species in moderately polluted areas, and the survival and even the proliferation of opportunistic species in the more polluted zones. In the most polluted zones, no macrofauna resists

(Dauvin et al., 2010). A critical first step to use benthos as bioindicator is to decide which recorded taxa. Nematodes and copepods are the most abundant meiofaunal phyla and are ubiquitous and easily preserved. Other meiofaunal taxa such as gastrotrichs, polychaetes and turbellarians may alternatively be used (Kenedy and Jacoby, 1999). Some researches have advocated that polychaetes are very useful organisms for monitoring the marine environment because they show sensitivity to anthropogenic compounds. The presence or absence of specific polychaetes in a sediment provides one excellent indication of the condition or health of the benthic environment and several species of polychaetes are already well know as pollution indicators (Pocklington and Well, 1992). The effects of anthropogenic disturbances on benthic invertebrate communities in many years can decrease ecological quality. The ecological classification of key species in the community and the balance expected between ecological groups of estuarine communities has great influence in the final ecological assessment (Teixera et al., 2009).

Dauvin et al. (2010) defined terms of ecological for qualifying benthic species as:

1) A sensitive species is a species that can only survive within a narrow range of environmental conditions and disappear from polluted areas and zones undergoing environmental change (i.e., climate or habitat changes).

2) A tolerant species is a species that is not sensitive to a particular stress and/or pollution.

3) An opportunistic species is a species that can quickly exploit new resources or ecological niches as they become available. For example, the species are

characterized by early reproduction, high reproduction rates, rapid development, small body size and an uncertain adult survival rate.

4) A characteristic species is a species linked to a particular biocenotic structure referred to as a community, a biotic assemblage or a biocenosis.

5) A sentinel species is a particular species which by its presence or its relative abundance warns an observer about possible imbalances in the surrounding environment and/or alterations of the community functions.

6) An indicator species is a species signaled the presence of a particular factor, either biotic or abiotic, within a given environment.

7) An indifferent species is a species with no real affinity for any particular community and which shows no response to pollution.

In term of used qualify, the ecological quality status of benthic communities have been defined as (Dauvin et al., 2010):

1) Index/Indices is a generic term used in very large range of scientific domains, from marine biology, sociology to economics. It corresponds mainly to a numerical scale used to compare one variable to another or to a reference number, a value of ration (a value or measurement scale) derived from a series of observed facts. It can reveal relative changes over time.

2) Biotic Index/Indices is a term used to give a status report about particular environment by indication the types of organisms that are in it. It is often to assess the quality of an environment. It generally ranges from a minimum value to a maximum value and permits to classify the status of an environment compared to a reference status.

Grall and Glemarec (1997) defined groups of species sensitivity to the environments into 5 groups as follows:

1) Group I: Species very sensitive to organic enrichment and present in normal conditions. They include the specialist carnivores and some deposit feeding tubicolous polychaetes.

2) Group II: Species indifferent to enrichment, always present in low densities with non-significant variations in time. These include suspension feeders, less selective carnivores and scavengers.

3) Group III: Species tolerant of excess organic matter enrichment. These species may occur in normal conditions but their populations are stimulated by organic enrichment. These are only some of the surface-deposit-feeding species, for example *Tubicolous spionids*, which ingest the superficial film of organic matter deposited at the surface.

4) Group IV: Second-order opportunistic species. These are the small species with a short life cycle, adapted to a life in reduced sediment where they can proliferate. They are the subsurface deposit feeders essentially related to the cirratulids.

5) Group V: First-order opportunistic species. These are the deposit feeders that proliferate in sediments reduced up to the surface. Two species of polychaetes of universal distribution are typical of this group, *Capitella capitata* and *Scolelepis fuliginosa*. Some nematodes and oligochaetes are also present.

According to Belan (2003), a few tolerant or opportunistic species will become relatively more numerous and will dominate in polluted communities, while many less tolerant species will become increasingly rare or disappear. Species which are sensitive to pollution may be used as indicators. The species which are opportunistic, and increase their dominance under pollution, can be regarded as positive pollution indicators. Species, which occur frequently in less polluted areas, but eventually disappear when their habitat becomes polluted, may be used as negative indicators of pollution.

The main goal of using biotic indices is the evaluation of the biological integrity of ecosystems. Focusing on this special issue, the predominant driver indicator would be population density changes in coastal regions with associated activities such as, industry development, port uses, etc. Indicators relate to large-scale of anthropogenic impacts and would include changes in coastal watersheds. The main strength of biotic indices is that they allow the integration of information and parameter of the ecosystems (Borja and Dauer, 2008).

Borja et al. (2000) considered that the distribution of the ecological groups as above, according to their sensitivity to pollution stress, provides a Biotic Index (BI) with eight levels, from 0 to 7. In order to improve the index, a single formula is calculated. This is based upon the percentages of abundance of each sample, to obtain a continuous index (the Biotic Coefficient (BC)), where

$$\text{Biotic Coefficient} = ((0 \times \%\ GI) + (1.5 \times \%GII) + (3 \times \%\ GIII) + (4.5 \times \%\ GIV) + (6 \times \%\ GV))/100$$

The above mentioned ecological groups (GI, GII, GIII, GIV and GV) are summarized in Table 2.2

Table 2.2 Summary of the Biotic Coefficient and Biotic Index.

Site pollution classification	Biotic Coefficient	Biotic Index	Dominating ecological group	Benthic community health
Unpolluted	0.0 < BC ≤ 0.2	0	I	Normal
Unpolluted	0.2 < BC ≤ 1.2	1		Impoverished
Slightly polluted	1.2 < BC ≤ 3.3	2	III	Unbalance
Meanly polluted	3.3 < BC ≤ 4.3	3		Transitional to pollution
Meanly polluted	4.5 < BC ≤ 5.0	4	IV-V	Polluted
Heavily polluted	5.0 < BC ≤ 5.5	5		Transitional to heavy pollution
Heavily polluted	5.5 < BC ≤ 6.0	6	V	Heavy polluted
Extremely polluted	Azoic	7	Azoic	Azoic

Source: Borja et al. (2000)

Biotic indices go one step further and attempt to summarize features of different elements of the ecosystem into a single value integrating relevant ecological overall expression of biotic integrity (Franzle, 2006).

As a prerequisite for Water Framework Directive (WFD) various multi-metrics containing several indicators have been and are being developed to give a measure of the ecological state of the benthic ecosystem in coastal and transitional waters as a reaction to human pressures. These indices are commonly based on quantitative calculations based on species composition, abundance (density, biomass) data and species sensitivity data. Assigning species or species groups and their abundance are determined to specific pressures (Boon et al., 2011).

Many species are representative of the most important soft-bottom communities present at European estuarine and coastal systems. The taxa have been classified in the Table 2.3 according to the above ecological groups and in the theoretical model in Figure 2.2 (Borja et al., 2000; Solis-Weiss et al., 2004). Benthic indices to translate community structure elements into a quality category summarize environmental status to a number, which allows for management decisions concerning environmental conditions (Borja and Dauer, 2008).

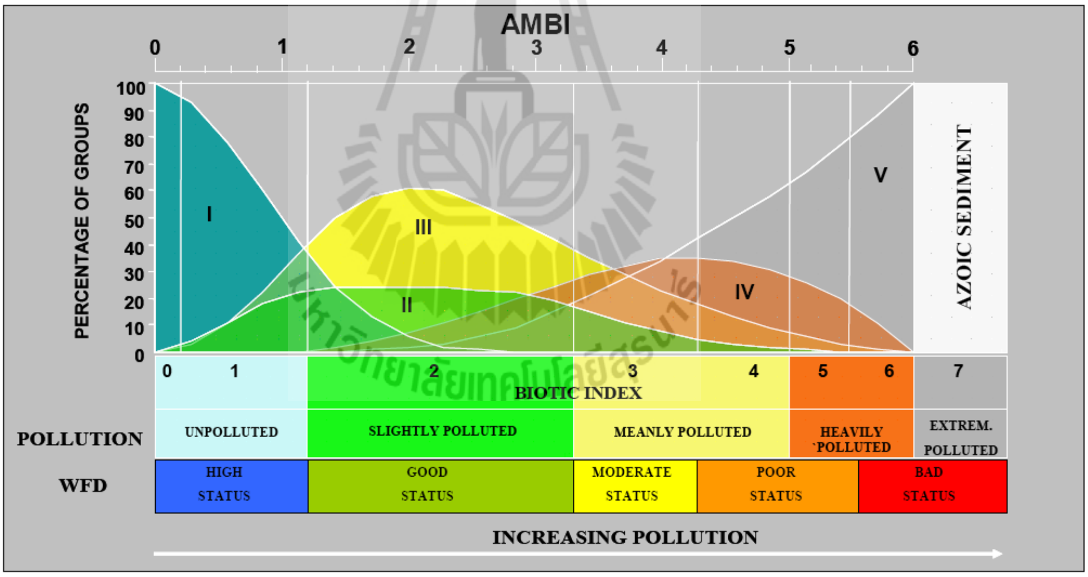


Figure 2.2 The theoretical model, ordination of benthic species into five ecological groups (Group I: species very sensitive; Group II: species in different enrichment; Group III: species tolerant; Group IV: second-order opportunistic species; Group V: first-order opportunistic species), according to their sensitivity to an increasing pollution gradient (Borja et al., 2000).

Table 2.3 List of species and taxa that have been found in European estuarine and coastal systems.

	Taxa	Sensitivity of pollution groups*
Polychaetes	*Ampharete acutifrons*	I
	Amphitrite cirrata	I
	Amphitrite edwardsi	I
	Amphitrite variabilis	I
	Amphitritides gracilis	I
	Ancistrosyllis groenlandica	I
	Apharoditidae sp.	I
	Aponuphis bilineata	II
	Brada villosa	I
	Capitella capitata	V
	Caulleriella caputesocis	III
	Chaetopterus variopedatus	I
	Chaetozone setosa	IV
	Cirratulidae sp.	III
	Dasybranchus sp.	III
	Eunereis longissima	III
	Eunice vittata	II
	Eupolymnia nebulosa	III
	Glycera capitata	II
	Glycera convoluta	II

Table 2.3 (Continued) List of species and taxa that have been found in European estuarine and coastal systems.

Taxa	Sensitivity of pollution groups*
Glycera rouxii	II
Glycera unicornis	II
Goniada maculata	II
Harmothoe extenuata	II
Harmothoe sp.	II
Heteromastus filiformis	III
Laeonereis glauca	III
Laonice cirrata	III
Lumbrineris fragilis	II
Lumbrineris gracilis	II
Lumbrineris latreilli	II
Lumbrineris tetraura	II
Magelona alleni	I
Magelona papillicornis	I
Magelona sp.	I
Malacoceros fuliginosus	V
Maldana glebifex	II
Marphysa sanguinea	II
Mysta picta	II
Neanthes caudata	IV

Table 2.3 (Continued) List of species and taxa that have been found in European estuarine and coastal systems.

Taxa	Sensitivity of pollution groups*
Neanthes succinea	III
Nephthys hystricis	II
Nephthys incisa	II
Nereis lamellosa	III
Nereis sp.	III
Notomastus sp.	III
Ophiodromus flexuosus	II
Owenia fusiformis	I
Pectinaria auricoma	I
Pectinaria koreni	I
Pherusa plumosa	I
Phyllodoce laminosa	II
Phyllodoce lineata	II
Phylo foetida	II
Piromis eruca	I
Pista cristata	I
Polydora caeca	IV
Polydora ciliate	IV
Polydora flava	IV
Polydora hoplura	IV

Table 2.3 (Continued) List of species and taxa that have been found in European estuarine and coastal systems.

	Taxa	Sensitivity of pollution groups*
	Polynoidae sp.	II
	Pomatoceros triqueter	II
	Prionospio cirrifera	IV
	Pseudopolydora antennata	IV
	Sabellidae sp.	I
	Sabellides octocirrata	II
	Serpula vermicularis	II
	Spiochaetopterus costarum	III
	Spiophanes bombyx	III
	Spiophanes kroyeri	III
	Sternaspis scutata	III
	Sthenelaia boa	II
	Sthenolepis hyleni	II
	Terebella lapidaria	I
	Terebellidae sp.	I
	Terabellides stroemi	I
Mollusks	*Abra alba*	III
	Abra nitida	III
	Abra prismatica	III
	Abra segmentum	III

Table 2.3 (Continued) List of species and taxa that have been found in European estuarine and coastal systems.

Taxa	Sensitivity of pollution groups*
Abra tenuis	III
Acanthcardia paucicostata	I
Anodontia fragilis	II
Anomia ephippium	I
Aporrhais pespelecani	I
Atrina pectinata	I
Azorinus chamasolen	I
Calyptraea chinensis	I
Cerastoderma edule	III
Cerastoderma glaucum	III
Cerastoderma gibba	III
Cylichnina umbilicata	I
Dentalium inaequicostatum	I
Diplodonta rotundata	I
Dosinia lupinus	I
Euspira guillemini	II
Euspira nitida	II
Gastrana fragilis	I
Hiatella arctica	I
Laevicardium oblongum	I

Table 2.3 (Continued) List of species and taxa that have been found in European estuarine and coastal systems.

Taxa	Sensitivity of pollution groups*
Loripes lacteus	I
Lucinella divaricata	I
Modiolarca subpicta	I
Myrtea spinifera	I
Mysella bidentata	I
Mysia undata	I
Mytilaster minimus	I
Mytilus galloprovincialis	II
Nassarius incrassatus	II
Nassarius pygmaeus	II
Nassarius reticulatus	II
Nucula nucleus	I
Nucula sulcata	I
Nuculana pella	II
Ostrea edulis	II
Paphia aurea	I
Parvicardium exiguum	I
Phaxas adriaticus	I
Philine aperta	II
Pholas dactylus	I

Table 2.3 (Continued) List of species and taxa that have been found in European estuarine and coastal systems.

	Taxa	Sensitivity of pollution groups*
	Spisula subtruncata	I
	Pitar rudis	I
	Plagiocardium papillosum	I
	Pododesmus patelliformis	I
	Scapharca inaequivalvis	II
	Solemya togata	I
	Tapes decussatus	I
	Tellimya ferruginosa	II
	Tellina distorta	II
	Tellina nitida	I
	Tellina serrata	I
	Tellina tenuis	I
	Thyasira flexuosa	III
	Turritella communis	I
	Venus verrucosa	I
Crustaceans	*Brachynotus gemmellari*	I
	Brachynotus sexdentatus	I
	Decapoda sp.	I
	Galathea intermedia	I
	Inachus comunissimus	I

Table 2.3 (Continued) List of species and taxa that have been found in European estuarine and coastal systems.

	Taxa	Sensitivity of pollution groups*
	Macropodia rostrata	I
	Philocheras bispinosus	I
	Pilumnus hirtellus	I
	Pisidia longicornis	I
	Processa sp.	I
	Sicyonia carinata	I
	Upogebia deltaura	I
	Upogebia pusilla	I
	Upogebia sp.	I
Echinoderms	*Amphiura chiajei*	I
	Astropecten aranciacus	I
	Ophiothrix quinquemaculata	II
	Opiura albida	II
	Ophiura grubei	II
	Ophiura texturata	II
	Psammechinus microtuberculatus	I
	Trachythyone elongata	I
	Trachyone tergestina	I

Sources: Modified from Borja et al. (2000) and Solis-Weiss et al. (2004)

Note: *Sensitivity of pollution groups

I = Species very sensitive to organic enrichment, intolerant to pollution;

II = Species indifferent to enrichment; III = Species tolerant to enrichment, slightly unbalanced environment; IV = Second-order opportunistic species, slight to pronounced unbalanced environment; V = First order opportunistic species, pronounced unbalanced environments

2.7 Studies of benthic macrofauna in Thailand

The studies on benthic macrofauna in Thailand had been reported both in Gulf of Thailand and Andaman Sea. The studied areas were in seagrass beds (Bantiwiwatkul, Pornchai, Rikadee, Rachaderm, and Daotun, 2010b; Jantharakhantee and Aryuthaka, 2007; To-on, 2002a; Vongpanich and Ruangkaew, 2010), mangrove areas (Vongpanich, 2008), off shore (Chantananthawej and Bussarawit, 1987), islands (Bantiwiwatkul, Pornchai, Polpayu and Wichianpet, 2010a; Rodcharoen, 2009; To-on, 2002b), salt lakes (Aungsupanich, 2004; Puttapreecha, 2009), estuary (Benjabanpot, 2007; Jualaong, Kan-atireklap, and Paipongpaew, 2010; Thongsriphong, 1999) and beaches and coastal areas (Jaritkuan and Mantajit, 1991; Meksumpun and Meksumpun, 1999; Putchakarn, 2005; Yamuen, 2007).

The density of benthic macrofauna on the coastal seabed of the Andaman Sea ranged from 200 to 1,000 individuals/m^2. The majority were polychaetes followed by crustaceans, echinoderms, mollusks and chordates. The biomass in the deeper offshore area (30 to 75 m depth) was about 3.9 times higher in the onshore zone. Grain size composition and organic content of sediment proved to be poorly correlated with total abundance and biomass (Chatananthawej and Bussarawit, 1987).

The distribution and abundance of main groups of benthic macrofauna in seagrass areas of the Gulf of Thailand were polychaetes, mollusks and crustaceans. The abundance and diversity of macrofauna were relative higher in seagrass areas compared to areas with no seagrass (To-on, 2002a). Major polychaete families were Orbiniidae, Maldanidae, Glyceridae, Syllidae, Nereididae, Spionidae, Capitellidae and Paraonidae (Bantiwiwatkul et al., 2010b). The abundance of macrofauna ranged from 2,017 to 24,253 individuals/m^2 belonging to 44 species. In Andaman seagrass bed at Phang-nga province, 14 macrobenthic groups were found. Of which the three dominant groups were polychaetes, amphipods and sipunculids (Jantharakhantee and Aryuthaka, 2007), whereas, Vongpanich and Ruangkaew (2010) found that the major families of polychaetes were Opheliidae and Eunicidae.

Benthic macrofauna can be recovered in mangrove plantation areas. An older mangrove forest has high species richness but lower density of macrobenthos (Vongpanich, 2008). Moreover, benthic macrofauna related to environmetal factors. Jaritkuan and Mantajit (1991) considered that at Pattaya to Leam Chabang port had low benthic macrofauna groups. The average density of benthic macrofauna was 127 individuals/m^2. Benjabanpot (2007) reported that the abundance and biomass of Polychaeta had a negative relationship with turbidity. The abundance and biomass of Polychaeta and Crustacea had a positive relationship with salinity and total dissolved solids in water. Benthic macrofauna and its environmental factors at the human activities area were correlated. Crustacean population were higher abundant than polychaetes along non-pristine areas. In a high human activity area was different, polychaetes were the dominant group. The trend of fauna distribution corresponded with dissolved oxygen. Some macrobenthic fauna can be use as useful indicators of pollution in the Outer Songkhla Lake in particular those associated with organic enrichment area namely oligochaete *Doliodrilus* sp. and polychaete *Parheteromastus* juvenile. Abundance of *Perinereis* sp. was negatively correlated with organic content of bottom sediments. *Notomastus* sp. was positively correlated with high sediment organic levels (Meksumpun and Meksumpun, 1999). Whereas, two polychaetes, *Nereis* sp. and *Parheteromastus* sp. were proposed as the indicator species of organic rich sediments of high organic carbon, nitrogen compound and available phosphorus content (Thongsripong, 1999).

Nowadays, the southern Andaman coastal areas are rapidly developing and increasing of pollution. Examination of the macrobenthic communities can be signaled about the local environments. The development of biological indicators as a tool for the knowledge of the environment and hence the protection of biological diversity of coastal and marine ecosystem should be taken into account. Although there are many studies of benthic macrofauna in Thailand, the study on biological indicators of beaches are neckless. Then this research is a pilot study on species, communities and distribution of benthic macrofauna along the anthropogenic and non-anthropogenic beaches in Krabi, Trang and Satun provinces. This knowledge will provide preliminary data regarding benthic macrofana assemblages as biological indicators to evaluate beach quality in the southern Andaman Sea coast of Thailand.

CHAPTER III

MATERIALS AND METHODS

3.1 Selected areas

The study on beach quality assessment using benthic macrofauna along the southern Andaman Sea coast of Thailand, to meet the objectives, the selected areas of the research were as follows:

Krabi province, landscape is undulating with hills and mountains. Coastline of Krabi is alternatively bays and capes. Much of the coastal area is covered by mangrove forest.

Trang province, magnificent coastal as it long coastline stretches along the Andaman Sea. In addition, the province has two major rivers flowing through it, the Trang River and the Palian River.

Satun province, most of the area is mountainous, with plains in the centre near the coast. Brooks lie in the east of Satun, mangroves can be found along the coast.

Krabi, Trang and Satun provinces were selected which represent anthropogenic and non-anthropogenic impacted beaches. These provinces have tourism areas and provide many attractive beaches where there are increasing population and coastal development. The selected provinces as shown in Figure 3.1.

The southern Andaman Sea coast of Thailand has particular oceanographic characteristics. The coastal is characterized by geologic nature of landforms. Krabi, Trang and Satun provinces are sandy to sandy/muddy beaches and dunes. The coastal wetland is tidal flat and marshes. Rocky coast, cliff coast and islands occurred in Trang and Krabi provinces, whereas Satun province has a long sandy/muddy intertidal flat but on the landward side is sandy. Selected beaches and length of each beach (in parenthesis) were as follows:

1) Krabi province: Nopparatthara beach (1.6 km), Ao-nang beach (1.3 km), and Nam Mao beach (2.7 km)

2) Trang province: Pak Meng beach (6.0 km), Chao Mai beach (3.6 km), and Yong Ling beach (2.7 km)

3) Satun province: Pak Bara beach (3.2 km), and Pak Bang beach (6.1 km)

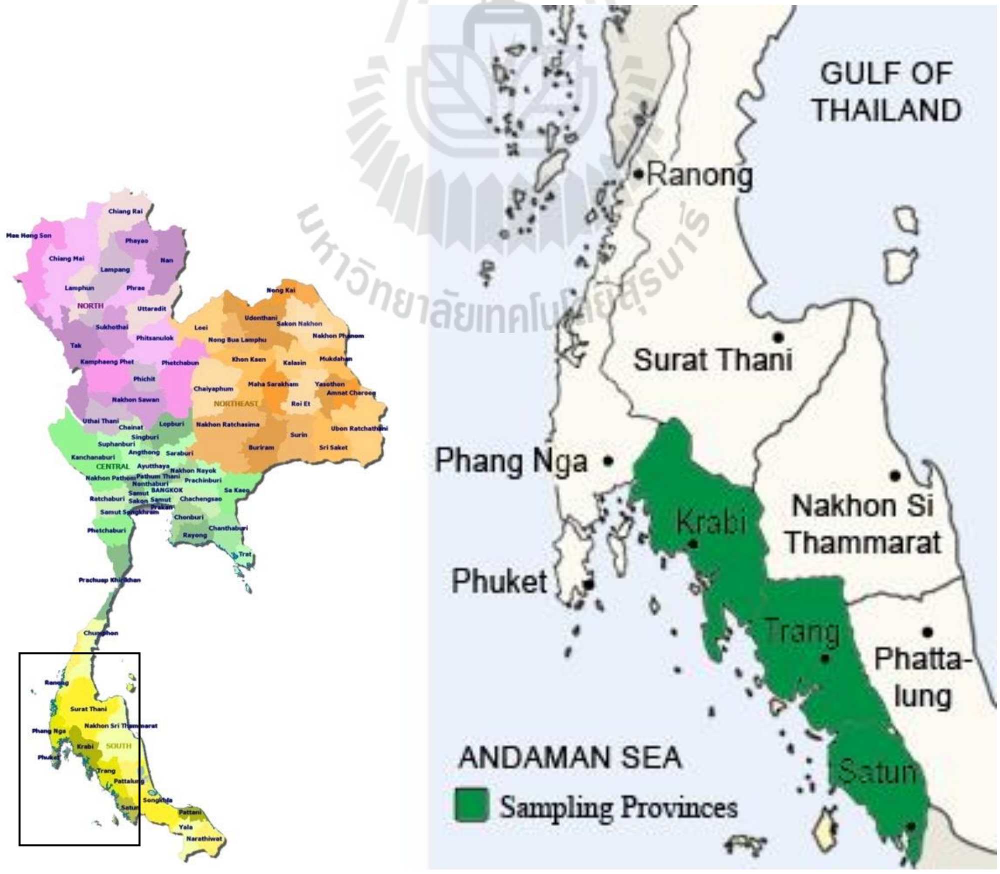


Figure 3.1 The study sites (modified from Map of Thailand, 2010).

3.1.1 Site description

3.1.1.1 Sampling beaches in Krabi province

Nopparatthara beach located in the Nopparatthara national park. The beach has three sections. The first is close to Ao-nang beach. Rocky coast and a small mountain occurred as a headland between the two beaches. Rocky barrier and road were constructed on the middle part of the beach. The end section of the beach is across a canal, adjacent to the Nopparatthara national park office. The beach has a very shallow intertidal flat.

Ao-nang beach is about 3 km southward of Nopparatthara beach. The beach is very famous and is a tourist attraction because there is a pier to many famous islands. Human uses in the area have been characterized by the increasing socioeconomic importance of recreational activities. Many souvenir shops, small resorts and restaurants generated a town there. A concrete wall was constructed at the beachfront to protect the land. This beach has moderate sandy slope and there located between two mountains where sediments are settled near the both end of the beach.

Nam Mao beach is separated from Ao-nang beach by a mountain which located at the southeast of Ao-nang beach. This mainland is vegetative areas. Rocky patches and corals scatter on the southward of the beach. A sampling station (KB-NM st3) located at the south of the beach which a drain pipe directly discharged from the land.

Sediment, water and benthic macrofauna samples were collected from 3 stations from Nopparatthara beach, 3 stations from Ao-nang beach and 3 stations from Nam Mao beach. The beach locations and the studied beaches are shown in Figure 3.2, 3.5 (a), 3.5 (b) and 3.5 (c).

3.1.1.2 Sampling beaches in Trang province

Pak Meng beach is about 6 km long. A pier is located at the north side of the beach which is for traveling to many islands. It is a very shallow sandy beach where mangrove areas and canals are found on both ends of the beach. At the south, a stone bank was build to protect the shore from the wave current. Small resorts and restaurants are situated along the upland of the beach. At the northward, the beach is partially protected from the waves of the open sea by the Khao Meng island.

Chao Mai beach is located southward of Pak Meng beach. Both beaches are separated by a canal running from an estuary. It has a long shallow sandy beach, below which is sandy/muddy flat. This beach is protected by Chao Mai National Park which is situated on the beachfront. The beach extends from Pak Meng beach to a small mountain at the south where the substrate becomes predominantly muddy.

Yong Ling beach is shorter than Pak Meng and Chao Mai beaches. The beach is separated from Chao Mai beach by a vegetative area. It is under management of Chao Mai national park, so this beach has not been disturbed and only one construction there. The upper part of the beach is slight steep sandy slope but the lower part of the beach is moderated steep sandy slope. On the northern side, a small mountain located there.

Sediment, water and benthic macrofauna samples were collected from 6 stations from Pak Meng beach, 3 stations from Chao Mai beach and

3 stations from Yong Ling beach. The beach locations and the studied beaches are shown in Figure 3.3, 3.5 (d), 3.5 (e) and 3.5 (f).

3.1.1.3 Sampling beaches in Satun province

Pak Bara beach is about 3 km long where the Pak Bara pier is located on the northern side of the beach. It has a long sandy/muddy intertidal flat but on the landward side is sandy. Small resorts and restaurants are situated along the upland of the beach. A stone bank was constructed at the southward end of the beach.

Pak Bang beach is about 6 km long. It has long, moderate sandy slope, below which is a long muddy flat. The flat is never drained completely even during lowest tides. On the southern side of the beach is scattered with rocky patches. On the terrestrial area is Ban Pak Bang village consisted of villager's houses, vegetative areas and a flood plain. Fisheries are conducted in the south side of the beach, mainly shrimp culture and fishing.

Sediment, water and benthic macrofauna samples were collected from 3 stations from Pak Bara beach started from the pier to the southward and 6 stations from Pak Bang beach started from one end of the beach to the another end of the beach. The beach locations and the studied beaches are shown in Figure 3.4, 3.5 (g) and 3.5 (h).

The numbers, the codes and the global position of the sampling stations in Krabi, Trang and Satun provinces are shown in Table 3.1.

Table 3.1 The numbers, the codes and the global positions of the sampling stations.

Province/ Name of the beaches	Length (km)	Number of stations	Code of stations	Global positions (UTM)
Krabi				
Nopparatthara	1.6	3	KB-NT st1	47P x 0478007y 0889371
			KB-NT st2	47P x 0478504 y 0889243
			KB-NT st3	47P x 0478933 y 0889061
Ao-nang	1.3	3	KB-AN st1	47P x 0479840 y 0888175
			KB-AN st2	47P x 0480144 y 0887939
			KB-AN st3	47P x 0480453 y 0887646
Nam Mao	2.7	3	KB-NM st1	47P x 0485929 y 0889716
			KB-NM st2	47P x 0486142 y 0886907
			KB-NM st3	47P x 0486142 y 0886907
Trang				
Pak Meng	6.0	6	TR-PM st1	47N x 0534489 y 0829622
			TR-PM st2	47N x 0535316 y 0829226
			TR-PM st3	47N x 0535572 y 0829037
			TR-PM st4	47N x 0536063 y 0828464
			TR-PM st5	47N x 0536317 y 0827948
			TR-PM st6	47N x 0536516 y 0827352
Chao Mai	3.6	3	TR-CM st1	47N x 0538058 y 0819549
			TR-CM st2	47N x 0538124 y 0819849
			TR-CM st3	47N x 0538157y 0820172
Yong Ling	2.7	3	TR-YL st1	47N x 0541146 y 0811480
			TR-YL st2	47N x 0541481 y 0811306
			TR-YL st3	47N x 0541706 y 0811019
Satun				
Pak Bara	3.2	3	ST-PR st1	47N x 0579710 y 0757872
			ST-PR st2	47N x 0580430 y 0757535
			ST-PR st3	47N x 0580829 y 0757389

Table 3.1 (Continued) The numbers, the codes and the global positions of the sampling stations.

Province/ Name of the beaches	Length (km)	Number of stations	Code of stations	Global positions (UTM)
Pak Bang	6.1	6	ST-BB st1	47N x 0586990 y 0754964
			ST-BB st2	47N x 0587369 y 0754435
			ST-BB st3	47N x 0587708 y 0753904
			ST-BB st4	47N x 0587955 y 0753461
			ST-BB st5	47N x 0588162 y 0753044
			ST-BB st6	47N x 0588303 y 0752719

Figure 3.2 The studied beach locations in Krabi province including Nopparathara, Ao-nang and Nam Mao beaches (modified from Google earth maps, 2012).

Figure 3.3 The studied beach locations in Trang province including Pak Meng, Chao Mai and Yong Ling beaches (modified from Google earth maps, 2012).

Figure 3.4 The studied beach locations in Satun province including Pak Bara and Pak Bang beaches (modified from Google earth maps, 2012).

(a) (b)

(c) (d)

(e) (f)

Figure 3.5 The studied beaches (a) Nopparatthara beach, (b) Ao-nang beach, (c) Nam Mao beach, (d) Pak Meng beach, (e) Chao Mai beach, (f) Yong Ling beach, (g) Pak Bara beach, and (h) Pak Bang beach.

(g)

(h)

Figure 3.5 (Continued) The studied beaches (a) Nopparatthara beach, (b) Ao-nang beach, (c) Nam Mao beach, (d) Pak Meng beach, (e) Chao Mai beach, (f) Yong Ling beach, (g) Pak Bara beach, and (h) Pak Bang beach.

3.2 Sample collection, identification and analysis

3.2.1 Water sampling and analysis

Based on the limiting factors for the survival of aquatic animals and water quality indices of marine and coastal water, eight water parameters were selected and measured in this study. They were pH, dissolved oxygen (DO), temperature, salinity, nitrate, phosphate, turbidity and biochemical oxygen demand (BOD). Water quality including dissolved oxygen, salinity, temperature and pH were recorded *in situ* by using multi-probe instrument (YSI 85 dissolved oxygen/conductivity meter and YSI 60 pH meter, USA). Those water qualities were measured along the benthic macrofauna sampling transects on each beach. Subsequently, an average data of each station were investigated. Pool water samples of each station were taken at random points along the perpendicular to a transect line. Water samples in each station were stocked with ice during fieldwork and brought back to a laboratory for turbidity, BOD and nutrients (phosphate and nitrate) analysis. A bench top turbidity meter was used for turbidity analysis (CyberScan TB1000, Netherland). The Winkler method for measuring dissolved oxygen in BOD analysis was utilized. The colorimetric method was used for phosphate and nitrate analysis. The total phosphate was analysed in a reaction with molybdate in the presence of ascorbic acid, and total phosphate in the blue compound was measured with UV absorption at 690 nm. Nitrate was reduced to nitrite by hydrazine in alkaline solution with copper as catalyst, and the nitrite then reacts with sulphanilamide and *N*-(1-naphthyl)-ethylenediamine dihydrochloride to form a pink compound and it was measured at 550 nm (Hitachi U2001 UV-VIS spectrophotometer, Japan). Water sample analysis in the laboratory followed the methods of APHA, AWWA and WEF (2005).

3.2.2 Sediment analysis

In addition to examining water variables, it is important to examine the sediment. In this study, the sediment variables were including pH, nutrients (nitrate and phosphate), organic matter content and sediment particle sizes.

Sediment pH in each station was recorded *in situ* by using a handset soil pH meter. Surface sediments were collected for sediment grain size, nutrients and organic matter content analyses. Sediment grain size structure was determined by dry sieving, using vibrating-sieving machine and a sieve series of resolution 0.5 phi. Before sieving, each sample was washed with deionized water over a filter paper to remove salt and then oven-dried at 80 ^{o}C for 24 h. The percentage weights of graval, sand and silt were calculated for each sediment sample, and the statistical parameters of the grain size distribution were calculated using moment and the sediment particles size fractions were determined following a standard mechanic sieving procedure and classified according to Wentworth scale. The classified particle sizes are: graval (∅ > 2 mm), very coarse sand (2 mm > ∅ > 1 mm), coarse sand (1 mm > ∅ > 0.5 mm), medium sand (0.5 mm > ∅ > 0.25 mm), fine sand (0.25 mm > ∅ > 0.125 mm), very fine sand (0.125 mm > ∅ > 0.062 mm) and silt (∅ < 0.062 mm) (Marine Environmental Laboratory, 1995 and De Pas, Neto, Marques, and Laborda, 2008).

Sediment for the analysis of nutrients and organic content was collected at a depth of 15 cm and stocked with ice during fieldwork and then frozen at -20 ^{o}C in the laboratory. Nitrate and phosphate in sediments were analyzed in a laboratory by the methods of APHA, AWWA and WEF (2005). The percentage of organic matter content in sediment was estimated by loss on ignition (500 ^{o}C for 24 h) by Eleftheriou and McIntyre (2005) method.

3.2.3 Sampling methods for benthic macrofauna

Benthic macrofauna were sampled once every season during the Northeast monsoon (mid October to mid February), in the dry season (mid February to mid May) and during the Southwest monsoon (mid May to mid October). Quadrate sampling (Rodil and Lastra, 2004) was used during low tide range at intertidal zone. The area of quadrat sampling as necessary to obtain >95% of macrofauna species living on exposed sandy beaches. The quadrate sampling area in each station accounted 2.25 m^2 (Jaramillo, McLanchlan, and Dugan, 1995). At each sampling point, a 0.5x0.5 m^2 quadrate was used. The sample was collected along the beach every 500 m long with three transects in each station as shown in Figure 3.6. Sampling positions were estimated by global positioning system (GPS). Each sample was sieved in the field using a 1000 μm mesh. The materials retained on the sieve were fixed in 4% buffer formalin according to Worsfold and Hall (2010) method and the samples were brought back to a laboratory for sorting and taxonomic identification.

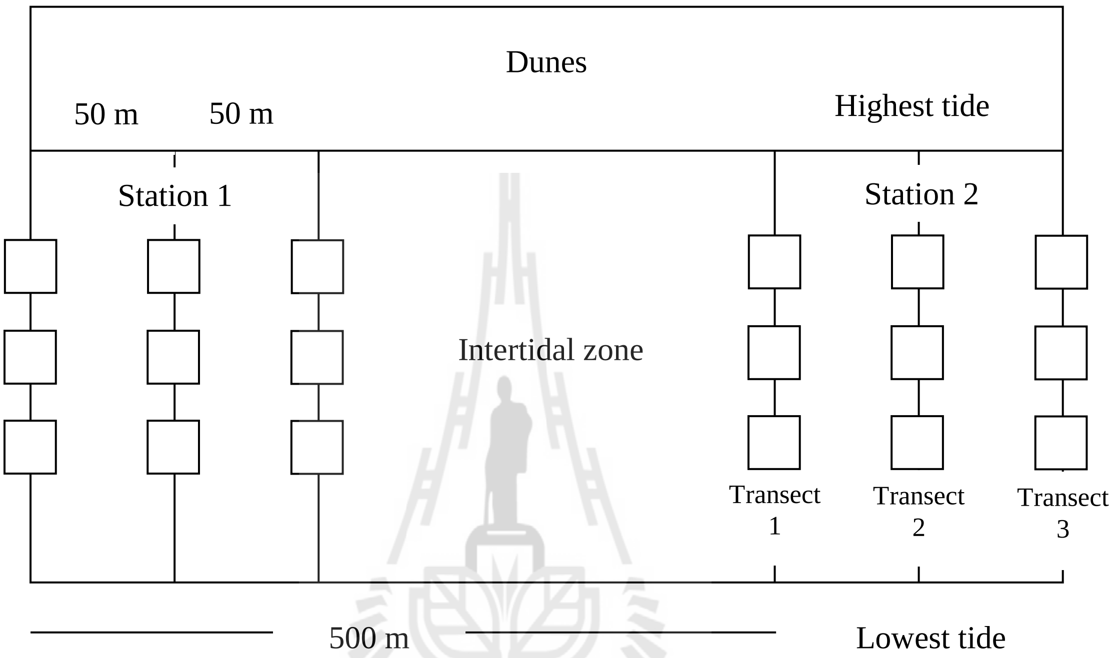


Figure 3.6 Sampling scheme showing the position of transect and stations of the sampling areas.

3.2.4 Laboratory analysis for benthic macrofauna samples

Sorting of benthic samples was conducted in the field with the use of a white tray, pen brushes and magnifying lens for preliminary identification by Collin et al. (2005) and Hibberd and Moore (2009). A remain of the sieved samples was taken into the white tray at a time and sorted with the aid of the magnifying lens for clearer vision. The sorted samples from each sampling station were put in a transparent glass bottle and were preserved again in 4% buffer formalin. Crustaceans were preserved in 70% ethanol. All specimens were taken to the laboratory for further analysis.

3.2.5 Identification and classification of the benthic macrofauna samples

In the laboratory, the benthic macrofauna samples were studied under a stereo microscope (Olympus SZX7, Japan) and a compound microscope (Olympus BX50, Japan) with the DP27 camera and the Cellsens Dimension program to magnify the detail of the specimens. The animals were identified and individuals of the same species or taxon in each station were enumerated under the microscope. All benthic macrofauna were identified to the lowest practicable taxa, ranging from phylum to species. To increase the visibility of certain specimen details, some crustacean families were air dried before identification. The benthic macrofauna were grouped and identified using the keys to marine invertebrates of the Wood Hole region of Marine Biology Laboratory (1964), the identification manuals and guides of Environmental Monitoring and Support Laboratory Office of Research and Development (1986), marine animal identification online of ETI Bioinformatics (2000) and polychaete identification keys of Natural History Museum (2011). The identification of polychaete families and genera followed Fauchald (1977). The polychaete species identification based on previous reports. The following keys were used for polychaete species identification: Glyceridae and Goniadidae followed Boggemann, Bienhold, and Goudron (2011) and Boggemann and Eible-Jacobsen (2002), Lumbrineridae (Fauchald, 1977; Oug, 2002), Nereididae (Tan and Chou, 1994; Chan, 2009), Onuphidae (Paxton, 1986), Orbiniidae (Hutchings and Murray, 1984; Mackie, 1991), Sternaspidae (Sendall and Salazar-Vallejo, 2013), Opheliidae (Fauchald, 1977), Phyllodocidae and Scalibregmatidae (Fauchald, 1977; Uebelacker and Jones, 1984), Spionidae (Delgado-Blas, 2006; Uebelacker and Johnson, 1984; Williams, 2007; Yokoyama, 2007; Yokoyama and Sukumaran, 2012), Capitellidae (Green, 2002; Fauvel, 1989), Magelonidae (Blake, 1996; Mortimer, Cassà, Martin and Gil, 2012; Mortimer and Mackie, 2003; Mortimer and Mackie, 2009), Maldanidae (Fauval, 1953; Garwood, 2007; Gillet, 1953), Cirratulidae (Bush, 2006; Cinar, 2007; Dean and Blake, 2009; Elias and Rivero, 2009), Pilargidae (Dean, 1998; Moreira and Parapar, 2002), Eunicidae (Glasby and Hutchings, 2010), Sabellidae (Fitzhugh, 1989), Oweniidae (Cupa, Parapar, and Hutchings, 2012), Eulepethidae (Pettibone, 1969), Pisionidae (Yamanashi, 1998), Amphinomidae (Arias, Barroso, Anadon, and Paiva, 2013; Barroso and Paiva, 2007) Terebellidae (Jirkov and Leontovich, 2013) and Polynoidae (Fauchald, 1977; Naeini and Rahimian, 2009). The identification of bivalves and gastropods is based on Poutiers (1998) and Swennen et al. (2001). The identification of marine crustaceans is based on Allen (2010), Allen, Clark, Paterson, Hawkins, and Aryuthaka (2011), Huang, Yu, and Takeda (1992), Kemp (1919), Komai, Reshmi, and Kumar (2013) and Tan and Ng (1999). The identification of Diogenidae is based on McLaughlin (2002).

3.3 Data analysis

3.3.1 Statistical analysis

PASW statistics 18 windows applications and Microsoft Excel package were used for preliminary data processing and all statistical analyses. PRIMER 6 (Plymouth Routines in Multivariate Ecological Research) package (Clarke and Warwick, 2001) which is a copyright from Rajamangala University of Technology, Trang Campus was used for cluster analysis, multi-dimensional scaling (MDS) and Principle Component Analysis (PCA).

Benthic macrofauna structures were analysed using the calculation diversity indices such as Margalef richness index, Shannon-Wiener index, Species equitability or Evenness index and Dominance species index.

3.3.2 Margalef richness index (D)

This index provides a measure of species richness that is the number of species encountered against the total number of individuals encountered. It is calculated according to the following equation (Margalef, 1951 as cited in Balogun, Ladigbolu, and Ariyo, 2011)

$$D = \frac{(S-1)}{\log_2 N}$$

Where: D = Margalef richness index

S = the number of species

N = the total number of individuals in the sample.

3.3.3 Shannon-Wiener diversity index (H)

This is a measure of faunal diversity. It usually indicates the degree of uncertainty involved in predicting the species identified of randomly selected individuals. It is calculated using the following equation (Shannon and Weiner, 1949 as cited in Nkwoji et al., 2010)

$$H = -\sum Pi \log Pi$$

Where: H = Diversity index

Pi = Number of individuals of a species/Total number of species in a station.

Log Pi = Natural log of Pi

3.3.4 Species equitability or Evenness index (J)

The species equitability or evenness index (J) is calculated using the following equation (Pielou, 1966 as cited in Balogun et al., 2011)

$$J = \frac{H}{\log_2 S}$$

Where: J = Equitability index

H = Shannon-Weiner index

S = Number of species in a population

3.3.5 Species dominance index (C)

The species dominance index (C) is calculated using the following equation (Simpson, 1949 as cited in Balogun et al., 2011)

$$C = \sum Pi^2$$

Where: C = Species dominance index

3.3.6 Synthesis of biotic and environmental data

After species identification, taxa occurring were grouped into larger taxonomic groups for analysis in phyla abundance and all species abundance were calculated in species diversity. All abundance data, biodiversity index, water qualities and sediment qualities were sorted in Microsoft Excel package. Species diversities were calculated by above formulas for processing into biotic and environmental relations. The similarity analysis of differences between stations was explored by cluster analysis and Multi-dimensional scaling (MDS). The nearest-neighbor approach was used for hierarchical clustering, prior to MDS analysis. The Bray-Curtis dissimilarity measure was used for cluster analysis (Bray and Curtis, 1957 as cited in Somerfield, 2008). The tool of hierarchical cluster analysis was used for station grouping diagrams and for consistent comparison with MDS. Stepwise multiple regression analysis and Principal Component Analysis (PCA) were used to determine the benthic macrofauna communities in relation to the environmental data. Benthic macrofauna, water qualities and sediment qualities data were natural log or root transformed prior to statistical analysis by the PRIMER. Equations of benthic macrofauna and environmental quality coordination were investigated by stepwise multiple regression analysis.

3.3.7 Ecological grouping and AMBI index application for beach quality assessment

Species abundance, diversity and ecological status of the benthic macrofauna communities were used as principal data to establish environmental status classification in each station. All detected individuals were classified into one of the five ecological groups proposed by Borja et al. (2000). It was mainly based on the ecological list presented in AMBI software version 5. The newest version is downloadable from AZTI website (http://ambi.azti.es/). In order to classify the disturbance and environmental status, the software was applied to use in this study. The software provides a list of 8,000 taxa representative of soft bottom communities present at estuarine and coastal ecosystems. The instructions of indicator package (AMBI) were used for the application (Borja, Mader, and Muxika, 2012).

CHAPTER IV

RESULTS AND DISCUSSIONS

The study on beach quality assessment using benthic macrofauna along the southern Andaman Sea coast of Thailand was conducted in 2012-2013. Water, sediment, and sediment particle size variables were measured in all seasons. Benthic macrofauna assemblages, biological indices and the relationships between the ecological and the biological data were investigated. Furthermore, the AMBI program was applied to determine the studied beach health status. The results of this study are as follows:

4.1 Water variables

Based on the limiting factors for the survival of aquatic animals and water quality indices of marine and coastal water, eight water parameters were selected and measured in this study. They were pH, dissolved oxygen (DO), temperature, salinity, nitrate, phosphate, turbidity and Biochemical Oxygen Demand (BOD). The results of the water quality measurement are as follow:

4.1.1 pH

The mean pH of the water collected from the intertidal zone of 8 beaches in all 3 provinces showed similar results. The water pH of all beaches in Krabi province during the Southwest monsoon (September - October, 2012), the Northeast monsoon (December, 2012) and the summer season (March - April, 2013) ranged from 7.5±0.01 - 8.1±0.02. These recorded pH of each beach were in the range of Class 3 and Class 4 of Thailand Marine Water Quality Standard (7.0 - 8.5) (Pollution Control Department, 2007). In Trang province, the pH ranged from 6.7±0.2 - 8.7±0.02 and values of almost all the beaches were not exceeding the standard except during the Northeast monsoon. The mean pH of all sampling stations in Pak Meng beach in the Northeast monsoon slightly exceeded the standard and only 1 station in Yong Ling beach (TR-YL st2) the water quality slightly exceeded the standard. In Satun province, the mean pH ranged between 7.4±0.02 and 8.6±0.1. During the Northeast monsoon, pH in a station (ST-BB st6) slightly exceeded the standard. The water pH values of 30 stations in 3 seasons are shown in Figure A1.1. The pH, one of the important environmental characteristics, decides the survival, metabolism, physiology and growth of aquatic organisms. The optimum range of pH for maximum growth and production of some crustaceans is 6.8-8.7. pH is influenced by acidity of the bottom sediment and biological activities. High pH may result from high rate of photosynthesis by dense phytoplankton blooms. The pH higher than 7 but lower than 8.5 is the ideal for biological productivity, but pH at less than 4 is detrimental to aquatic life (Hinga, 2002; Kim, Barry, and Micleli, 2013).

4.1.2 Dissolved oxygen (DO)

The mean DO levels in some study stations were lower than the Thailand Marine Water Quality Standard (not less than 4.0 mg/L). In Krabi province, the mean of DO ranged between 1.3±0.01 and 5.5±0.2 mg/L. The DO in Trang province ranged from 2.2±0.01 - 6.8±0.03 mg/L while in Satun province ranged from 1.7±0.2 - 6.7±0.2 mg/L. However, it could be noted that the slightly low water quality results may be due to the sampling method. In this study, the water samples were collected near the bottom areas of the beach. The DO levels were lower than the surface areas and they were taken during the low tide in which the wave current was lower than the high tide. The DO of 30 stations in 3 seasons are shown in Figure A1.2. DO concentration is governed by various physical, chemical, and biological factors such as BOD and benthic oxygen dynamics (Vander, 1997). Usually high dissolved oxygen values indicate healthy and stable environments, which can advocate a diversity of organisms. Diaz and Rosenberg (2008) stated that DO concentrations below 1.5 ml/L were shown to lead to an aberrant behavior of benthic fauna and even to mass mortality. Diaz and Rosenberg (1995) reported that less motile groups of large species can tolerate lower DO concentrations and no large species, pelagic or benthic, can survive in concentrations below 0.3 ml/L. Many infaunal species leave the sediment at oxygen concentrations below 0.7 ml/L (12% saturation). Hypoxia-stressed benthos is typified by short-lived, smaller sediment-surface deposit-feeding polychaetes and the absence of marine invertebrates, such as pericaridean crustaceans, bivalves, gastropods and ophiuroids. When oxygen is sufficient to support the benthic macrofauna, small and soft-bodied invertebrates normally predominate. These animals are typically annelids, often with short generation times and elaborate branchial structures. In general, large taxa are more sensitive than small taxa to hypoxia. Crustaceans are typically more sensitive to hypoxia, with lower oxygen thresholds, than annelids and mollusks (Levin et al., 2009). The DO levels in all stations were lower than the recommended DO concentration of 7 mg/L but they still indicated satisfaction for the protection of benthic macrofauna.

4.1.3 Temperature

The mean water temperature of the beaches in Krabi province ranged from 25.2±0.3 - 29.9±0.1 ^{o}C while in Trang province ranged between 27.5±0.1 ^{o}C and 29.9±0.1 ^{o}C. For overall results, water temperature in Satun province was slightly lower than in those 2 provinces. The temperatures were in the range of 26.0±0.5 - 28.4±0.4 ^{o}C. By comparing to the report of marine and coastal water quality from 2011 to 2012 (Pollution Control Department, 2012), the result showed that the temperature was in the ranged of 25-33 ^{o}C. According to the Pollution Control Department (2007), the establishing of marine and coastal water temperature shall not be changed from nature background conditions. So, the temperatures of all stations were not different with the range of the water quality background. In coastal sandy beaches, maximum temperature variations in the intertidal occur on the surface at upper tide levels, and temperatures become more stable toward the sea and down into the sediment. Otherwise, most of the sand body takes on temperatures close to those of the adjacent sea (McLachlan and Brown, 2006). On the basis of limiting factors for aquatic animals, water temperature is probably the most important variable. It affects metabolic activities, growth, feeding, reproduction, distribution and migratory behaviors of aquatic organisms (Diaz and Rosenberg, 1995). Rising temperature will contribute to decrease the average dissolved oxygen in the oceans, and may also affect the oxygen requirements of marine benthic macrofauna (Guevara-Fletcher, Kintz, Mejea-Ladina, and Cortes, 2011). The water temperatures of 30 stations in 3 seasons are shown in Figure A1.3.

4.1.4 Salinity

With few exceptions, salinities during the sampling period at all stations remain relatively constant. The results of all beaches, the mean salinity ranged between 25.0 and 34.0 ppt. The water salinities in Krabi province were in the range of 30.0 – 33.0 ppt. The water salinities in Trang province were in the range of 28.0±0.1 – 34.0 ppt whereas in Satun province were in the range of 25.3±0.6 – 31.7±0.6 ppt. During the Southwest and the Northeast monsoon of the sampling period, the salinities of Trang province were mostly lower than in the summer. Also the results of Satun province, the salinities during monsoon were relatively low except in the Southwest monsoon of sampling station ST-BB st4. For overall results, water salinities of sampling stations in Satun province were relatively lower than in other provinces. These results consider seasonal variability and it could be documented that debased salinities in theses beaches commonly result from water run-off. However, the salinities were considerably in the range of Thailand Marine Water Quality Standard. The salinities of 30 stations in 3 seasons are shown in Figure A1.4. Normally salinity is the total of all salts dissolved in water. The salt content of water affects the distribution of animal communities in marine system, based on the amount of salt in their penetrated environment that they can tolerate. Salinity changes daily with the tides or seasonally with the changing environmental conditions. Salinity can also decrease during major storm events that result in a lot of precipitation (Dunbar, Coates, and Kay 2003). Normally, water salinity range from 24 to 35 ppt (Pollution Control Department, 2012). Constituent in the southern part, Krabi, Trang and Satun provinces are influenced by semi-diurnal tides of approximately 3 m in spring and 1 m in neap tide (Pornpinatepong, 2005). So, these sampling areas are subjected to a relatively large tidal range which affects salinity. Moreover, in the coastal zones, variations of salinity, temperature, and dissolved oxygen in the water-sediment interface are also important (Guevara- Fletcher et al., 2011).

4.1.5 Nitrate (NO_3-N)

Nitrate concentrations in water of all sampling stations of Krabi province ranged from 0.01±0.01 to 4.81±0.44 μg/L. In Nopparatthara beach, at all sampling stations showed low nitrate concentrations in all seasons. They were in the range of 0.01±0.01 - 0.17±0.01 μg/L. Nitrate concentrations of the sampling stations at Ao-Nang beach were higher than at Nopparatthara beach. The nitrate concentrations that higher than 1.00 μg/L presented in some stations of Ao-Nang beach during the Southwest monsoon and the Northeast monsoon. During the Southwest monsoon, the nitrate concentrations were relatively high in KB-AN st1, KB-AN st2, KB-AN st3, KB-NM st2. The mean concentrations were 1.43±0.02, 3.29±0.11, 4.27±0.13 1.76±0.03 μg/L, respectively. During the Northeast monsoon, the nitrate concentrations were higher than in other seasons. At KB-AN st3, KB-NM st1, KB-NM st2 and KB-NM st3, the mean nitrate concentrations were 4.81±0.44, 3.16±0.19, 4.86±1.47 and 3.21±0.01 μg/L, respectively. In Trang province, nitrate concentrations were relatively low. They ranged between 0.03±0.01 and 17.30±0.30 μg/L. At the stations TR-PM st2 and TR-CM st2, nitrate concentrations were recorded higher than 1.00 μg/L in the Southwest monsoon which were 17.3±0.3 and 2.37±0.06, respectively. In Satun province, the results indicated that the nitrate concentrations were relatively high in almost all stations which were in the range of 0.03±0.01 - 31.67±0.58 μg/L. These results were lower than 1.00 μg/L at the station ST-BB st4 in the summer, ST-BB st2 and ST-BB st6 in the Northeast monsoon. The other stations had higher nitrate concentrations which ranged from 1.35±0.28 to 31.67±0.58 μg/L. However, there was observed that nitrate concentrations of all beaches during the sampling period were lower than the Thailand Marine Water Quality Standard Class 3 and Class 4 (shall not exceed 60 μg/L). The nitrate concentrations of 30 stations in 3 seasons are shown in Figure A1.5.

4.1.6 Phosphate (PO_4-P)

Phosphate concentrations in water of all sampling stations in Krabi province were low. They ranged from 0.01±0.001 to 3.45±0.15 μg/L. The phosphate concentrations that higher than 1.00 μg/L presented in 2 stations during the Northeast monsoon. At the station KB-AN st2 and KB-NM st3 were 3.45±0.15 and 1.07±0.11μg/L, respectively. In Trang province, the phosphate concentrations were lower than 1.00 μg/L at all stations whereas in Satun province, the phosphate concentrations were relatively high. At station ST-BB st4, during the Southwest monsoon, the phosphate concentrations was 6.28±4.5 μg/L. During the summer, the phosphate concentrations were high in 8 of 9 stations with the exception at ST-BB st4. The concentrations of the 8 stations were in the range of 2.27±0.20 – 7.80±2.57 μg/L. These result indicated that the phosphate concentrations in sampling stations of Satun province were higher than those 2 provinces. However, there was observed that phosphate concentrations were lower than the Thailand Marine Water Quality Standard Class 3 and Class 4 (shall not exceed 45 μg/L) during the sampling period. The phosphate concentrations of 30 stations in 3 seasons are shown in Figure A1.6.

Nutrient concentrations (nitrate and phosphate) in interstitial waters are generally several times higher than in overlying waters and can exceed 5 mg/L in areas of groundwater discharge. This much release of nutrients may be regular and governed by water output and diffusion. Sewage has been a major source of nitrate and phosphate pollution in the water. Moreover, agricultural runoff flushes nitrates and phosphates into coastal areas. Storms reworking the sediment are also important forces for episodic release of stored nutrients. The more water circulation and rapid flushing rate cause the lower nutrient concentrations. Sheltered situations will exhibit the highest concentrations. In low-energy beaches, nutrient concentrations and distribution in the interstitial system may be controlled by wave action (Chongprasith and Praekuvanich, 2003; McLachlan and Brown, 2006).

4.1.7 Turbidity

The means turbidity of sampling stations in Krabi province ranged between 0.1±0.1 and 35.3±4.5 NTU. The relatively high turbidity presented in the summer. At station KB-AN st1, KB-AN st2 and KB-AN st3, the turbidity were 35.3±4.5, 33.0±1.7 and 32.0±1.0 NTU, respectively while the other stations had lower turbidity than 10.0 NTU. Sampling station in Trang province showed high mean turbidity results in the Southwest monsoon at Chao Mai beach and Yong Ling beach. At station TR-CM st1, TR-CM st2, TR-CM st3, TR-YL st1, TR-YL st2 and TR-YL st3, the turbidity were 84.0±1.5, 47.1±2.0, 27.6±2.0, 19.9±0.6, 19.9±0.4 and 21.6±0.8 NTU, respectively. During the Northeast monsoon, only TR-PM st1 showed the high mean turbidity which was 19.9±2.0 NTU. In the other sampling stations the mean turbidity were in the range of 0.6±0.1 - 10.5±2.0 NTU. The sampling stations in Satun province showed high turbidity. The highest was as high as 116.3±2.4 NTU at ST-BB st2 during the Northeast monsoon. The low mean turbidity presented at ST-PR st1 during the Northeast monsoon and the summer which were 8.0±2.5 and 5.9±2.5 NTU, respectively and at ST-BB st2 was 2.9±2.5 NTU. Overall turbidity results in other stations were in the range of 19.1±2.8 - 103.6±1.4 NTU. Turbidity is resulted from soil erosion, water runoff, algal blooms and bottom sediment disturbances. At high levels of turbidity, dissolved oxygen is decreased (Simeonov et al., 2003). High turbidity and freshwater input which differences in processes and conditions exist in different times during the day or in different seasons, allowing a wide range of physiologically adaptive macrofaunal species to live there (Guevara- Fletcher et al., 2011). The turbidity levels of 30 stations in 3 seasons are shown in Figure A1.7.

4.1.8 Biochemical oxygen demand (BOD)

The results of the wide range samples of diverse intertidal from Krabi to Satun province showed similar results. At all sampling stations in Krabi province, the mean BOD did not exhibit large change over 3 sampling seasons. The BOD level was in the range of 1.5±0.4 - 4.9±0.3. Also the low BOD results in Trang and Satun provinces ranged between 0.1±0.1 - 5.6±0.3 and 0.2±0.1 - 4.3±0.2 mg/L, respectively. The BOD levels were typically less than 7 mg/L during the sampling period, indicating generally low levels of organic loading. Although some sampling stations had low DO, there were also low BOD (<0.1-7.5 mg/L). It indicated efficient maintenance of DO of tidal seawater and adequate assimilation of brought-in organic load in beach water. Ingole and Kadam (2003) proposed that high DO (3.8-7.8 mg/L) and low BOD (<0.1-7.5 mg/L) indicate well oxygenated conditions possibly through the surfing action of tidal seawater and adequate assimilation of brought-in organic load in beach water, respectively. Moreover, a gradual variation of soft bottom polychaete assemblages in shallow water appears related with changes in BOD but the multivariate analyses performed suggest that the relation of the physical-chemical variables with assemblage distribution is limited when compared to sediment structural variables (Dorgham, Handy, El-Rashidy, Atta, and Musco 2014). The BOD levels of 30 stations in 3 seasons are shown in Figure A1.8.

4.1.9 Water quality similarity of sampling stations

The objective of cluster analysis was to identify relative similarity, that is, homogeneous groups of objects. In the present study, sampling stations of all the beaches were analysed with respect to all water quality variables in all seasons. Bray and Curtis similarity (Somerfield, 2008) based on the mean of the water qualities which transform by forth root was applied to detect multivariate similarities of the coastal water qualities. A dendrogram provides a visual summary of the clustering processes, presenting a picture of the groups and their proximity, with a dramatic reduction in the dimensionality of the original data. The dendrogram in Figure 4.1 showed the results of the cluster analysis from the different stations. It generated a grouping the sampling stations into two groups. The two distinct groups were identified with 90% similarity between the clusters. Cluster 1 consisted of all 9 sampling stations in Satun province and cluster 2 consisted of 21 sampling stations in Krabi and Trang provinces. These results showed that overall water qualities of sampling stations in Satun province were homogeneity whereas in Krabi and Trang provinces were clustered into the same group. At 95% similarity, the cluster exhibited separation of the two groups. The cluster 1 could be separated into 2 groups and the cluster 2 could be separated into 2 groups. These results showed the distinction of water qualities between 3 beaches in Krabi province, that is, Nopparatthara beach had homogeneity of water qualities to beaches in Trang province. However, in the case of all station similarity, the results exhibited high water quality similarity (85% similarity). The dendrogram of cluster analysis is shown in Figure 4.1.

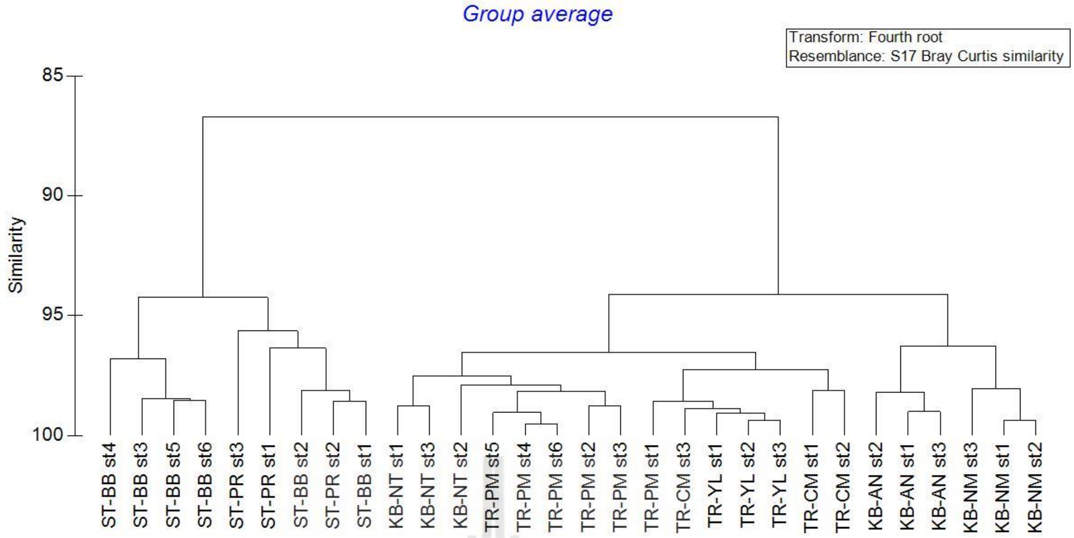


Figure 4.1 A dendrogram of cluster analysis illustrated water quality variable similarity among 30 stations.

4.2 Sediment variables

The benthic macrofauna are commonly living in sediment, so their lives are severely related to the surrounded sediment. Relationships between benthic organisms and the seabed have long been recognized. The organisms, living mainly in the interstitial spaces in burrows or tubes, or moving freely through the sediment, continually modify the structure of the sediment (bioturbation) by mixing, sorting, and aggregating small particles into pellets and by pumping water into and out of the seabed. These organisms are capable of modifying the biological and physicochemical characteristics of sediments through their circulatory, respiratory, and excretory behaviors. At the same time, sediment characteristics influence organism distributions, both in the larval and adult stages (Meksumphan and Meksumphan, 1999). Therefore, this study examined the sediment quality variables included pH, phosphate, nitrate, organic matter content and sediment particle sizes. The results of the sediment quality measurement are as follow:

4.2.1 pH

The pH of sediment at all stations was typically below 7.5 during sampling period. The results indicated that almost all sediment types were neutral to acidic. The pH at all sampling stations in Krabi province ranged from 5.7±0.3 to 6.8±0.8 while in Trang province was in the range of 5.8±0.6 - 7.3±0.3. The pH values of sampling stations in Satun province were relatively low. It ranged from 4.0±0.5 to 6.8±0.3. These pH values showed slightly varied among sampling stations. In stepwise multiple linear regression results, the sediment pH did not show any significant correlation with biological indices of benthic macrofauna. Geetha, Thasneem, and Nandan (2010) claimed that nematodes, crustaceans and molluscs are absence in very high pH fluctuated areas of estuary. The fluctuation of pH may be due to the effect of high river discharge and rainfall in the monsoon season. The sediment pH of 30 stations in 3 seasons is shown in Figure A2.1.

4.2.2 Nitrate (NO_3-N)

Nitrate concentrations in sediment of all sampling stations of Krabi province ranged from 0.08±0.03 to 9.65±1.38 mg/kg. The concentrations of the sampling stations were similar. All sampling stations showed low nitrate concentrations in the summer and much higher in the Southwest monsoon. During the Northeast monsoon, the nitrate concentrations were slightly higher than in the summer. In Trang province, nitrate concentrations were relatively low. They ranged between 0.02±0.01 and 0.3±0.16 mg/kg. The station TR-CM st1 and TR-YL st3 in the Northeast monsoon were relatively high when compared to the other sampled stations.

In Satun province, the results indicated that nitrate concentrations were in the range of 0.04±0.04 - 1.85±0.26 mg/kg. The nitrate concentrations were also showed seasonal change in all sampled stations with drastically higher in both monsoons. The nitrate concentrations of 30 stations in 3 seasons are shown in Figure A2.2.

Furthermore, there was no correlation between nitrate in the sediment and nitrate in the water (Table 4.6, 4.7 and 4.8).

4.2.3 Phosphate (PO_4-P)

Phosphate concentrations in sediment of all sampling stations ranged from 0.02 to 5.25±0.64 mg/kg. In Krabi province, the phosphate concentrations were relatively higher than in Trang and Satun provinces in overall results. In Krabi province, the phosphate concentrations ranged from 0.12 - 5.25±0.64 mg/kg. In Trang province, the phosphate concentrations were relatively low. It was in the range of 0.02 - 2.75±0.21 mg/kg. At station TR-PM st1 showed markedly highest concentration of phosphate in the province but it was not much fluctuated at the other stations. The results of Satun province indicated that the phosphate concentrations were also varied. They were in the range of 0.2±0.02 - 3.57±0.37 mg/kg. The phosphate concentrations of 30 stations in 3 seasons are shown in Figure A2.3.

Overall, nitrate and phosphate in sediment exhibited seasonal changes. During the Northeast monsoon and the Southwest monsoon, nitrate and phosphate concentrations of all sampling stations in Krabi and Satun provinces presented markedly high amount. Although all sampling stations of Trang province showed relatively low concentrations of the nutrients, the seasonal variation were obvious.

In coastal habitat, macrofaunal activities on sediment nutrient dynamics can also result in a higher N : P ratio of the sediments efflux compared with sediments without macrofauna (Karlson et al., 2007). Mineralization pathways and transport of organic and inorganic solutes across the sediment–water interface largely depend on the redox conditions of the bottom water and surface sediment layers (Aller, 1994). Thus, during anoxia alternative pathways of nutrient flows will dominate compared to oxic situations (Christensen, Rysgaard, Sloth, Dalsgaard, and Schwaerter, 2000).

4.2.4 Organic matter content

Although organic matter is important to most benthic macrofauna as a source of food, sediment with a high percentage of organic do not lend themselves well to infaunal community establishment. Too much organic matter can negatively affect species richness and abundance. Microbial breakdown of these materials can potentially release toxic materials and decrease DO at the water-sediment interface where these organism reside (Gray, Wu, and Or, 2002; Hyland et al., 2005). Mean percentages of organic matter content varied from 0.25±0.01% to 18.18±8.27% throughout the sampling stations and seasons. The percentages of organic matter content were relatively high in Krabi province. There ranged between 0.77±0.93 and 18.18±8.27% whereas in Satun province, it ranged from 0.59±0.10% to 13.46±0.81%. Sampling stations in Trang province had relatively low organic matter in sediment which ranged from 0.25±0.01 to 9.11±4.26. Station KB-AN st2 markedly showed highest percentage at 18.18±8.27% in the Southwest monsoon but the others showed lower than 10% of organic matter content. At ST-BB st1 also showed high organic matter content. They were in the range of 5.62±0.35% - 9.83±2.99% in all seasons and at ST-BB st2, the organic matter contents in the Southwest monsoon and the Northeast monsoon were 7.80±4.83% and 13.46±0.81%, respectively. Organic matter content in sediment corresponds to higher range of the mud content within the sediment. It broadly ranged from 0.1% to 30% (Borja et al., 2000). In general the percentage of organic matter is higher in estuary and decreasing in littoral, intertidal and subtidal zone (Colosio et al., 2007). For this study, the organic matter content at most stations was relatively low. The exceptional stations were at KB-AN st2, TR-CM st1, ST-BB st1 and ST-BB st2 in some seasons. This result showed high proportion of the mud content of the areas. Particulate organic matter includes larger debris cast ashore as well as fine particulate matter that may be carried directly into the interstices. The particulate organic matter in larger debris will enter the interstitial system after breakdown and consumption by the macrofauna and it is capable for supporting diverse interstitial fauna (McLachlan and Brown, 2006). Although organic matter content is an important variable, in this study, the correlation between organic matter contents and biological indices was not manifested. The organic matter contents of 30 stations in 3 seasons are shown in Figure A2.4.

4.2.5 Sediment quality similarity of sampling stations

The dendrogram in Figure 4.2 shows the results of the cluster analysis from the different stations. Exhibitive two distinct groups were identified with 90% similarity between the clusters. Cluster 1 consisted of all 18 sampling stations in Satun and Krabi provinces and cluster 2 consisted of 12 sampling stations in Trang province. These results showed that overall sediment qualities of sampling stations in Trang province were homogeneity whereas in Krabi and Satun province were clustered into the same group. These results showed the distinction of sediment qualities of sampling stations between in Trang province and the other provinces. It had homogeneity of sediment qualities of sampling stations in 3 sampling beaches. Sampling stations in Krabi and Satun province presented high similarity at 96%

similarity. In the case of all station similarity, the results exhibited high sediment quality similarity (82% similarity). The dendrogram of cluster analysis is shown in Figure 4.2.

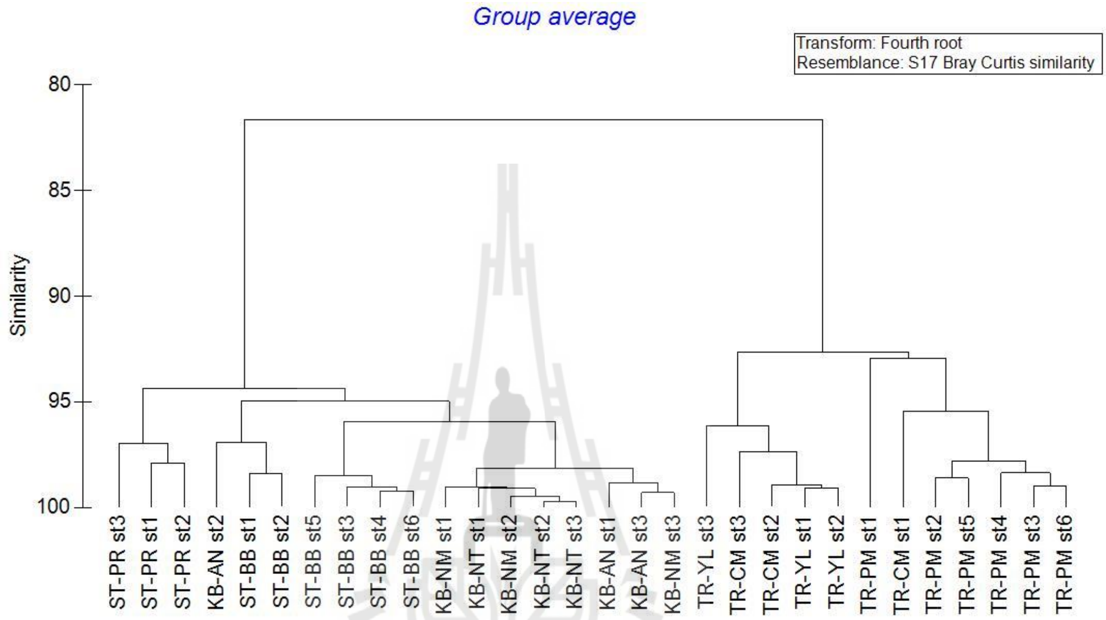


Figure 4.2 A dendrogram of cluster analysis illustrated sediment quality variable similarity among 30 stations.

4.2.6 Sediment particle sizes

In the case of sediment particle sized for all sampling beaches, according to Wentworth scale (De Pas et al., 2008; Marine Environmental Laboratory, 1995), the sampling beaches in Krabi province had very fine sand to fine sand. All sampling stations on Nopparathara and Ao-nang beaches had predominantly very find sand. The highest percentage of particle size was 0.075 mm, whereas Nam Mao had fine sand which the highest percentage of particle size was 0.15 mm. Sampling beaches in Trang province had very fine sand and medium sand. At Pak Meng beach, it was markedly showed larger sediment particle sizes at the edge of sampling beach (TR-PM st1, TR-PM st5 and TR-PM st6) where particle size at 0.3 mm had the highest percentage. All sampling station of both Chao Mai and Yong Ling beaches had very fine sand. Sampling beaches in Satun province had fine sand at all sampling station on Pak Bara beach and medium sand at all sampling station on Pak Bang beach. The sediment characteristics exhibited that the granulometrical typology of the sampling stations were sandy beach with varied sediment particle sizes from a very fine sand enriched environment to medium sand. In addition, the sandy/muddy area could be defined by organic matter content. For organic matter content results of the sampling stations were also varied and reached to 13% and 18% at sampling stations in Pak Bang beach and Ao-nang beach, respectively. This result showed that there was sandy/muddy in the stations. The sediment particle sizes determination is shown in Table 4.1. The percentages of sediment particle sizes at each beach are shown in Figure 4.3 and seasonal results are showed in Figure A3.1. To compare the result of sediment particle size of all sampling station, the cluster analysis was used. Sediment particle sizes were calculated in the multivariate analysis. Bray and Curtis similarity based on the sediment particle size percentage which transformed by forth root was applied to detect multivariate similarities of the sediment particle size. The dendrogram of station grouping by sediment particle size in Figure 4.4 showed three distinct groups at 85% similarity between the clusters. Cluster 1 consisted of all 6 sampling stations of Pak Bang beach in Satun province. Cluster 2 consisted of all 3 sampling stations from Pak Bara beach, 6 sampling stations from Krabi and 9 sampling stations from Trang provinces. Cluster 3 consisted of 3 sampling stations from Krabi province and 3 sampling stations from Trang province. These results showed that overall sediment particle size percentages of sampling stations in Pak Bang beach, Satun province were homogeneity whereas Pak Bara beach, Krabi and Trang province were not distinctive separation at 80% similarity. The dendrogram of cluster analysis is shown in Figure 4.4. In general, a greater percentage of soft bottoms is structurally more homogeneous and contain less diversity, while the ones with greater variety in the size of the sediment particles have a structurally heterogeneous habitat and therefore more diversity (Guevara- Fletcher et al., 2011). The results of species composition showed that stations TR-PM st1, KB-NM st3 and ST-PR st1 had the highest richness in their sampling provinces whereas stations TR-YL st3, KB-NT st2 and ST-BB st6 had the lowest abundance (Table 4.3). Comparing to the sediment particle size compositions, those high species richness were occurred in more proportion variety of sediment particle sizes (Figure A3.1). The composition and selection of beach sediments are related to the patterns of current circulation. In the high percentages of fine sand and clay are accumulated due to weaker tidal currents, at the same time the effect of freshwater is greater (Guevara- Fletcher et al., 2011).

Table 4.1 Particle size determinations of 30 sampling stations.

Beach	Station	Main sediment texture
Nopparatthara	KB-NT st1	Very fine sand
	KB-NT st2	Very fine sand
	KB-NT st3	Very fine sand
Ao-nang	KB-AN st1	Very fine sand
	KB-AN st2	Very fine sand
	KB-AN st3	Very fine sand

Table 4.1 (Continued) Particle size determinations of 30 sampling stations.

Beach	Station	Main sediment texture
Nam Mao	KB-NM st1	Fine sand
	KB-NM st2	Fine sand
	KB-NM st3	Fine sand
Pak Meng	TR-PM st1	Medium sand
	TR-PM st2	Very fine sand
	TR-PM st3	Very fine sand
	TR-PM st4	Very fine sand
	TR-PM st5	Medium sand
	TR-PM st6	Medium sand
Chao Mai	TR-CM st1	Very fine sand
	TR-CM st2	Very fine sand
	TR-CM st3	Very fine sand
Yong Ling	TR-YL st1	Very fine sand
	TR-YL st2	Very fine sand
	TR-YL st3	Very fine sand
Pak Bara	ST-PR st1	Fine sand
	ST-PR st2	Fine sand
	ST-PR st3	Fine sand
Pak Bang	ST-BB st1	Medium sand
	ST-BB st2	Medium sand
	ST-BB st3	Medium sand
	ST-BB st4	Medium sand
	ST-BB st5	Medium sand
	ST-BB st6	Medium sand

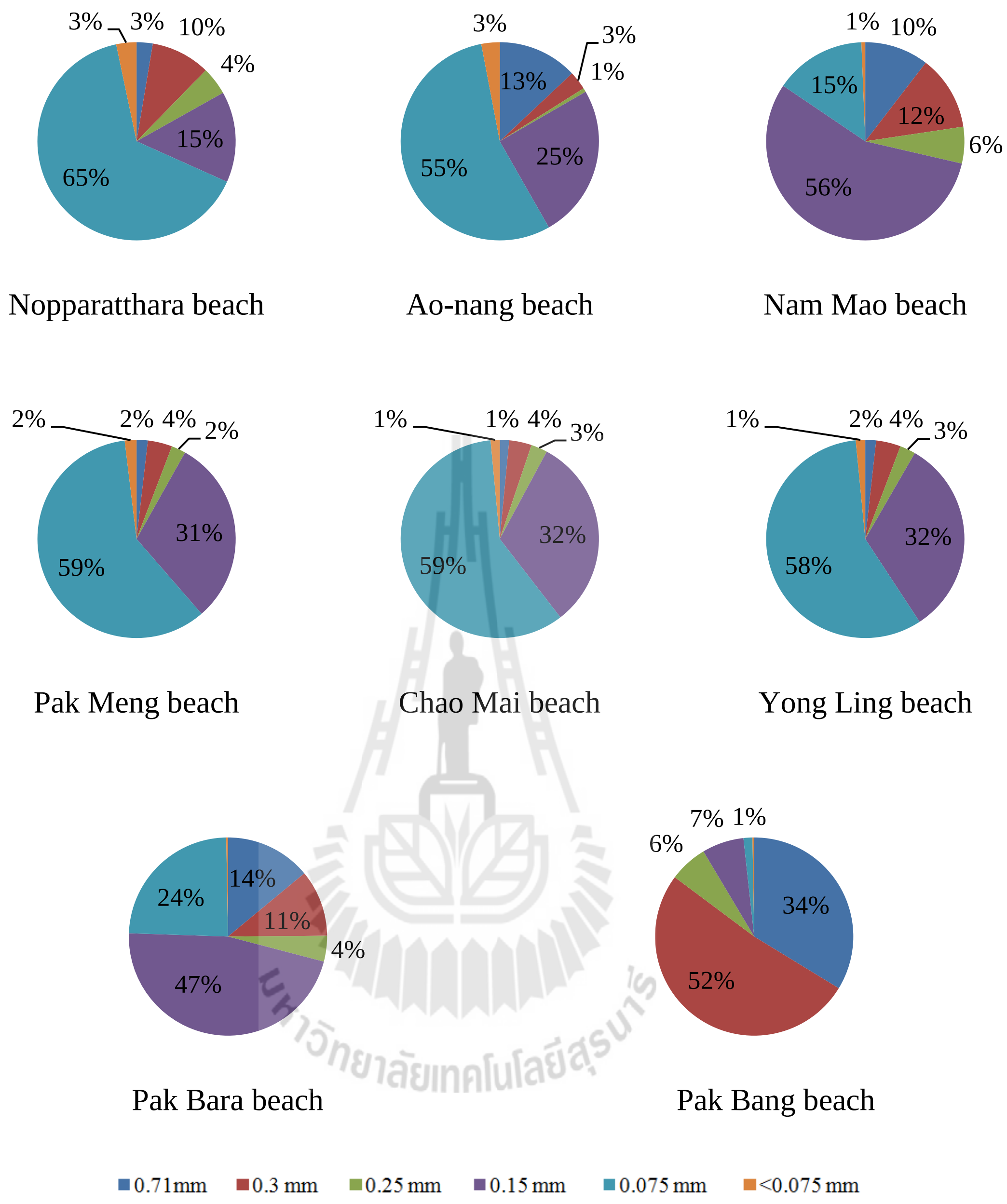


Figure 4.3 Percentages of sediment particle sizes at 8 beaches.

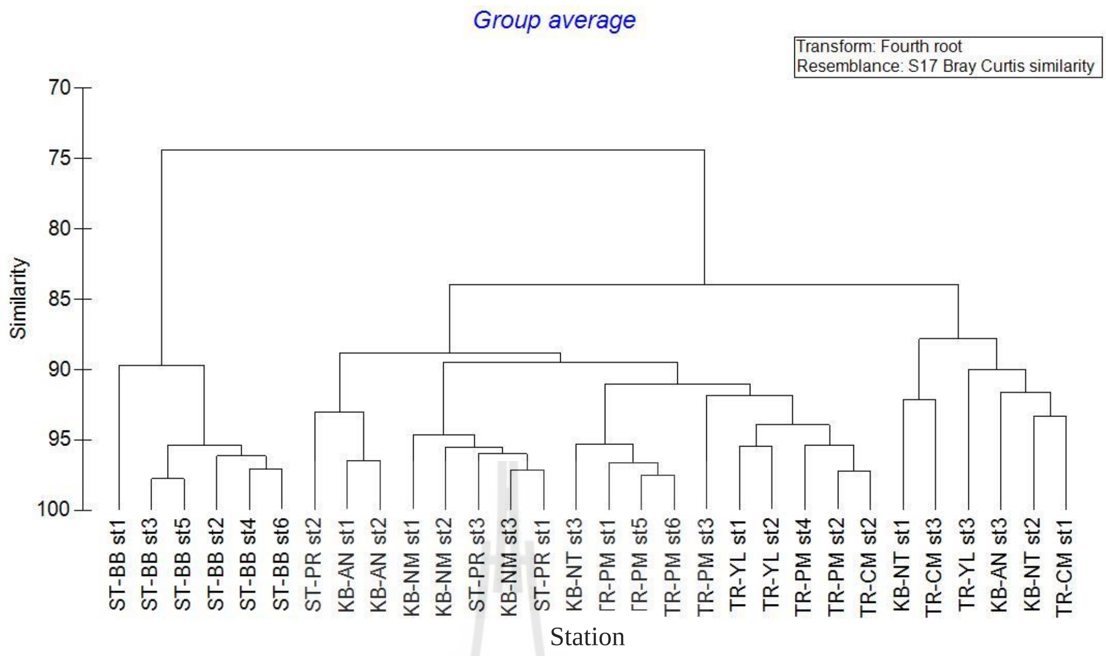


Figure 4.4 A dendrogram of cluster analysis illustrated sediment particle size similarity among 30 stations.

4.2.7 Water and sediment variable similarity of sampling stations

The resultant similarity matrix of sampling stations based on water and sediment variable was subjected to cluster analysis and nonmetric multidimensional scaling (MDS) with Bray and Curtis similarity.

The cluster analysis of ecological variables generated a grouping of the sampling stations into three groups. The three distinct groups were identified with 90% similarity. Cluster 1 consisted of all sampling stations from Pak Bang beach. Cluster 2 only included 12 sampling stations from Trang province. Cluster 3 showed similarity of 3 sampling stations from Pak Bara beach with all sampling stations from Krabi province. In the case of all station similarity, the results exhibited high ecological similarity (83% similarity). Moreover, the two dimensional configuration of forth root transformed of all ecological variables using sum seasonal data from each stations were also analysed. The result showed that the sampling stations were grouped into three groups supporting the similarity cluster with stress 0.07. The stress value between 0.05 - 0.10 provided a good representation of the MDS. These results of similarity and MDS grouping exhibited less change in ecological variables comparing in near stations and also from further stations. The dendrogram of cluster analysis and MDS configuration based on all variable data of 30 stations are shown in Figure 4.5 and 4.6, respectively.

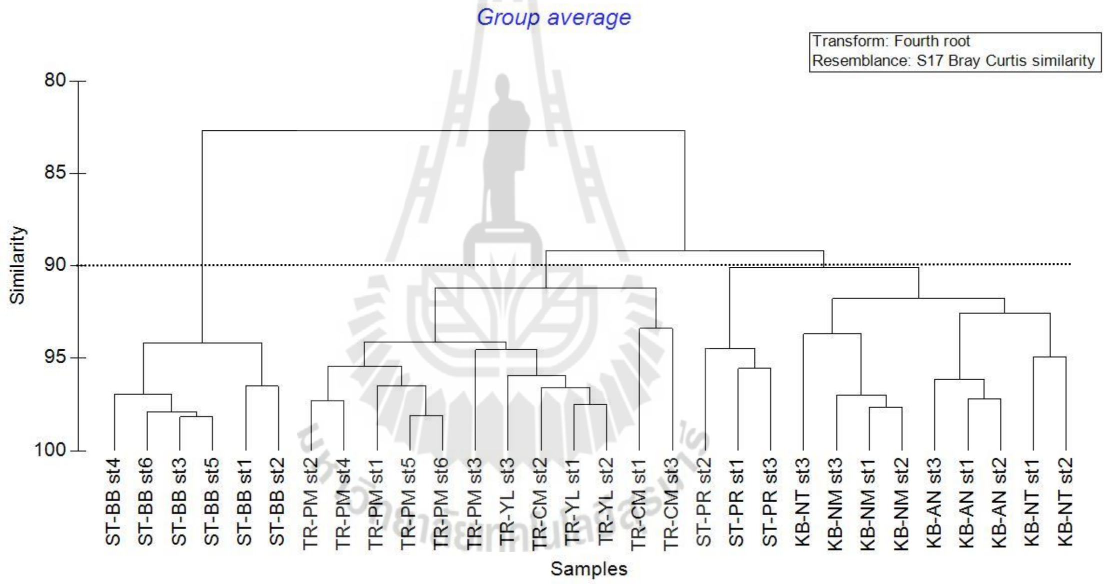


Figure 4.5 A dendrogram of cluster analysis illustrated all variables similarity among 30 stations.

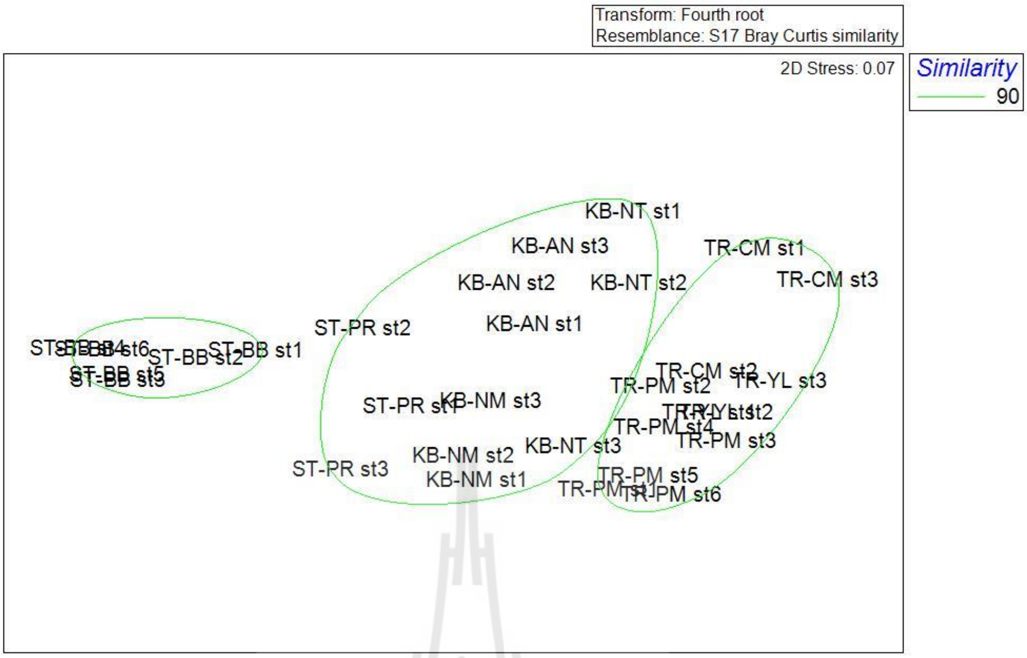


Figure 4.6 Two-dimensional MDS configuration for forth root transformed all variables of 30 stations using sum seasonal data (stress value = 0.07).

4.3 Biodiversity of macrofauna in Krabi, Trang and Satun provinces

The 30 sampling stations were selected to evaluate the biodiversity of benthic macrofauna during September 2012 to April 2013. Before this study, there is no information about benthic macrofauna along the beaches of southern Andaman Sea coast of Thailand. This result gave basic information of the organisms at 8 beaches in Krabi, Trang and Satun provinces.

4.3.1 Taxonomic classification of benthic macrofauna

A total of 116 species of benthic macrofauna were collected from the 30 sampling stations representing 4 phyla, 5 classes, 20 orders, and 51 families. These macrofauna species are illustrated in appendix A. The numbers of benthic macrofauna found in Krabi, Trang and Satun provinces were 65, 72 and 64 species, respectively.

Of theses, the phylum Polychaeta had the highest number of species. They composed of 11 orders, 22 families and 65 species. Furthermore, of these taxa, *Petersenaspis* sp. was the first record in Thailand (Tantikamton, Thanee, Jikpukdee, and Potter, 2015). Phylum Mollusca was the second highest number of species. Mollusks composed of 2 classes which were Bivalvia and Gastropoda. The class Bivalvia consisted of 3 orders, 11 families and 22 species whereas the class Gastropoda accounted for 4 orders, 9 families and 15 species. Phylum Arthopoda was found only in class Malacostraca (subphylum Crustacea). The class was found only in the order Decapoda which consisted of infraorder Anomura (hermit crabs) and infraorder Brachyura (crabs). The infraorder Anomura had 3 species belonging to the family Diogenidae and the Brachyura had 10 species of 5 families. The lowest species number was found in the phylum Brachiopoda. It was found only a single species (*Lingula* sp.) in Satun province. The taxonomic classification is shown in Table 4.3. Previous study on beaches and coastal areas reported that the abundance of benthic macrofauna on the coastal seabed of the Andaman Sea ranged from 200 to 1,000 individuals/m^2 (Chantananthawej and Bussarawit, 1987; Jantharakhantee and Aryuthaka, 2007). In this study, the mean densities of benthic macrofauna in the sampling stations were in the range of 23-935 individuals/2.25 m^2. The highest abundance was at KB-AN st2 during the summer (935 individuals/2.25 m^2) and the lowest abundance was at TR-YL st3 during the summer (23 individuals/2.25 m^2). The highest number of species was at TR-PM st1 which was 26 species during the Southwest monsoon whereas the lowest species number was 3 species at TR-YL st1, TR-YL st2, TR-YL st3 and ST-BB st6 in different collecting seasons. The abundance and number of species are shown in

Table C1.1, C1.2 and C1.3. Taxonomic classification of benthic macrofauna collected from study areas are shown in Table 4.2

Table 4.2 Taxonomic classification of benthic macrofauna collected from study areas.

Taxa	Family	No.	Species
Phylum Annelida			
Class Polychaeta			
Orbinida	Orbiniidae	1	*Scoloplos* (*Leodamas*) *gracilis*
		2	*Scoloplos* (*Scoloplos*) *marsupialis*
		3	*Scoloplos* (*Scoloplos*) *tumidus*
		4	*Scoloplos* (*Scoloplos*) sp. 1
		5	*Scoloplos* (*Scoloplos*) sp. 2
		6	*Scoloplos* (*Scoloplos*) sp. 3
Spionida	Spionidae	7	*Scolelepis* (*Scolelepis*) sp.
		8	*Paraprionospio* cf. *oceanensis*
		9	*Paraprionospio* sp.
		10	*Prionospio* (*Prionospio*) *steenstrupi*
		11	*Dispio latilamella*
	Magellonidae	12	*Magelona* cf. *cincta*
		13	*Magelona conversa*
		14	*Magelona sacculata*
	Cirratulidae	15	*Aphelochaeta* sp.
		16	*Timarete* sp.
		17	*Chaetozone* sp. 1
		18	*Chaetozone* sp. 2

Table 4.2 (Continued) Taxonomic classification of benthic macrofauna collected from study areas.

Taxa	Family	No.	Species
		19	*Monticellina* sp.
Capitellida	Capitellidae	20	*Mediomastus* sp.
		21	*Heteromastus filiformis*
		22	*Heteromastus* sp. 1
		23	*Heteromastus* sp. 2
		24	*Heteromastus* sp. 3
		25	*Heteromastus* sp. 4
		26	*Capitellus branchiferus*
	Maldanidae	27	*Euclymene annandalei*
		28	*Axiothella obockensis*
Opheliida	Opheliidae	29	*Ophelina* sp. 1
		30	*Ophelina* sp. 2
		31	*Armandia* sp.
	Scalibregmatidae	32	*Asclerocheilus* sp.
Phyllodocida	Phyllodocidae	33	*Anaitides* sp.
		34	*Phyllodoce* sp.
		35	*Eteone* sp.
	Polynoidae	36	*Lepidonotus* sp.
	Eulepethidae	37	*Grubeulepis geayi*
	Pisionidae	38	*Pisione* sp.
	Pilargidae	39	*Sigambra pettiboneae*
	Nereididae	40	*Neanthes caudata*
		41	*Neanthes* sp.

Table 4.2 (Continued) Taxonomic classification of benthic macrofauna collected from study areas

Taxa	Family	No.	Species
		42	*Dendronereis arborifera*
		43	*Tylonereis heterochaeta*
	Glyceridae	44	*Glycera alba*
		45	*Glycera natalensis*
		46	*Glycera* sp.
	Goniadidae	47	*Goniadopsis incerta*
Amphinomida	Amphinomidae	48	*Linopherus canariensis*
Eunicida	Onuphidae	49	*Diopatra amboinensis*
		50	*Diopatra semperi*
		51	*Diopatra sugokai*
		52	*Diopatra* sp. 1
		53	*Diopatra* sp. 2
	Eunicidae	54	*Marphysa macintoshi*
	Lumbrineridae	55	*Lumbrineris heteropoda*
		56	*Lumbrineris* sp. 1
		57	*Lumbrineris* sp. 2
		58	*Scoletoma* sp. 1
		59	*Scoletoma* sp. 2
		60	*Scoletoma* sp. 3
Sternaspida	Sternaspidae	61	*Sternaspis andamanensis*
		62	*Peternaspis* sp.
Oweniida	Oweniidae	63	*Owenia fusiformis*
Terebellida	Terebellidae	64	*Lanice conchilega*

Table 4.2 (Continued) Taxonomic classification of benthic macrofauna collected from study areas.

Taxa	Family	No.	Species
Sabellida	Sabellidae	65	*Chone* sp.
Phylum Mollusca			
Class Bivalvia			
Arcoida	Arcidae	1	*Anadora granosa*
Ostreoida	Propeamussiidae	2	*Chlamys* sp.
Veneroida	Lucinidae	3	*Pillucina* sp.
	Mactridae	4	*Mactra olorina*
		5	*Mactra cuneata*
	Pharidae	6	*Siliqua fasciata*
		7	*Siliqua radiata*
	Tellinidae	8	*Tellina* sp. 1
		9	*Tellina* sp. 2
	Donacidae	10	*Donax cuneatus*
		11	*Donax incarnatus*
		12	*Donax faba*
		13	*Donax scortum*
	Psammobiidae	14	*Gari* (*Psammotaea*) *elongata*
	Corbiculidae	15	*Meretrix* sp.
	Veneridae	16	*Pitar* sp.
		17	*Anomalocardia squamosa*
		18	*Paphia gallus*
		19	*Timoclea scabra*
		20	*Timoclea imbricata*

Table 4.2 (Continued) Taxonomic classification of benthic macrofauna collected from study areas.

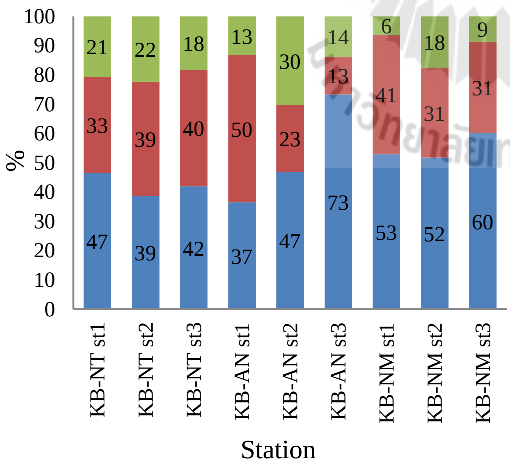
Taxa	Family	No.	Species
		21	*Circe scripta*
	Cardiidae	22	*Fragum fragum*
Class Gastropoda			
Vestigastropoda	Trochidae	23	*Umbonium vestiarium*
Vestigastropoda	Neritidae	24	*Clithon oualaniensis*
Sorbeoconcha	Cerithiidae	25	*Cerithium coralium*
	Naticidae	26	*Natica tigrina*
		27	*Natica vitellus*
		28	*Polinices mammilla*
	Nassaridae	29	*Nassarius pullus*
		30	*Nassarius livescens*
		31	*Nassarius jacksonianus*
		32	*Nassarius stolatus*
		33	*Nassarius globosus*
	Costellariidae	34	*Vexillum* sp.
	Turridae	35	*Turricula javana*
	Vitrinellidae	36	*Lodderia novemcarinata*
Cephalaspidae	Bullidae	37	*Atys cylindricus*
Phylum Arthropoda			
Subphylum Crustacea			
Class Malacostraca			
Order Decapoda			

Table 4.2 (Continued) Taxonomic classification of benthic macrofauna collected from study areas.

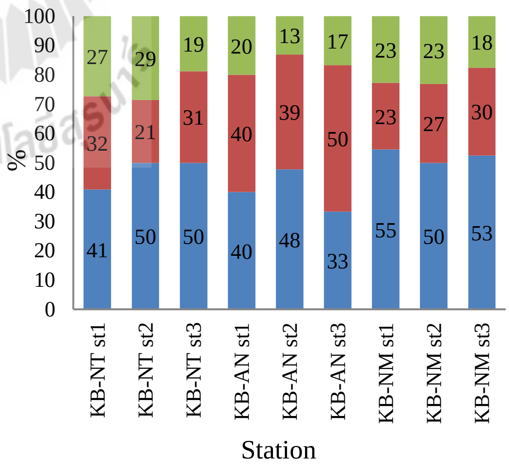
Taxa	Family	No.	Species
Infraorder			
Anomura	Diogenidae	1	*Diogenes klassi*
		2	*Diogenes dubius*
		3	*Diogenes planimanus*
Infrorder			
Brachyura	Leucosiidae	4	*Philyra olivacea*
		5	*Philyra platycheira*
	Matutidae	6	*Matuta victor*
	Ocypodidae	7	*Dotilla intermedia*
		8	*Dotilla myctiroides*
		9	*Ocypode macrocera*
		10	*Ocypode ceratopthalma*
		11	*Scopimera proxima*
	Macrothalmidae	12	*Macrophthalmus convexus*
	Camtandriidae	13	*Camptandrium sexdentatum*
Phylum Brachiopoda			
Class Lingulata			
Order Lingulida	Lingulidae	1	*Lingula* sp.

4.3.2 Composition of benthic macrofauna communities

The faunal composition of the benthic samples that were analysed in the period 2012-2013 showed a poorly structured community with a relatively small number of species in some stations which were TR-YL st1, TR-YL st2 and TR-YL st3 and a moderate number of species in most stations. In addition, there was no particularly seasonal pattern in total macrofaunal abundance. For overall results, polychaetes had the highest percent abundant representation followed by mollusks and crustaceans. Most sampling stations of Krabi, Trang and Satun provinces, polychaetes showed the highest abundance but in some stations were exceptional. The mollusks groups presented highest total abundance at 5 stations comprising KB-AN st1, ST-BB st1, ST-BB st2, ST-BB st3, ST-BB st5 and ST-BB st6. The crustaceans groups displayed highest total abundance at TR-PM st4, TR-YL st1, TR-YL st3, ST-PR st2 and ST-PR st3. In case of percent composition of number species, almost all stations manifested that the polychaetes had the highest species numbers. In exception, at KB-AN st3 and ST-PR st3 mollusks exhibited the highest species number composition. The distribution of abundance and species by groups is shown in Figure 4.7.

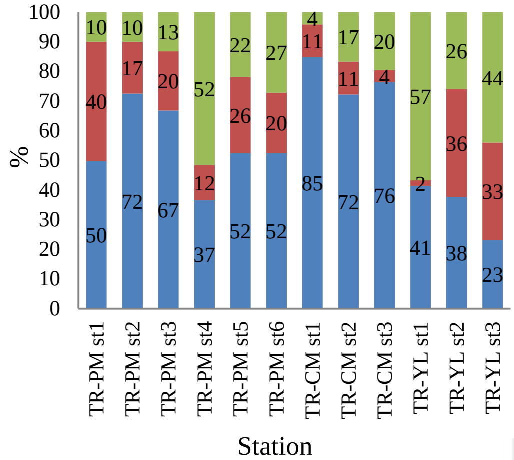


(a) Abundance composition of benthic macrofauna of sampling stations in Krabi province,

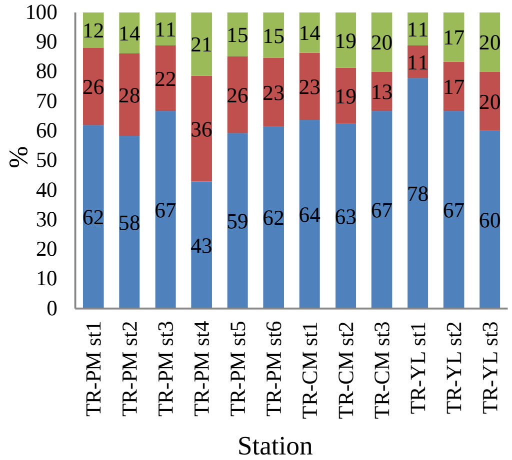


(b) Species composition of benthic macrofauna of sampling stations in Krabi province

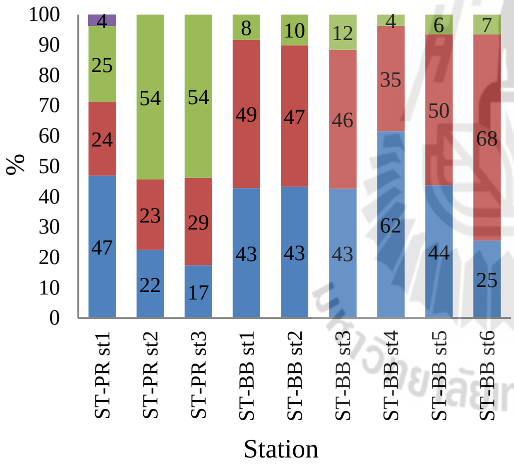
Figure 4.7 Charts of percent benthic macrofauna compositions by groups.



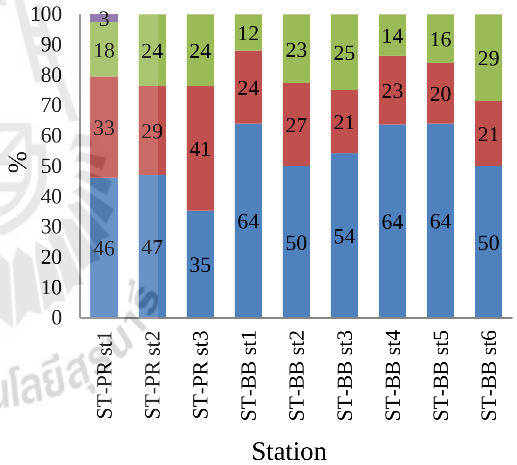
(c) Abundance composition of benthic macrofauna of sampling stations in Trang province



(d) Species composition of benthic macrofauna of sampling stations in Trang province



(e) Abundance composition of benthic macrofauna of sampling stations in Satun province



(f) Species composition of benthic macrofauna of sampling stations in Satun province

Polychaetes Molluscs Crustaceans Brachiopods

Figure 4.7 (Continued) Charts of percent benthic macrofauna compositions by groups.

4.3.3 Biodata indices of sampling stations

Benthic macrofauna are thought to be ideal for monitoring coastal sediment environments as they are in direct contact with the habitat by burrowing in the sediment and often respond to changes in the sediment environment. Consequently, benthic macrofauna have been successfully used to monitor differences between sites and changes in sites over time (Pocklington and Wells, 1992). The condition of a coastal area has been assessed by measuring the biodiversity of the area (Borja and Dauer, 2008; Borja et al., 2000; Borja et al., 2012). Common measures of biodiversity were species richness and species diversity. The value of studying biodiversity was to compare the reflection of overall ecological variables. It is thought that higher species richness and diversity is associated with good ecological condition compared to areas of lower species richness. Therefore, the species diversity, evenness, richness and dominant index of benthic macrofauna among the sampling stations in Krabi, Trang and Satun provinces were practiced.

Species richness was determined by Magalef richness index (D). It exhibited the number of species found at a certain locality. The various species encountered in a sampling station was determined by a number. High number explained high abundance and amount of species. Taking the overall proportion represented by all species found at a sampling station. TR-PM st1 came out as the most species rich with its 42 species found representing 5.80 species richness index. The following was KB-NM st3 consisting of 40 species but the species richness index was higher at 6.15. The least species number was at TR-YL st3 with 5 species and 0.82 species richness index. The lowest occurrence of species rich and richness index of Krabi province was at KB-NT st2 where 14 species were found with its 2.28

species richness index. In Satun province, the highest species number was at station ST-PR st1 where 39 species were found with the highest species diversity richness at 6.21. In addition, the lowest species number of Satun province was at ST-BB st6 which had 14 species and 2.25 species richness index.

The determination of the values of Shanon-Weiner diversity index (H) reiterates the finding on species richness. High diversity indicated that nich space, habitat and food sources are adequate for the survival of many species. The results showed that the highest species diversity index was 3.08 at station ST-PR st1 whereas the lowest was at TR-YL st3 with its 1.30 species diversity index.

Evenness index is determined base on species number equality at each station. In contrast, species dominance index utilize to describe a sampling station by number of dominant species encountered against the total number of individuals encountered. Evenness index is an inverse value to species dominant index. The result of evenness index values ranged from 0.53 to 0.95 of total seasons. In Krabi province the highest evenness index was at KB-NT st1 (0.88) where exhibited the lowest species dominance index (0.08). The lowest evenness index was at KB-AN st3 where the abundant species was highest (total 1,265 individuals/2.25 m^2) and species dominance index value was the least at 0.19. Sampling stations in Trang province markedly presented highest evenness index at TR-PM st3 (0.95) of total sampling seasons. It was contrary to the species dominance index which exhibited lowest value (0.05). At station TR-PM st4, the evenness index was lowest (0.62). The lowest species dominance index presented at TR-YL st1 (0.37) where 9 species were found. In Satun province, at station ST-PR st1 had the highest evenness index at 0.84 whereas the lowest was at ST-BB st6 (0.53). In contrast, ST-PR st1 had lowest dominance (0.06) and ST-BB st6 showed the highest value (0.43). The biodata index results of 30 stations in 3 seasons are shown in Table 4.3.

Table 4.3 Abundance, number of species, species richness (D), species diversity index (H), evenness index (J) and species dominance index (C) of 30 sampling stations in 3 seasons and all seasons.

Stations	Seasons	Abundance (individuals)	Number of species	D	H	J	C
KB-NT st1	SWM	95	7	1.32	1.53	0.79	0.27
	NEM	126	13	2.48	2.26	0.88	0.12
	SM	182	11	1.92	1.94	0.81	0.19
	Y	403	22	3.50	2.72	0.88	0.08
KB-NT st2	SWM	83	5	0.91	1.33	0.82	0.32
	NEM	108	9	1.71	1.95	0.89	0.16
	SM	106	8	1.50	1.82	0.87	0.19
	Y	297	14	2.28	2.16	0.82	0.14
KB-NT st3	SWM	70	8	1.65	1.58	0.76	0.31
	NEM	122	8	1.46	1.95	0.94	0.15
	SM	160	6	0.99	1.38	0.77	0.31
	Y	352	16	2.56	2.29	0.83	0.13
KB-AN st1	SWM	129	10	1.85	1.25	0.54	0.47
	NEM	117	6	1.05	1.51	0.85	0.26
	SM	217	11	1.86	1.81	0.76	0.20
	Y	463	20	3.10	2.32	0.78	0.12

Table 4.3 (Continued) Abundance, number of species, species richness (D), species diversity index (H), evenness index (J) and species dominance index (C) of 30 sampling stations in 3 seasons and all seasons.

Stations	Seasons	Abundance (individuals)	Number of species	D	H	J	C
KB-AN st2	SWM	175	10	1.74	1.23	0.53	0.45
	NEM	129	4	0.62	0.76	0.55	0.61
	SM	935	13	1.75	1.70	0.66	0.24
	Y	1239	23	3.09	2.18	0.70	0.15
KB-AN st3	SWM	484	15	2.26	1.42	0.52	0.44
	NEM	80	6	1.14	1.48	0.82	0.25
	SM	701	14	1.98	1.75	0.66	0.20
	Y	1265	24	3.22	2.08	0.65	0.19
KB-NM st1	SWM	47	10	2.34	1.74	0.76	0.26
	NEM	93	6	1.10	1.49	0.83	0.28
	SM	115	15	2.95	2.15	0.79	0.16
	Y	255	22	3.79	2.31	0.75	0.16
KB-NM st2	SWM	182	15	2.69	1.82	0.67	0.26
	NEM	133	14	2.66	2.19	0.83	0.15
	SM	214	12	2.05	2.03	0.82	0.17
	Y	529	26	3.99	2.52	0.77	0.12
KB-NM st3	SWM	192	20	3.61	2.29	0.76	0.14
	NEM	94	13	2.64	2.21	0.86	0.15
	SM	281	24	4.10	2.29	0.72	0.19
	Y	567	40	6.15	2.76	0.75	0.12

Table 4.3 (Continued) Abundance, number of species, species richness (D), species diversity index (H), evenness index (J) and species dominance index (C) of 30 sampling stations in 3 seasons and all seasons.

Stations	Seasons	Abundance (individuals)	Number of species	D	H	J	C
TR-PM st1	SWM	375	26	4.25	2.45	0.75	0.15
	NEM	422	21	3.37	1.89	0.62	0.32
	SM	371	22	3.56	2.51	0.81	0.12
	Y	1168	42	5.80	2.76	0.74	0.14
TR-PM st2	SWM	150	14	2.62	2.25	0.85	0.13
	NEM	534	20	3.08	2.14	0.71	0.18
	SM	334	19	3.13	2.42	0.82	0.13
	Y	1018	36	5.05	2.89	0.81	0.08
TR-PM st3	SWM	96	7	1.36	1.73	0.89	0.20
	NEM	232	13	2.28	2.38	0.93	0.09
	SM	127	7	1.34	1.89	0.97	0.10
	Y	455	18	2.78	2.75	0.95	0.05
TR-PM st4	SWM	154	5	0.79	0.70	0.43	0.69
	NEM	48	2	0.26	0.51	0.74	0.67
	SM	159	13	2.37	1.77	0.69	0.29
	Y	361	14	2.21	1.64	0.62	0.30
TR-PM st5	SWM	87	7	1.37	1.65	0.85	0.24
	NEM	71	8	1.70	1.95	0.94	0.14
	SM	351	18	2.97	2.43	0.84	0.10
	Y	509	27	4.17	2.86	0.87	0.07

Table 4.3 (Continued) Abundance, number of species, species richness (D), species diversity index (H), evenness index (J) and species dominance index (C) of 30 sampling stations in 3 seasons and all seasons.

Stations	Seasons	Abundance (individuals)	Number of species	D	H	J	C
TR-PM st6	SWM	183	7	1.16	1.55	0.80	0.25
	NEM	23	5	1.31	1.52	0.94	0.23
	SM	366	17	2.75	1.76	0.62	0.27
	Y	572	26	3.94	2.40	0.74	0.14
TR-CM st1	SWM	288	10	2.14	1.50	0.65	0.01
	NEM	43	8	2.00	1.92	0.92	0.11
	SM	31	5	1.16	1.47	0.92	0.25
	Y	362	22	3.56	2.16	0.70	0.01
TR-CM st2	SWM	51	6	1.47	1.48	0.83	0.18
	NEM	78	8	1.68	1.83	0.88	0.16
	SM	51	7	1.60	1.74	0.89	0.17
	Y	180	16	2.89	2.32	0.84	0.12
TR-CM st3	SWM	62	7	1.67	1.64	0.84	0.10
	NEM	52	6	1.38	1.68	0.94	0.12
	SM	39	4	0.82	1.03	0.75	0.46
	Y	153	15	2.78	2.41	0.89	0.08
TR-YL st1	SWM	136	3	0.41	0.43	0.39	0.79
	NEM	28	4	0.97	1.12	0.81	0.37
	SM	53	7	1.59	1.80	0.93	0.17
	Y	217	9	1.49	1.40	0.64	0.37

Table 4.3 (Continued) Abundance, number of species, species richness (D), species diversity index (H), evenness index (J) and species dominance index (C) of 30 sampling stations in 3 seasons and all seasons.

Stations	Seasons	Abundance (individuals)	Number of species	D	H	J	C
TR-YL st2	SWM	48	3	0.52	0.78	0.71	0.55
	NEM	50	4	1.00	1.09	0.79	0.06
	SM	64	3	0.49	0.50	0.45	0.74
	Y	162	6	0.98	1.52	0.85	0.22
TR-YL st3	SWM	70	3	0.47	0.83	0.75	0.49
	NEM	41	5	1.16	1.57	0.98	0.15
	SM	23	3	0.64	1.03	0.94	0.37
	Y	134	5	0.82	1.30	0.81	0.32
ST-PR st1	SWM	185	15	2.68	2.39	0.88	0.12
	NEM	93	15	3.09	2.32	0.86	0.15
	SM	176	19	3.48	2.48	0.84	0.12
	Y	454	39	6.21	3.08	0.84	0.06
ST-PR st2	SWM	86	8	1.57	1.81	0.87	0.20
	NEM	134	14	2.65	1.86	0.70	0.27
	SM	43	7	1.60	1.82	0.93	0.18
	Y	263	17	2.87	2.09	0.74	0.19
ST-PR st3	SWM	285	8	1.24	0.87	0.42	0.62
	NEM	75	6	1.16	1.65	0.92	0.21
	SM	112	12	2.33	2.26	0.91	0.12
	Y	472	17	2.60	1.88	0.66	0.29

Table 4.3 (Continued) Abundance, number of species, species richness (D), species diversity index (H), evenness index (J) and species dominance index (C) of 30 sampling stations in 3 seasons and all seasons.

Stations	Seasons	Abundance (individuals)	Number of species	D	H	J	C
ST-BB st1	SWM	64	4	0.72	1.05	0.76	0.44
	NEM	257	13	2.16	1.99	0.77	0.20
	SM	172	12	2.14	1.74	0.70	0.28
	Y	493	25	3.87	2.44	0.76	0.13
ST-BB st2	SWM	70	5	0.94	1.07	0.66	0.44
	NEM	274	18	3.03	2.10	0.73	0.20
	SM	121	10	1.88	1.57	0.68	0.30
	Y	465	22	3.42	2.28	0.74	0.15
ST-BB st3	SWM	74	4	0.70	0.82	0.59	0.58
	NEM	254	14	2.35	1.93	0.73	0.23
	SM	163	11	1.96	1.62	0.67	0.33
	Y	491	24	3.71	2.33	0.73	0.15
ST-BB st4	SWM	82	4	0.68	0.50	0.36	0.78
	NEM	407	17	2.66	1.87	0.66	0.28
	SM	73	8	1.63	1.77	0.85	0.23
	Y	562	22	3.32	2.18	0.71	0.19
ST-BB st5	SWM	70	4	0.71	0.78	0.56	0.60
	NEM	210	12	2.06	1.73	0.70	0.25
	SM	234	14	2.38	1.42	0.54	0.43
	Y	514	25	3.84	2.22	0.69	0.18

Table 4.3 (Continued) Abundance, number of species, species richness (D), species diversity index (H), evenness index (J) and species dominance index (C) of 30 sampling stations in 3 seasons and all seasons.

Stations	Seasons	Abundance (individuals)	Number of species	D	H	J	C
ST-BB st6	SWM	74	3	0.46	0.58	0.53	0.68
	NEM	153	8	1.39	1.36	0.66	0.34
	SM	95	7	1.32	1.02	0.53	0.56
	Y	322	14	2.25	1.40	0.53	0.43

Note: SWM = Southwest monsoon, NEM = Northeast monsoon, SM = summer,

Y = all seasons

4.3.4 Common species and dominant species of benthic macrofauna

Common species of benthic macrofauna defined as organisms typically found in all seasons in particular beach. The common species of this study were 20 species including 11 species of polychaetes, 4 species of mollusks and 5 species of crustaceans. The common polychaetes species were *Glycera alba*, *Goniadopsis incerta*, *Scoloplos* (*Scoloplos*) *tumidus*, *Prionospio* (*Prionospio*) *steenstrupi*, *Axiothella obockensis*, *Lumbrineris* sp. 2, *Scoletoma* sp. 3, *Glycera natalensis*, *Paraprionospio* sp., *Mediomastus* sp. and *Dendronereis arborifera*. The 4 common mollusks were *Donax incarnates*, *Donax faba*, *Umbonium vestiarium* and *Pitar* sp. The 5 common crustaceans were *Matuta victor*, *Dotilla intermedia*, *Diogenes dubius*, *Diogenes klassi*, *Ocypode macrocera*. Of these common species, *Glycera alba* were frequently encountered. It was found living in 6 beaches of 8 sampling beaches. The following common species were *Donax incarnates*, *Donax faba* and *Dotilla intermedia*. These species were found on 4 beaches. With the lack of faunal communities of these areas, the results could be used as reference states for coastal and platform communities of the sampled stations. The common species varied among beaches are shown in Table 4.4. In addition, *Glycera alba* lived in broadly sandy habitats and it was determined as group IV of ecological indicator (Borja et al., 2000). All the common bivalve species were group I to indicate normal conditions. Paolo, Nicoletti, Finoia, and Ardizzone (2011) reported that a Donacidae could help pinpoint the presence of natural or human-made phenomena that led to grain-size variations in the sediment. In Table 4.5, Donacidae were also found as dominant species in some sampling beaches.

Table 4.4 Common species of benthic macrofauna found at the beaches during sampling period.

Krabi	Trang	Satun
Nopparathara beach	**Pak Meng beach**	**Pak Bara beach**
Glycera alba (Pol)	*Scoloplos* (*Scoloplos*)	*Scoloplos* (*Scoloplos*)
Goniadopsis incerta (Pol)	*tumidus* (Pol)	*tumidus* (Pol)
Donax incarnatus (Mol)	*Prionospio* (*Prionospio*)	*Glycera alba* (Pol)
Donax faba (Mol)	*steenstrupi* (Pol)	*Donax incarnatus* (Mol)
Ao-nang beach	*Glycera alba* (Pol)	*Donax faba* (Mol)
Glycera alba (Pol)	*Goniadopsis incerta* (Pol)	*Diogenes klassi* (Cru)
Donax faba (Mol)	*Lumbrineris* sp. 2 (Pol)	*Dotilla intermedia* (Cru)
Umbonium vestiarium (Mol)	*Donax incarnatus* (Mol)	**Pak Bang beach**
Matuta victor (Cru)	*Diogenes dubius* (Cru)	*Paraprionospio* sp. (Pol)
Nam Mao beach	*Dotilla intermedia* (Cru)	*Mediomastus* sp. (Pol)
Scoloplos (*Scoloplos*)	**Chao Mai beach**	*Dendronereis arborifera*
tumidus (Pol)	*Glycera alba* (Pol)	(Pol)
Axiothella obockensis (Pol)	*Glycera natalensis* (Pol)	*Donax faba* (Mol)

Table 4.4 (Continued) Common species of benthic macrofauna found at the beaches during sampling period.

Krabi	Trang	Satun
Glycera alba (Pol)	*Umbonium vestiarium* (Mol)	*Pitar* sp. (Mol)
Lumbrineris sp. 2 (Pol)	*Diogenes dubius* (Cru)	*Diogenes klassi* (Cru)
Scoletoma sp. 3 (Pol)	**Yong Ling beach**	*Ocypode macrocera* (Cru)
Donax faba (Mol)	*Glycera alba* (Pol)	
Umbonium vestiarium (Mol)	*Donax incarnates* (Mol)	
Dotilla intermedia (Cru)	*Dotilla intermedia* (Cru)	

Note : Pol = Polychaetes, Mol = Molusks, Cru = Crustaceans

The dominant species of benthic macrofauna defined as the most frequently occurring species. In this study, the percent abundance of a species in each station during the sampling period was calculated by its relative number. It is the encountered number of a species against the total number of individuals in the sampling station. The highest relative abundance of the species represented its dominance. The dominant species accounted 15 species including 4 polychaete species i.e. *Scoloplos* (*Leodamas*) *gracilis*, *Lumbrineris* sp. 2, *Lumbrineris heteropoda*, *Scoloplos* (*Scoloplos*) *tumidus*, *Prionospio* (*Prionospio*) *steenstrupi*, *Glycera alba* and *Dendronereis arborifera*. The 6 dominant mollusk species were *Umbonium vestiarium*, *Donax incarnatus*, *Donax cuneatus*, *Pitar* sp. *Donax faba* and *Pillucina* sp. Only 2 crustacean species including *Diogenes dubius* and *Dotilla intermedia* were dominated. Some macrobenthic fauna species dominated in several stations e.g. *Donax faba*, *Dotilla intermedia* and *Scoloplos* (*Leodamas*) *gracilis*. The dominant species found at the stations during sampling period and the percent abundance of the species are shown in Table 4.5.

Table 4.5 Dominant species of benthic macrofauna found at the stations during sampling period and the percent abundance in each station of the species.

Stations	Dominant species	Abundance (%)
KB-NT st1	*Scoloplos* (*Leodamas*) *gracilis* (Pol)	14
KB-NT st2	*Umbonium vestiarium* (Mol)	19
KB-NT st3	*Donax incarnatus* (Mol)	27
KB-AN st1	*Donax cuneatus* (Mol)	19
KB-AN st2	*Diogenes dubius* (Cru)	29
KB-AN st3	*Scoloplos (Leodamas) gracilis* (Pol)	34
KB-NM st1	*Donax faba* (Mol)	29
KB-NM st2	*Lumbrineris* sp. 2 (Pol)	26
KB-NM st3	*Lumbrineris* sp. 2 (Pol)	27
TR-PM st1	*Pillucina* sp. (Mol)	34
TR-PM st2	*Lumbrineris heteropoda* (Pol)	18
TR-PM st3	*Scoloplos* (*Scoloplos*) *tumidus* (Pol)	12
TR-PM st4	*Dotilla intermedia* (Mol)	49
TR-PM st5	*Pillucina* sp. (Mol)	13
TR-PM st6	*Prionospio (Prionospio) steenstrupi* (Pol)	28
TR-CM st1	*Scoloplos (Leodamas) gracilis* (Pol)	34
TR-CM st2	*Glycera alba* (Pol)	31
TR-CM st3	*Glycera alba* (Pol)	22
TR-YL st1	*Dotilla intermedia* (Cru)	57
TR-YL st2	*Donax incarnatus* (Cru)	37
TR-YL st3	*Dotilla intermedia* (Cru)	44
ST-PR st1	*Glycera alba* (Pol)	12
ST-PR st2	*Dotilla intermedia* (Cru)	38
ST-PR st3	*Dotilla intermedia* (Cru)	51
ST-BB st1	*Donax faba* (Mol)	24
ST-BB st2	*Donax faba* (Mol)	24
ST-BB st3	*Pitar* sp. (Mol)	27
ST-BB st4	*Dendronereis arborifera* (Pol)	37

Table 4.5 (Continued) Dominant species of benthic macrofauna found at the stations during sampling period and the percent abundance in each station of the species.

Stations	Dominant species	Abundance (%)
ST-BB st5	*Donax faba* (Mol)	35
ST-BB st6	*Donax faba* (Mol)	64

Note : Pol = Polychaetes, Mol = Molusks, Cru = Crustaceans

4.3.5 Community of benthic macrofauna similarities of sampling stations

The resultant similarity matrix of sampling stations based on benthic macrofauna community was subjected to cluster analysis and nonmetric multidimensional scaling (MDS).

Benthic macrofauna abundance data was forth root transformed to reduce the effect of dominant species on the analysis. A ranked similarity matrix was conducted on abundance data (individual/2.25 m^2) of each species at all stations. The similarity was conducted by using Bray and Curtis similarity. The species that contributed to 75% of the average dissimilarities among stations were identified using the similarities percentages procedure.

Similarity of species found among sampling stations was related to its abundance and number of species. When sampling stations were compared by Bray and Curtis similarity, it generated a grouping of the sampling stations into three groups. The three distinct groups were identified with 35% similarity between the clusters. Cluster 1 consisted of all 9 sampling stations in Satun province and cluster 2 consisted of 17 sampling stations from Krabi and Trang provinces. Cluster 3 was consisted of TR-PM st4, TR-YL st1, TR-YL st2 and TR-YL st3 in Trang province.

These results showed that overall benthic macrofauna communities of sampling stations in Satun province were homogeneity whereas in Krabi and Trang provinces were clustered into the same group. These results showed the distinction of benthic macrofauna communities in Satun province, that is, sampling stations in Satun province had different types of species or number of species to Krabi and Trang sampling stations. The results in Table C1.1, C1.2 and C1.3 showed that Satun province had 41 benthic macrofauna species that also found in Krabi or Trang provinces whereas the species found in both Krabi and Satun provinces were 58 species. The 26 species of benthic macrofauna were found in all three provinces including 11 species of polychaetes, 9 species of mollusks and 6 species of crustaceans. These polychaetes were *Scoloplos* (*Scoloplos*) *tumidus*, *Scolelepis* (*Scolelepis*) sp., *Prionospio* (*Prionospio*) *steenstrupi*, *Phyllodoce* sp., *Neanthes caudata*, *Glycera alba*, *Glycera natalensis*, *Glycera* sp., *Goniadopsis incerta*, *Scoletoma* sp. 2, and *Scoletoma* sp. 3. The mollusks included *Donax incarnatus*, *Donax faba*, *Umbonium vestiarium*, *Natica vitellus*, *Nassarius pullus*, *Nassarius livescens*, *Nassarius jacksonianus*, *Nassarius stolatus* and *Turricula javana*. The crustaceans consisted of *Diogenes klassi*, *Matuta victor*, *Dotilla intermedia*, *Ocypode macrocera*, *Scopimera proxima* and *Macrophthalmus convexus*. Furthermore, in the case of all station similarity, the results exhibited moderate similarity (20% similarity). When this cluster was compared with the water variables, sediment variables and sediment particle sizes clusters, the sampling stations grouping obtained from benthic macrofauna abundant similarity superimposed the water variables cluster rather than those 2 clusters. The dendrogram in Figure 4.8 showed the results of the cluster analysis from the different stations.

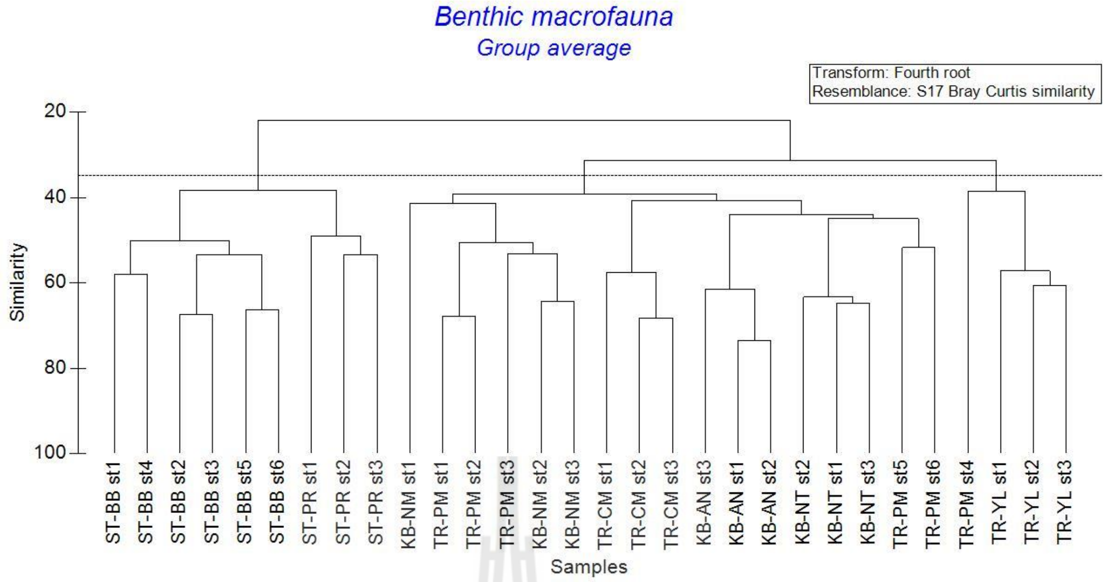


Figure 4.8 A dendrogram of cluster analysis illustrated species abundance similarity among 30 stations.

The groups of sampling stations subjected by multidimensional scaling (MDS) showed that the results of cluster analysis coincided results with MDS at 35% similarity. A stress value was calculated for the MDS procedure. It is a useable measure of the relationship among the sampling stations that was represented by the MDS. A value < 0.10-0.20 is considered to provide a good representation (Clarke and Warwick, 2001). Two-dimensional ordination plot from multidimensional scaling analysis of the 30 sampling stations examining species similarity among stations is shown in Figure 4.9.

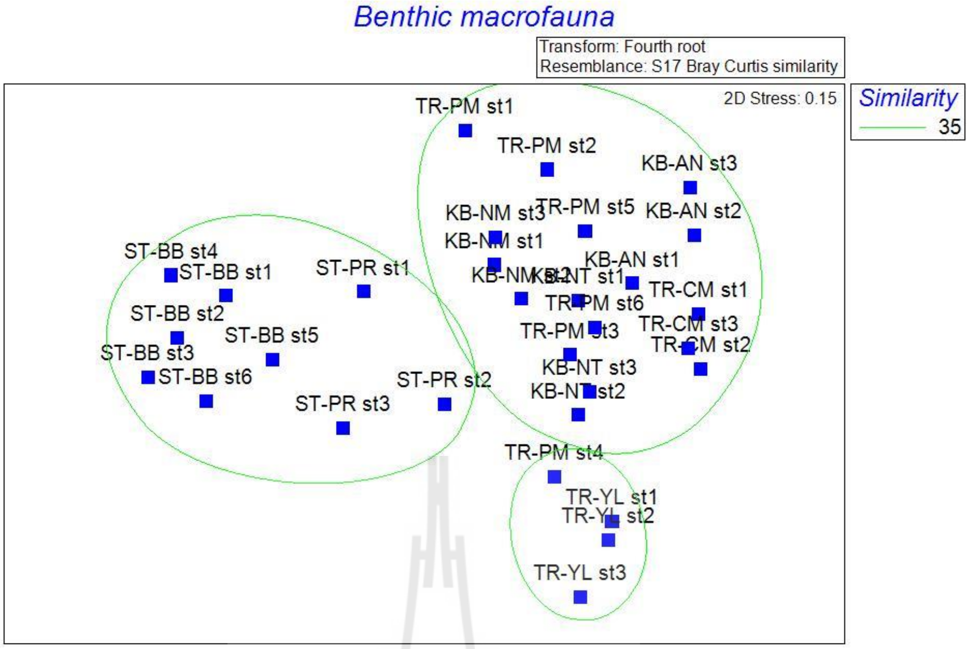


Figure 4.9 Two-dimensional MDS configuration for forth root transformed benthic macrofauna assemblages of 30 stations using sum seasonal data (stress value = 0.15).

The species and the number of individuals of TR-PM st4, TR-YL st1, TR-YL st2 and TR-YL st3 that were collected during the Southwest monsoon, the Northeast monsoon and the summer seasons were separated from other stations. In general, differences between sampling stations of Krabi, Trang and Satun provinces seemed to be due to the differences between types of presented species. Meanwhile, the differences of those 4 sampling stations were due to the difference in the number of species that were only represented by a few numbers. Moreover, the abundances of crustaceans were higher than other benthic macrofauna groups presenting in those sampling stations (Table 4.3, C1.1 and C1.2). These lower number of benthic macrofauna found in TR-PM st4, TR-YL st1, TR-YL st2 and TR-YL st3 compared to the other sampling stations. However, unpolluted and unanoxic conditions were observed in the analysed water and sediment during the sampled seasons, therefore, the depletion of faunal communities by the reducing conditions in the areas could not be explained by pollution. This result may be influenced by the other beach physical characteristics. Its open areas and the moderate slope could potentially be an artifact of low taxonomic resolution of the taxa found here (Jaramillo et al., 1995).

4.4 Biodata and ecological relation

Many studies of benthic macrofauna communities were reported but a few researches speculated on the extant community relationship to their ecological characteristics especially on the sandy beaches. This study attempted to completely describe the intertidal communities of the 8 sampling beaches. Principle component analysis (PCA) were analysed to obtain the most meaningful variables. A stepwise linear regression was a predictive relationship among a biodata index (dependent variable) and ecological variables (independent variables).

4.4.1 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is one of the best multivariate statistical techniques for extracting linear relationships among a set of variables (Simeonov et al., 2003). It is a pattern recognition tool that attempt to explain the variance of a large data set of inter-correlated variables with a smaller set of variables and provides information on the significant parameters with minimum loss of original information (Singh, Malik, Mohan, and Sinha,, 2004). The PCA was applied on the ecological variables data with the aim of identifying the main variables. Eighteen physico-chemical water and sediment quality variables were selected for analysis (Table 4.6, 4.7 and 4.8). The environmental variable data were normalized and the draftsman plotted correlation were setup for checking the normal distribution of the data before analysis. The PCA investigated the origin of each environmental variable and yielded best 2 varimax factors.

The results showed that the tool could reduce the contribution of less significant variables to simplify even more of the data structure coming from PCA. The environmental variable data could be achieved by rotating the axis defined by PCA. The measure of sampling adequacy obtained by eigenvalues, indicating that the degree of correlation among the variables and the appropriateness of PCA was valid. The factors that have eigenvalues greater than one are retained for interpretation (Fabrigar, Wegener, MacCallum, and Strahan, 1999). However, for this research, the 2 best Principal Components (PCs) were interpreted. The eigenvalues of the PCs and correlated matrixes were achieved.

The result of PCA on ecological variables of sampled stations in Krabi province showed that PC1 (eigenvalue = 4.72) explained 26.1% of total variance. It had strong positive coefficient on nitrate concentration and phosphate concentration in their sediments and strong negative coefficient on sediment particle size 0.075 mm and <0.075 mm. The 13 retained variables had moderate positive or negative coefficient. Moreover, the coefficient of nitrate concentration in water was relatively low when explained by the matrix of the PC1. The PC2 had strong positive coefficient on sediment pH, turbidity and BOD and strong negative coefficient on DO and nitrate concentration in water. The PC2 explained 20.1% of total variance. In addition, the estimate coefficient of the model presented in Table 4.9 supported the PCA result. The PC1 could similarly explain the main variables as stepwise multiple regression. It is clear that phosphate concentration in water, salinity, turbidity, nitrate concentration in sediment and sediment particle size 0.71 mm exhibited to be considerable parameters for the sampled beach environment in Krabi province. The PCA result after rotation, including the eigenvalues, the amount of variance explained by each PC and the cumulative variance are shown in Figure 4.10 and Table 4.6

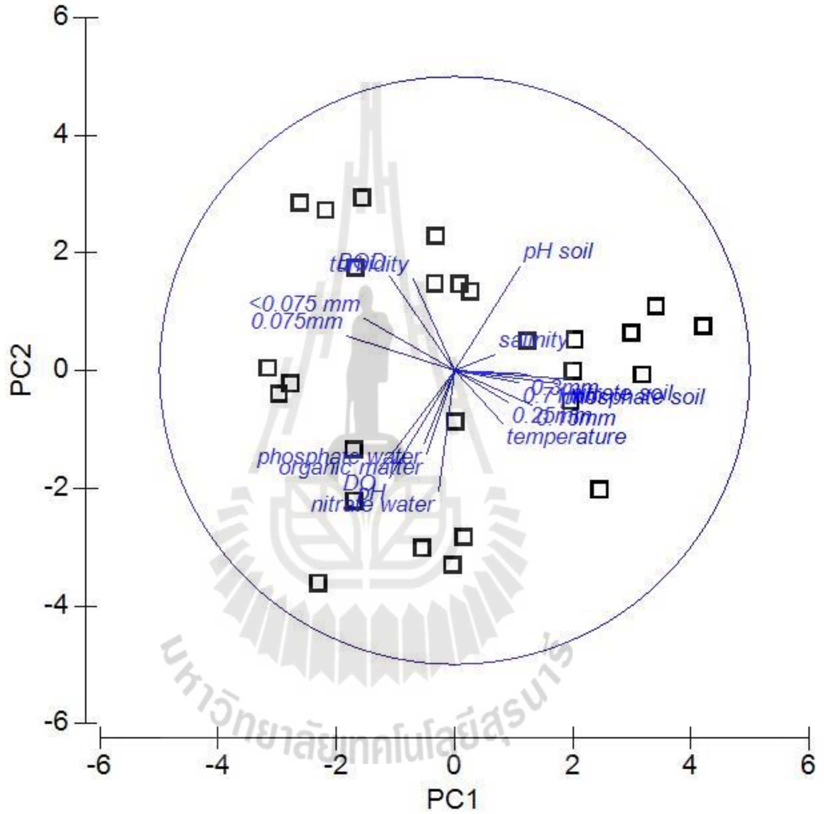


Figure 4.10 A PCA ordination illustrated first two principal components based on ecological variables of sampling stations in Krabi province. Length of the lines indicates the strength of the component.

□ = Sampling stations

Table 4.6 Summary of the PCA coefficients in the linear combinations of ecological variables from Krabi province and eigenvalues of the two best principle components.

Eigenvectors (Coefficients in the linear combinations of variables making up PC's)		
Variables	PC1	PC2
pH sediment	0.223	0.356
nitrate in sediment	0.375	-0.029
phosphate in sediment	0.350	-0.044
organic matter	-0.094	-0.284
0.71mm	0.218	-0.041
0.3mm	0.245	-0.012
0.25mm	0.182	-0.109
0.15mm	0.261	-0.118
0.075mm	-0.367	0.117
<0.075 mm	-0.307	0.178
pH	-0.224	-0.369
DO	-0.253	-0.338
temperature	0.162	-0.179
salinity	0.135	0.054
nitrate in water	-0.055	-0.413
phosphate in water	-0.103	-0.248
turbidity	-0.140	0.312
BOD	-0.220	0.320
Eigenvalues	4.72	3.63
Variation (%)	26.2	20.1
Cumulative Variation (%)	26.2	46.4

Figure 4.11 and Table 4.7 summarize the PCA result after rotation of ecological variables from sampled stations of Trang province. PC1 explained 22.5%

of total variance with 4.06 of eigenvalue. Five factors had strong negative coefficient. They were phosphate in sediment, organic matter content, DO, phosphate concentration in water and BOD. The factors that had low positive or negative coefficients were sediment size 0.71 mm, 0.25 mm, 0.075 mm, <0.075 mm and salinity. The retained variables had moderate positive or negative coefficients. PC2 had strong negative coefficients to pH sediment and sediment particle size 0.075 mm whereas sediment particle size 0.3 mm, 0.25 mm and salinity had strong positive coefficient. In addition, the estimate correlations of the model presented in Table 4.10 conformed to both PC1 and PC2. Phosphate concentration in sediment, sediment particle size 0.3, temperature and salinity were the main variables in these sampling stations. The PC2 had strong positive coefficient on sediment particle size 0.71 mm and 0.3 mm whereas the sediment particle size 0.15 mm and 0.075 mm had strong negative coefficient.

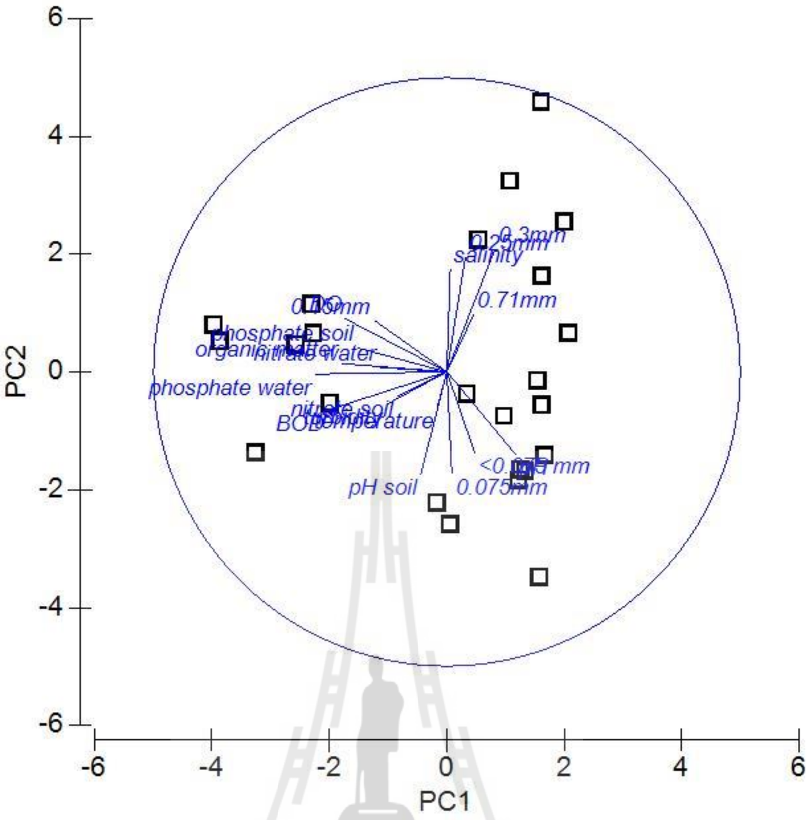


Figure 4.11 A PCA ordination illustrated first two principal components based on ecological variables of sampling stations in Trang province. Length of the lines indicates the strength of the component.

□ = Sampling stations

Table 4.7 Summary of the PCA coefficients in the linear combinations of ecological variables from Trang province and eigenvalues of the two best principle components.

Eigenvectors (Coefficients in the linear combinations of variables making up PC's)		
Variables	PC1	PC2
pH sediment	-0.089	-0.347
nitrate in sediment	-0.170	-0.083

Table 4.7 (Continued) Summary of the PCA coefficients in the linear combinations of ecological variables from Trang province and eigenvalues of the two best principle components.

Eigenvectors (Coefficients in the linear combinations of variables making up PC's)		
Variables	PC1	PC2
phosphate in sediment	-0.304	0.081
organic matter	-0.357	0.028
0.71mm	0.091	0.194
0.3mm	0.164	0.418
0.25mm	0.062	0.388
0.15mm	-0.247	0.175
0.075mm	0.017	-0.345
<0.075 mm	0.094	-0.274
pH	0.234	-0.281
DO	-0.346	0.181
temperature	-0.034	-0.123
salinity	0.012	0.350
nitrate in water	-0.226	0.015
phosphate in water	-0.450	-0.008
turbidity	-0.202	-0.108
BOD	-0.405	-0.130
Eigenvalues	4.06	3.77
Variation (%)	22.5	21.0
Cumulative Variation (%)	22.5	43.5

The result of PCA on ecological variables of sampled stations in Satun province showed that PC1 had strong negative on sediment particle size 0.25 mm, DO, temperature, salinity and phosphate in water. It explained 23.3% of total variance with 4.19 of eigenvalue. The sediment particle size 0.71 mm, <0.075 mm and BOD were minor coefficients. The retained variables had moderate negative or positive coefficients. The PCA result after rotation, including the eigenvalues, the amount of variance explained by each PC and the cumulative variance are shown in Figure 4.12 and Table 4.8

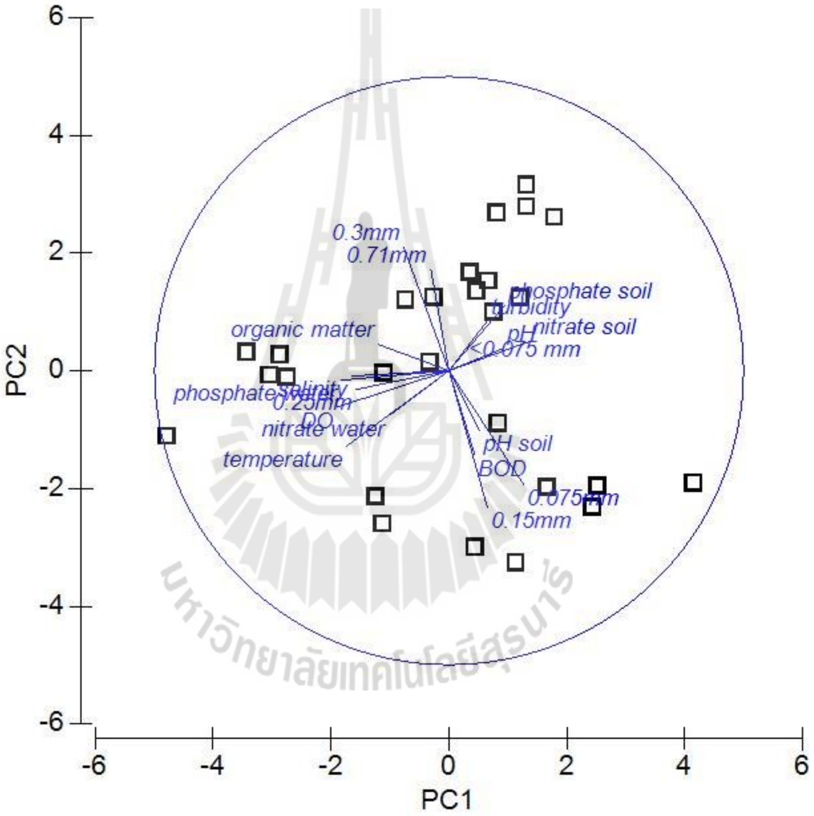


Figure 4.12 A PCA ordination illustrated first two principal components based on ecological variables of sampling stations in Satun province. Length of the lines indicates the strength of the component.

□ = Sampling stations

Table 4.8 Summary of the PCA coefficients in the linear combinations of ecological variables from Satun province and eigenvalues of the two best principle components.

Eigenvectors (Coefficients in the linear combinations of variables making up PC's)		
Variables	PC1	PC2
pH sediment	0.103	-0.205
nitrate in sediment	0.272	0.099
phosphate in sediment	0.189	0.222
organic matter	-0.239	0.089
0.71mm	-0.062	0.346
0.3mm	-0.154	0.419
0.25mm	-0.314	-0.063
0.15mm	0.131	-0.466
0.075mm	0.253	-0.388
<0.075 mm	0.056	0.024
pH	0.184	0.076
DO	-0.381	-0.124
temperature	-0.350	-0.258
salinity	-0.332	-0.018
nitrate in water	-0.202	-0.152
phosphate in water	-0.367	-0.032
turbidity	0.130	0.170
BOD	0.087	-0.288
Eigenvalues	4.19	3.62
Variation (%)	23.3	20.1
Cumulative variation (%)	23.3	43.3

4.4.2 Stepwise linear regression

Benthic macrofauna communities are influenced by complex relationships between their abundance and habitats. Distinct ecological variables differ the benthic macrofauna composition (Kratzer et al., 2006). Combinations of different features together by using multivariate statistical analyses are useful (Koklu, R., Sengorur, and Topal, 2010). In this study stepwise multiple linear regressions were performed to study the relationships between ecological variables (8 water variables and 10 sediment variables) and biological indices (4 indices). The ecological variables of all seasons and sampling stations in a province were compiled to a data set to fit in regression models. Stepwise multiple regressions were generated to fit models in steps, first selecting the variable that had the greatest correlation, followed by the second greatest, and so on. The independent variables were then fit into a linear regression equation. Multiple linear regressions identified the contribution of each variable with significant ($p<0.05$) and highly significant value ($p<0.01$). This indicated that, the slope of the estimated linear regression model was not equal to zero, confirming that, there was the linear relationship between the predictors of the models. For correcting the models, autocorrelations was also tested by Durbin and Watson score.

The 4 biological indices were used to detect whether or not the ecological variables would be related to the benthic macrofauna communities. The results showed that biological indices of 26 sampling stations related to the ecological variables with varied correlation. The r^2 values ranged from 0.199 to 0.745. Water variables correlated to the biotic indices were phosphate concentration in water, nitrate concentration in water, salinity, temperature, DO and turbidity. The sediment variables related to the indices were nitrate and phosphate concentration in sediment and sediment pH. The sediment particle sizes 0.71 mm, 0.3 mm and 0.075 mm were also related to the indices.

Benthic macrofauna communities of sampling stations at Krabi province exhibited 4 models of multiple regressions. The model (1) was the linear regression between species richness index (D) and the environmental data. The model explained that species richness was positively related to dissolved oxygen but the correlation was relatively low (r^2=0.199). This model could not be exactly used to predict the data because this model could explain only 19% of all data. However, the p value was between 0.00 and 0.02 which showed statistical relation between the ecological variables and the biological indices. The model (2) explained that species diversity (H) negatively related to phosphate and nitrate concentration in water with moderate relation. The model (3) had high correlation (r^2 = 0.745). It explained that the evenness index (J) had markedly negative relation with sediment particle size 0.71 mm, nitrate concentration in sediment, phosphate concentration in water and turbidity whereas salinity was positively related to this index. The model (4) showed positive relation between species dominance index (C) and nitrate concentration in sediment and phosphate concentration but the salinity result was inverse (r^2 = 0.605). Models of the regressions presenting the relations of biological indices and environmental variable of Krabi province are shown in Table 4.9. Moreover, partial regression plots provided additional insights into the patterns observed. The partial regression plots are shown in Figure D1.1(a) - D1.1(k).

Table 4.9 Summary of predictive models for the multiple regressions between biological indices and ecological variables of sampling stations in Krabi province.

Biological indices		Models	
D	=	2.821 + 0.253 (DO)……………………………..………………(1)	
		Durbin-Watson score [a]	1.120
		r^2	0.199
		p	0.000 – 0.020*
H	=	1.908 – 2.920 (Phosphate in water) – 0.33 (Nitrate in water).......(2)	
		Durbin-Watson score[a]	0.939
		r^2	0.345
		p	0.000 - 0.044*
J	=	1.422 – 0.05 (Sediment particle size 0.71 mm) + 0.73 (salinity) – 0.18 (Nitrate in sediment) – 0.693 (Phosphate in water) – 0.05 (Turbidity)…………………………………..…….…………….…(3)	
		Durbin-Watson score [a]	2.445
		r^2	0.745
		p	0.000 – 0.028*
C	=	1.807 + 1.094 (Phosphate in water) + 0.017 (Nitrate in sediment) – 0.051 (Salinity)…………………………………..……………(4)	
		Durbin-Watson score [a]	1.353
		r^2	0.605
		p	0.000 – 0.037*

Note : * Statistically significant ($p<0.05$), ** Statistically highly significant ($p<0.01$)

[a] If Durbin-Watson score is in the range of 0.531-2.531, it shows non autocorrelation between the dependent variable and independent variables (n=27) (Montgomery, Peck, and Vining, 2001).

Upon compiling the environment variables and biological indices to fit into the predictive models, stations TR-PM st4, TR-YL st1, TR-YL st2 and TR-YL st3 were excluded from the models due to the environmental data and biological indices of the stations were not fit into all stepwise regression models (P>0.05). These sampling stations had different benthic macrofauna communities may as a result of other ecological variables exceeding the relations given by these models. The multiple regression models of the sampling stations in Trang province showed 2 statistically related models. The relationship between biotic indices and ecological variables through multiple regression analysis indicated that the species richness showed significant and positive relation to phosphate concentration in sediment whereas a negative relationship was observed with sediment particle size 0.3 mm (model (5), $r^2 = 0.402$, p = 0.000 – 0.014). The species diversity index was positively related to water temperature and salinity (model (6), $r^2 = 0.553$, p =0.000 – 0.001). The evenness and species dominance indices were not related to ecological variables (p>0.05). The multiple linear regressions had some correlations to biological indices. These benthic macrofauna communities of this sampled stations may partial influenced by other factors. Even excluded TR-PM st4, TR-YL st1, TR-YL st2 and TR-YL st3, in Figure 4.11 a sampling station was low correlated with the ecological variables. The reduction in number of species observed in some stations of Trang beaches but the evenness and species dominance indices were remained mostly constant. These results possibly affected the models. The multiple regressions between biological indices and ecological variables of sampling stations in Trang province are shown in Table 4.10. The partial regression plots are shown in Figure D1.2(a) - D1.2(d).

Table 4.10 Summary of predictive models for the multiple regressions between biological indices and ecological variables of sampling stations in Trang province.

Biological indices		Models	
D	=	1.456 + 0.780 (Phosphate in sediment) – 0.028 (Sediment size 0.3 mm)……………………………..……………………………..(5)	
		Durbin-Watson score [a]	1.552
		r^2	0.402
		p	0.000 – 0.014*
H	=	– 21.829 + 0.658 (Temperature) + 0.143 (Salinity)…………..….(6)	
		Durbin-Watson score[a]	1.568
		r^2	0.553
		p	0.000 – 0.001**
J	=	---	
		No statistically significant (p>0.05)	
C	=	---	
		No statistically significant (p>0.05)	

Note : * Statistically significant (p<0.05), ** Statistically highly significant (p<0.01) [a]

[a] If Durbin-Watson score is in the range of 0.554-2.554, it shows non autocorrelation between the dependent variable and independent variables (n=24) (Mongomery et al., 2001).

The multiple linear regressions on biotic indices and environment variables of sampling stations in Satun province showed statistically significant relationships. Species richness index was negatively related to phosphate in water (model (7), r^2 = 0.411). Species diversity and evenness indices were positive relation with sediment particle size 0.075 but were negatively related to Phosphate concentration in water (model (8), r^2 = 0.629 and model (9), r^2 = 0.520). According to the model (10), the relation value was relatively high (0.702). The model explained that the species dominance index was positively related to phosphate concentration in water but there was negative relation with sediment pH. The multiple regressions between biological indices and ecological variables of sampling stations in Satun province are shown in Table 4.11. The partial regression plots are shown in Figure D1.3(a) - D1.3(g).

Table 4.11 Summary of predictive models for the multiple regressions between biological indices and ecological variables of sampling stations in Satun province.

Biological indices		Models	
D	=	2.066 – 0.027 (Phosphate in water)…………………..……....…(7)	
		Durbin-Watson score [a]	1.748
		r^2	0.411
		p	0.000**
H	=	1.597 – 0.018 (Phosphate in water) + 0.015 (Sediment size 0.075 mm)…………………………………...……………………..(8)	
		Durbin-Watson score[a]	1.526
		r^2	0.629
		p	0.000 – 0.011*
J	=	0.685 + 0.06 (Sediment size 0.075) – 0.03 (Phosphate in water)..(9)	
		Durbin-Watson score [a]	2.336
		r^2	0.520
		p	0.000 – 0.006**
C	=	0.727 + 0.007 (Phosphate in water) – 0.079 (Sediment pH)…...(10)	
		Durbin-Watson score [a]	1.760
		r^2	0.702

Table 4.11 (Continued) Summary of predictive models for the multiple regressions between biological indices and ecological variables of sampling stations in Satun province.

Biological indices	Models
	p 0.000 – 0.004**

Note : * Statistically significant (p<0.05), ** Statistically highly significant (p<0.01)

[a] If Durbin-Watson score is in the range of 0.531-2.531, it shows non autocorrelation between the dependent variable and independent variables (n=27) (Mongomery et al., 2001).

4.5 Application of AMBI to classify the beach health

The AZTI’s Marine Biotic Index (AMBI) was developed in 2000 and some years later the software was designed to establish the ecological quality of European coasts. This software originated for analysing the response of soft bottom communities to natural and man-induced changes in water and sediment quality (Borja et al., 2000; Borja and Dauer, 2008; Borja et al., 2012). Borja and Muxika (2005) claimed that the geographical areas where it has been applied extend over the Atlantic Ocean, Baltic Sea, Mediterranean Sea, North Sea, and Norwegian Sea, all in Europe, similarly, also in Hong Kong, Uruguay and Brazil. Consequently, the AMBI was once used in Thailand to evaluate the estuarine health at Pak Phanang, Nakhon Si Thammarat province which calculated polychaete assemblages in this area (Nootchareon, 2009). The author concluded that the ratio of dominant benthic groups, indicator species/groups and AMBI indicated the Pak Phanang River. So, in this study, the software version 5.0 for window 7 with updated benthic macrofauna species in June 2014 was applied for the calculation of the index and to assess the sampling beach health. Benthic macrofauna species encountered in 30 stations were uploaded to the program for AMBI value calculations. The analysis could determine most species into ecological groups which were group I, group II, group III, group IV and group V (see Table 2.2 for summary of the Biotic Coefficient and Biotic Index). The AMBI program could assign 58 species of 65 polychaete species. Of these some species were applied into family for determination of ecological groups. The polychaete species were defined as 5 ecological groups: 15 species in group I; 19 species in group II; 8 species in group III; 15 species in group IV; a species in group V and 7 species had no assignment. Mollusks were mainly assigned into group I which had 19 species whereas in group II had 11 species. Only 1 species of mollusks was defined in group III and 6 species had no assignment. This program was lack of crustacean determination. Only the hermit crabs were applied into an ecological group. The 3 *Diogenes* spp. were defined in group II. Moreover, a brachiopod was set into group I. The list of benthic macrofauna species found in all the stations and the AMBI assignment are shown in Table 4.12.

Table 4.12 List of benthic macrofauna species found in all the stations and its AMBI assigned ecological groups.

No.	Species	AMBI assignment	Group
	Polychaetes		
1	*Scoloplos* (*Leodamas*) *gracilis*	*Scoloplos* sp.	I
2	*Scoloplos* (*Scoloplos*) *marsupialis*	*Scoloplos* (*Scoloplos*) *marsupialis*	I
3	*Scoloplos* (*Scoloplos*) *tumidus*	*Scoloplos* sp.	I

Table 4.12 (Continued) List of benthic macrofauna species found in all the stations and its AMBI assigned ecological groups.

No.	Species	AMBI assignment	Group
4	*Scoloplos* (*Scoloplos*) sp. 1	*Scoloplos* sp.	I
5	*Scoloplos* (*Scoloplos*) sp. 2	*Scoloplos* sp.	I
6	*Scoloplos* (*Scoloplos*) sp. 3	*Scoloplos* sp.	I
7	*Magelona* cf. *cincta*	*Magelona cincta*	I
8	*Magelona conversa*	Magellonidae	I
9	*Magelona sacculata*	Magellonidae	I
10	*Euclymene annandalei*	*Euclymene annandalei*	I
11	*Axiothella obockensis*	*Axiothella* sp.	I
12	*Armandia* sp.	*Armandia* sp.	I
13	*Grubeulepis geayi*	*Grubeulepis geayi*	I
14	*Pisione* sp.	*Pisione* sp.	I
15	*Marphysa macintoshi*	Eunicidae	I
16	*Anaitides* sp.	*Anaitides* sp.	II
17	*Phyllodoce* sp.	*Phyllodoce* sp.	II
18	*Lepidonotus* sp.	*Lepidonotus* sp.	II
19	*Glycera natalensis*	Glyceranidae	II
20	*Glycera* sp.	*Glycera* sp.	II
21	*Diopatra amboinensis*	*Diopatra amboinensis*	II
22	*Diopatra semperi*	Onuphidae	II
23	*Diopatra sugokai*	Onuphidae	II
24	*Diopatra* sp. 1	Onuphidae	II
25	*Diopatra* sp. 2	Onuphidae	II
26	*Lumbrineris heteropoda*	*Lumbrineris heteropoda*	II
27	*Lumbrineris* sp. 1	*Lumbrineris* sp.	II
28	*Lumbrineris* sp. 2	*Lumbrineris* sp.	II
29	*Scoletoma* sp. 1	*Scoletoma* sp.	II
30	*Scoletoma* sp. 2	*Scoletoma* sp.	II
31	*Scoletoma* sp. 3	*Scoletoma* sp.	II

Table 4.12 (Continued) List of benthic macrofauna species found in all the stations and its AMBI assigned ecological groups.

No.	Species	AMBI assignment	Group
32	*Owenia fusiformis*	*Owenia fusiformis*	II
33	*Lanice conchilega*	*Lanice conchilega*	II
34	*Chone* sp.	*Chone* sp.	II
35	*Scolelepis* (*Scolelepis*) sp.	*Scolelepis* sp.	III
36	*Dispio latilamella*	*Dispio* sp.	III
37	*Mediomastus* sp.	*Mediomastus* sp.	III
38	*Asclerocheilus* sp.	*Asclerocheilus* sp.	III
39	*Eteone* sp.	*Eteone* sp.	III
40	*Neanthes* sp.	*Neanthes* sp.	III
41	*Tylonereis heterochaeta*	*Tylonereis* sp.	III
42	*Sternaspis andamanensis*	*Sternaspis* sp.	III
43	*Paraprionospio* cf. *oceanensis*	*Paraprionospio oceanensis*	IV
44	*Paraprionospio* sp.	*Paraprionospio* sp.	IV
45	*Prionospio* (*Prionospio*) *steenstrupi*	*Prionospio steenstrupi*	IV
46	*Aphelochaeta* sp.	*Aphelochaeta* sp.	IV
47	*Timarete* sp.	*Timarete* sp.	IV
48	*Chaetozone* sp. 1	Cirratulidae	IV
49	*Chaetozone* sp. 2	Cirratulidae	IV
50	*Monticellina* sp.	*Monticellina* sp.	IV
51	*Heteromastus filiformis*	*Heteromastus filiformis*	IV
52	*Heteromastus* sp. 1	*Heteromastus* sp.	IV
53	*Heteromastus* sp. 2	*Heteromastus* sp.	IV
54	*Heteromastus* sp. 3	*Heteromastus* sp.	IV
55	*Heteromastus* sp. 4	*Heteromastus* sp.	IV
56	*Neanthes caudata*	*Neanthes caudata*	IV
57	*Glycera alba*	*Glycera alba*	IV
58	*Capitellus branchiferus*	Capitellidae	V

Table 4.12 (Continued) List of benthic macrofauna species found in all the stations and its AMBI assigned ecological groups.

No.	Species	AMBI assignment	Group
59	*Ophelina* sp. 1	No assigned	-
60	*Ophelina* sp. 2	No assigned	-
61	*Sigambra pettiboneae*	No assigned	-
62	*Dendronereis arborifera*	No assigned	-
63	*Goniadopsis incerta*	No assigned	-
64	*Linopherus canariensis*	No assigned	-
65	*Peternaspis* sp.	No assigned	-
	Mollusks		
1	*Pillucina* sp.	Lucinidae	I
2	*Mactra olorina*	Mactridae	I
3	*Mactra cuneata*	Mactridae	I
4	*Siliqua fasciata*	Pharidae	I
5	*Siliqua radiata*	Pharidae	I
6	*Tellina* sp. 1	Tellinidae	I
7	*Tellina* sp. 2	Tellinidae	I
8	*Donax cuneatus*	*Donax* sp.	I
9	*Donax incarnatus*	*Donax* sp.	I
11	*Donax faba*	*Donax* sp.	I
12	*Donax scortum*	*Donax* sp.	I
13	*Gari* (*Psammotaea*) *elongata*	Psammobiidae	I
14	*Meretrix* sp.	*Meretrix* sp.	I
15	*Anomalocardia squamosa*	Veneridae	I
16	*Paphia gallus*	*Paphia gallus*	I
17	*Timoclea scabra*	Veneridae	I
18	*Timoclea imbricata*	Veneridae	I
19	*Circe scripta*	Veneridae	I
20	*Turricula javana*	*Turricula javana*	I
21	*Pitar* sp.	*Pitar* sp.	II

Table 4.12 (Continued) List of benthic macrofauna species found in all the stations and its AMBI assigned ecological groups.

No.	Species	AMBI assignment	Group
22	*Umbonium vestiarium*	*Umbonium vestiarium*	II
23	*Cerithium coralium*	*Cerithium* sp.	II
24	*Natica tigrina*	*Natica tigrina*	II
25	*Natica vitellus*	*Natica vitellus*	II
26	*Polinices mammilla*	Naticidae	II
27	*Nassarius pullus*	*Nassarius* sp.	II
28	*Nassarius livescens*	*Nassarius* sp.	II
29	*Nassarius jacksonianus*	*Nassarius* sp.	II
30	*Nassarius stolatus*	*Nassarius* sp.	II
31	*Nassarius globosus*	*Nassarius* sp.	II
32	*Fragum fragum*	Cardiidae	III
33	*Anadora granosa*	No assigned	-
34	*Chlamys* sp.	No assigned	-
35	*Clithon oualaniensis*	No assigned	-
36	*Vexillum* sp.	No assigned	-
37	*Lodderia novemcarinata*	No assigned	-
38	*Atys cylindricus*	No assigned	-
	Crustaceans		
1	*Diogenes klassi*	*Diogenes* sp.	II
2	*Diogenes dubius*	*Diogenes* sp.	II
3	*Diogenes planimanus*	*Diogenes* sp.	II
4	*Philyra olivacea*	No assigned	-
5	*Philyra platycheira*	No assigned	-
6	*Matuta victor*	No assigned	-
7	*Dotilla intermedia*	No assigned	-
8	*Dotilla myctiroides*	No assigned	-
9	*Ocypode macrocera*	No assigned	-
10	*Ocypode ceratopthalma*	No assigned	-

Table 4.12 (Continued) List of benthic macrofauna species found in all the stations and its AMBI assigned ecological groups.

No.	Species	AMBI assignment	Group
11	*Scopimera proxima*	No assigned	-
12	*Macrophthalmus convexus*	No assigned	-
13	*Camptandrium sexdantatum*	No assigned	-
	Brachiopods		
1	*Lingula* sp.	*Lingula* sp.	I

As the above assignment, the benthic macrofauna communities of this study were interpreted to ecological status of 26 stations. According to low number of fauna species, the station TR-PM st4, TR-YL st1, TR-YL st2 and TR-YL st3 were excluded for analysis by this program. Low AMBI values are associated with the dominance of sensitive species and thus high quality environments, whereas high AMBI values are associated with the dominance of tolerant species and thus low quality environments. The M-AMBI was also calculated as it has been shown to simplify the value of sampling stations. In this study the M-AMBI was 0 to 1. AMBI value from this program was defined as: 0 - 1 = undisturbed/unpolluted; 2 - 3 = slightly disturbed/slightly polluted; 4 - 5 = moderately disturbed/meanly polluted; 6 = heavily disturbed/ heavily polluted; 7 = extremely disturbed/ extremely polluted. The results showed that the mean AMBI values of these sampling stations were in the range of 0.49 – 2.32 (Table 4.14). These numbers could interpret that the environment of all sampling stations still undisturbed or slightly disturbed. For seasonal data, the benthic macrofauna communities varied among seasons but the ecological groups were mainly in group I or group II. In different seasons, the sampling stations in Trang province showed high percentage of fauna species in group IV with the exception in TR-PM st1. In addition, a sampling station (KB-NT st3) in Krabi province and 2 sampling stations in Satun province (ST-PR st1 and ST-BB st2) had high percentage of benthic macrofauna in the ecological group IV in different seasons. Sampling station KB-NM st1 and KB-NM st3 of Nam Mao beach and station TR-PM st1, TR-PM st2 and TR-PM st6 of Pak Meng beach had benthic marofauna in ecological group V. The species is a first-order opportunistic species. Disturbed sediments are commonly invaded by opportunistic species, and this has in the past been considered a result of reduced competition (McLachlan and Brown, 2006). The species was only capable small colonization and the sensitive fauna has been dominated. The eventual return of the normal species was then assumed to result in the sensitive and transitional species being outcompeted. Although the group IV and V presented in the areas, the dominated community in those 5 stations were group I or II which classified as unpolluted or slightly impoverished benthic community. The percentage of benthic macrofauna species in ecological groups of 26 sampling stations in 3 seasons are shown in Table 4.13.

Table 4.13 Percentage of benthic macrofauna species in ecological groups of 26 sampling stations in 3 seasons.

Stations	Replicates	Ecological groups				
		I (%)	II (%)	III (%)	IV (%)	V (%)
KB-NT st1	SWM	74.1	0.0	11.1	14.8	0.0
	NEM	34.0	56.6	0.0	9.4	0.0
	SM	74.1	12.4	1.8	11.8	0.0

Table 4.13 (Continued) Percentage of benthic macrofauna species in ecological groups of 26 sampling stations in 3 seasons.

Stations	Replicates	Ecological groups				
		I (%)	II (%)	III (%)	IV (%)	V (%)
KB-NT st2	SWM	52.3	0.0	15.9	31.8	0.0
	NEM	50.6	35.3	0.0	14.1	0.0
	SM	34.0	41.2	0.0	24.7	0.0
KB-NT st3	SWM	43.3	0.0	26.7	30.0	0.0
	NEM	52.5	28.8	0.0	18.8	0.0
	SM	92.4	0.0	0.0	7.6	0.0
KB-AN st1	SWM	69.8	11.9	4.8	13.5	0.0
	NEM	67.0	20.0	0.0	13.0	0.0
	SM	60.7	26.7	0.0	12.6	0.0
KB-AN st2	SWM	86.0	0.0	7.0	7.0	0.0
	NEM	91.5	2.3	0.0	6.2	0.0
	SM	55.4	44.6	0.0	0.0	0.0
KB-AN st3	SWM	87.5	10.2	0.0	2.3	0.0
	NEM	62.8	21.8	0.0	15.4	0.0
	SM	80.7	18.5	0.0	0.7	0.0
KB-NM st1	SWM	73.2	17.1	2.4	7.3	0.0
	NEM	65.6	11.8	5.4	17.2	0.0
	SM	58.7	25.0	0.0	5.8	10.6
KB-NM st2	SWM	7.9	82.8	1.3	7.9	0.0
	NEM	65.6	32.0	0.0	2.5	0.0
	SM	52.7	37.9	0.0	9.3	0.0
KB-NM st3	SWM	32.4	58.4	0.0	2.2	7.0
	NEM	58.2	26.6	8.9	6.3	0.0
	SM	30.9	56.9	0.7	7.8	3.7
TR-PM st1	SWM	41.9	30.4	1.8	10.0	15.9
	NEM	80.3	18.1	1.6	0.0	0.0
	SM	23.5	68.1	0.6	6.8	1.0

Table 4.13 (Continued) Percentage of benthic macrofauna species in ecological groups of 26 sampling stations in 3 seasons.

Stations	Replicates	Ecological groups				
		I (%)	II (%)	III (%)	IV (%)	V (%)
TR-PM st2	SWM	17.1	71.4	2.9	5.7	2.9
	NEM	35.9	55.4	2.2	6.6	0.0
	SM	20.3	43.5	5.2	28.4	2.6
TR-PM st3	SWM	27.1	57.6	0.0	15.3	0.0
	NEM	46.5	40.8	1.3	11.4	0.0
	SM	47.7	0.0	20.9	31.4	0.0
TR-PM st5	SWM	63.5	11.5	7.7	17.3	0.0
	NEM	51.9	11.5	26.9	9.6	0.0
	SM	42.2	29.0	4.0	24.7	0.0
TR-PM st6	SWM	84.7	0.0	3.2	12.1	0.0
	NEM	26.1	73.9	0.0	0.0	0.0
	SM	12.1	38.9	1.4	46.6	1.1
TR-CM st1	SWM	81.9	14.9	0.0	3.1	0.0
	NEM	40.5	37.8	5.4	16.2	0.0
	SM	7.7	46.2	0.0	46.2	0.0
TR-CM st2	SWM	52.2	2.2	0.0	45.7	0.0
	NEM	17.9	42.3	0.0	39.7	0.0
	SM	31.1	35.6	0.0	33.3	0.0
TR-CM st3	SWM	45.6	54.4	0.0	0.0	0.0
	NEM	32.6	21.7	0.0	45.7	0.0
	SM	0.0	24.2	0.0	75.8	0.0
ST-PR st1	SWM	38.3	22.5	5.8	33.3	0.0
	NEM	7.2	79.7	0.0	13.0	0.0
	SM	24.5	44.0	20.8	10.7	0.0
ST-PR st2	SWM	69.8	24.5	0.0	5.7	0.0
	NEM	39.7	38.1	1.6	20.6	0.0
	SM	46.9	37.5	0.0	15.6	0.0

Table 4.13 (Continued) Percentage of benthic macrofauna species in ecological groups of 26 sampling stations in 3 seasons.

Stations	Replicates	Ecological groups				
		I (%)	II (%)	III (%)	IV (%)	V (%)
ST-PR st3	SWM	80.6	0.0	0.0	19.4	0.0
	NEM	76.1	16.9	0.0	7.0	0.0
	SM	42.2	26.7	20.0	11.1	0.0
ST-BB st1	SWM	81.3	18.8	0.0	0.0	0.0
	NEM	9.4	43.4	7.8	39.3	0.0
	SM	59.9	14.3	25.9	0.0	0.0
ST-BB st2	SWM	60.0	28.6	8.6	2.9	0.0
	NEM	19.3	63.7	6.7	10.4	0.0
	SM	51.3	21.4	18.8	8.5	0.0
ST-BB st3	SWM	78.4	13.5	8.1	0.0	0.0
	NEM	24.4	69.5	0.0	6.1	0.0
	SM	14.6	72.9	9.0	3.5	0.0
ST-BB st4	SWM	87.8	2.4	6.1	3.7	0.0
	NEM	42.3	20.2	16.1	21.4	0.0
	SM	4.4	82.4	13.2	0.0	0.0
ST-BB st5	SWM	91.7	0.0	8.3	0.0	0.0
	NEM	33.6	64.7	0.9	0.9	0.0
	SM	72.8	17.4	2.3	7.5	0.0
ST-BB st6	SWM	81.1	14.9	0.0	4.1	0.0
	NEM	76.0	13.0	0.0	11.0	0.0
	SM	82.2	11.1	6.7	0.0	0.0

Note: SWM = Southwest monsoon, NEM = Northeast monsoon, SM = summer

For application of benthic macrofauna community to interpret the ecological habitats, the results manifested that all sampling stations were defined as 2 ecological groups. Group I as undisturbed habitats included 11 sampling stations. Group II included all sampling stations of Trang province and some sampling stations of Krabi and Satun provinces (Table 4.14, Figure 4.13(a), 4.13(b) and 4.13(c)). Weisberg et al. (1997) stated that a benthic community responds to improvements in habitat quality in three progressive steps: the abundance increases; species diversity increases; and dominant species change from pollution-tolerant to pollution-sensitive species. The major benthic macrofauna encountered in this study was clearly in ecological group I and group II and the results of main ecological variables were in the range of Thailand Marine Water Quality Standard. Thus, these results were consistent. However, some species were not assigned in the program especially the common and dominant crustaceans. *Dendronereis arborifera* was a common species at Pak Bang beach and was a dominant species at ST-BB st4 but the AZTI program was not adding this species into an ecological group. This result may cause minor misinterpretation. The complete assignment by long monitoring period and offering the crustaceans to the program should be examined. Although AMBI values have been recognized as an efficient tool for detecting changes in benthic communities receiving impacts derived from human activities, the AMBI values were still indicating a major presence of European species rather than Asian ones. The typology within an eco-region must have its own reference conditions. The stations from different topologies must be analysed by own benthic community datasets (Borja et al., 2012). Interestingly, at station KB-AN st1, KB-AN st2 and KB-AN st3 had multiplicity of human activities that could be loaded pollutants to the marine environment. The benthic community inhabiting these environments is mirroring unaffected in pollutants and organic input. It is a fact that the marine environment can assimilate a certain quantity of domestic wastes without large adverse change in the sampled areas.

It is clear that nutrients in water and sediment, temperature, turbidity and sediment particle sizes associated with changing of the benthic macrofauna. Hence, the relative position of the sampling stations, changed and moved away from the mouth of estuaries would involve a change in the physico-chemical conditions (Borja et al., 2000).

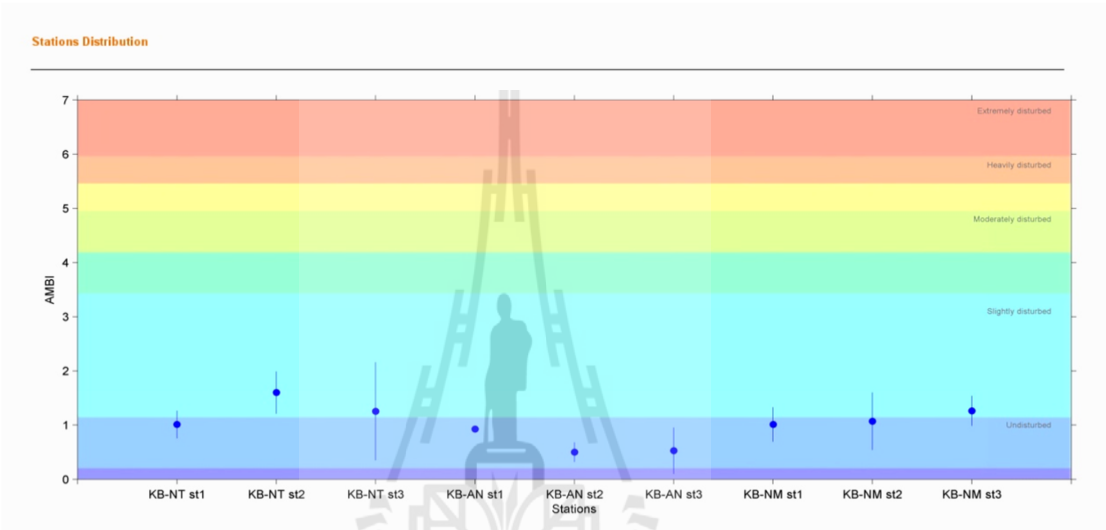
Table 4.14 Summary results of AMBI value and ecological status assessed by the benthic macrofauna communities.

Station	Number of species	AMBI	M-AMBI value	Ecological status
KB-NT st1	22	1.01	0.82	Undisturbed
KB-NT st2	14	1.60	0.65	Slightly disturbed
KB-NT st3	16	1.26	0.70	Slightly disturbed
KB-AN st1	20	0.93	0.76	Undisturbed
KB-AN st2	23	0.50	0.79	Undisturbed
KB-AN st3	24	0.53	0.78	Undisturbed
KB-NM st1	22	1.01	0.77	Undisturbed
KB-NM st2	26	1.07	0.82	Undisturbed
KB-NM st3	40	1.26	0.95	Slightly disturbed
TR-PM st1	42	1.21	0.97	Slightly disturbed
TR-PM st2	36	1.67	0.91	Slightly disturbed
TR-PM st3	18	1.59	0.78	Slightly disturbed
TR-PM st5	27	1.42	0.87	Slightly disturbed
TR-PM st6	26	1.51	0.80	Slightly disturbed
TR-CM st1	22	1.53	0.74	Slightly disturbed
TR-CM st2	16	2.18	0.67	Slightly disturbed
TR-CM st3	15	2.32	0.66	Slightly disturbed
ST-PR st1	39	1.85	0.92	Slightly disturbed
ST-PR st2	17	1.15	0.66	Undisturbed

Table 4.14 (Continued) Summary results of AMBI value and ecological status assessed by the benthic macrofauna communities.

Station	Number of species	AMBI	M-AMBI value	Ecological status
ST-PR st3	17	0.98	0.64	Undisturbed
ST-BB st1	25	1.31	0.76	Slightly disturbed
ST-BB st2	22	1.24	0.72	Slightly disturbed
ST-BB st3	24	1.09	0.75	Undisturbed
ST-BB st4	22	1.26	0.71	Slightly disturbed
ST-BB st5	25	0.65	0.77	Undisturbed
ST-BB st6	14	0.49	0.59	Undisturbed

In European coastal environment, the usual methods for identifying pollution effects on benthic communities are based on the species response to organic pollution and eutrophication (Pearson and Rosenberg, 1987). Most of the impact sources (outfalls, harbours, aquaculture, dredging etc.) on marine habitats produce increasing levels of organic loading, depletion of dissolved oxygen and spatial differences in the faunal distribution (Borja, Muxika, and Franco, 2003). A normally environmental variable of such ecological importance to coastal marine ecosystems that has changed so drastically and affected in such a short period is dissolved oxygen (Diaz and Rosenberg, 2008). In this study, the results obtained that the AMBI were compatible with using several methods for environmental and biological relation investigation. However, the ecological qualities of all sampling stations were unpolluted or slightly impoverished. The major environment variables were different from the European habitats. The benthic macrofauna communities still depended on natural factors such as temperature, salinity, nutrients and sediment particle sizes rather than organic matter content, BOD or DO depletion. The biological indices such as richness, diversity, evenness, species dominance, correlation plot by multivariate linear regression were visualised the benthic communities and their ecological habitat in the sampling stations.



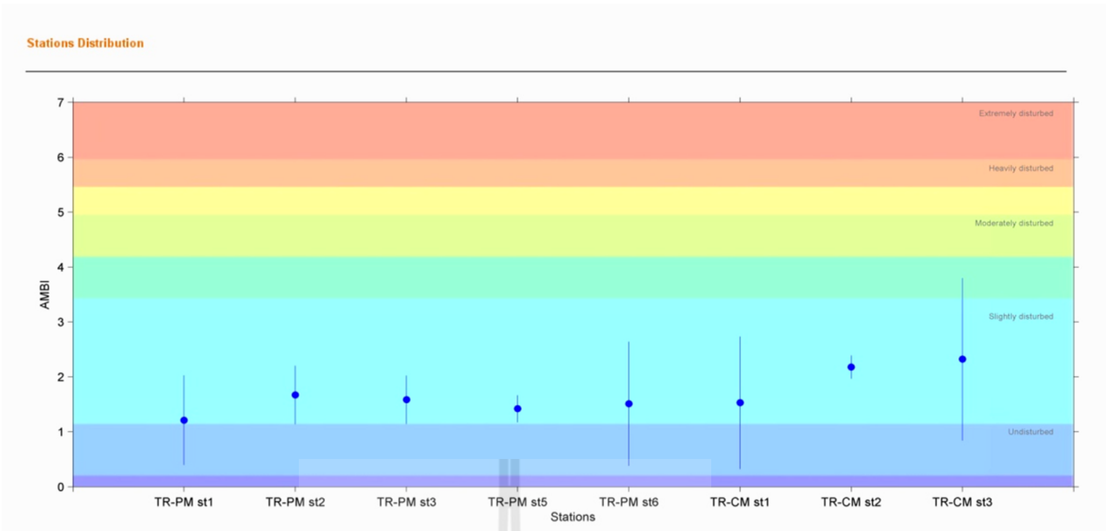
(a)

Extremely disturbed Heavily disturbed

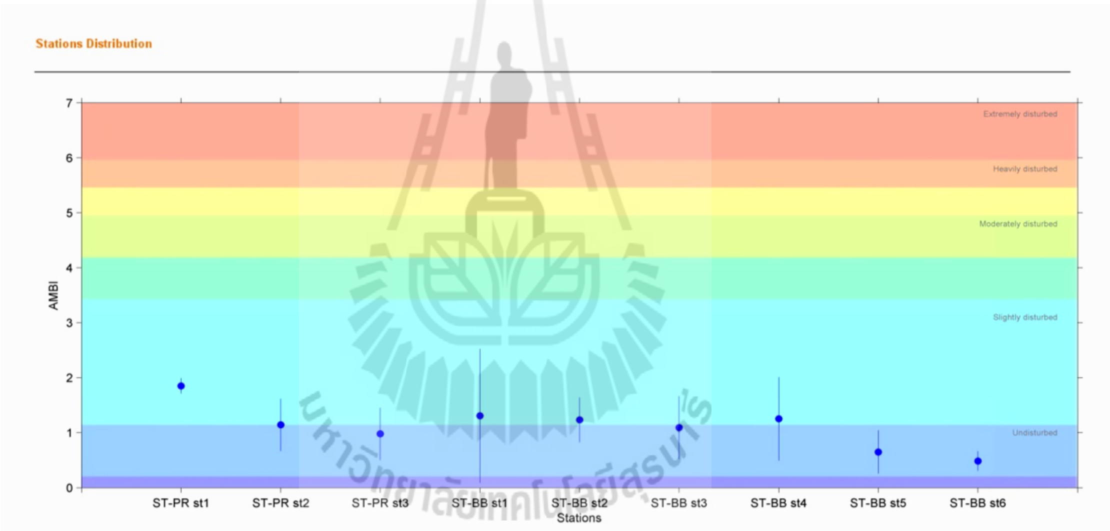
Moderately disturbed Slightly disturbed

Undisturbed

Figure 4.13 Means and standard error values of AMBI in three seasons interpreted by benthic macrofauna communities at all stations, (a) 9 sampling stations in Krabi province, (b) 8 sampling stations in Trang province, and (c) 9 sampling stations in Satun province.



(b)



(c)

Extremely disturbed   Heavily disturbed

Moderately disturbed   Slightly disturbed

Undisturbed

Figure 4.13 (Continued) Means and standard error values of AMBI in three seasons interpreted by benthic macrofauna communities at all stations (a) 9 sampling stations in Krabi province, (b) 8 sampling stations in Trang province, and (c) 9 sampling stations in Satun province.

Common and dominant crustaceans were found at the sampling stations but no assignment of crustaceans into an ecological group. Genus *Ocypode* is the most widespread of the Ocypodidae, is a much-studied animal and of all sandy-beach invertebrates has the most sophisticated behavior patterns. It is territorial and lives in semipermanent burrows near the top of the shore. Genus *Dotilla* is also essentially tropical and subtropical in its distribution. Its mouth parts are highly specialized for deposit sorting, and it shows very high efficiency in extracting organic material from organically poor sands (McLachlan and Brown, 2006). So, previous studies reported that *Dotilla myctiroides*, which can be found relatively in large numbers along the intertidal sandy-shore, is suggested to be a beneficial biomonitoring agent to indicate the present of heavy metals in their niches (Zulkifli, Ismail, and Mohamat-Yusuff, 2012). Barros (2001) and Neves and Bemvenuti (2006) found evidence suggesting significantly higher burrow density of ghost crabs in beaches with lower anthropogenic impact. Yong and Lim (2009) reported that human activities affect the abundance of *Ocypode ceratophthalma*, thereby establishing its potential as a bioindicator to assess the extent of human impact on the sandy beaches of Singapore. Considering the complexity of the beach ecosystem and develop alternative methods are needed to assess beach environmental health. A distinctive benthic group is aiming to obtain precisely assessment of an ecosystem condition. The crustacean group is satisfied to be added in the AMBI assessment.

The evaluation of beach ecosystem is nowadays become an important for pollution management in Thailand (Pollution control department, 2012). Water and sediment also have been widely applied to monitor beach pollution. However, they do not give a direct estimate of the availability of the pollutants to biota. The benthic macrofauna are found related to ecological variables of their habitats. The using benthic macrofauna as indicator to assess the beach health is the availability of quick methods to assess a beach ecosystem. Furthermore, besides physical and chemical, biological status should be included to environmental monitoring program of Thailand.

CHAPTER V

CONCLUSIONS

5.1 Conclusion

The study on beach quality assessment using benthic macrofauna along the southern Andaman Sea coast of Thailand was conducted in Krabi, Trang and Satun provinces. Of these, 8 beaches including Nopparatthara, Ao-nang, Nam Mao, Pak Meng, Chao Mai, Yong Ling, Pak Bara and Pak Bang beaches were studied. The ecological factors including 8 water variables, 4 sediment variables and 6 sediment particle sizes were measured in the sampling period which was carried out in 3 seasons: the Southwest monsoon (September-October, 2012), the Northeast monsoon (December, 2012) and the summer (March-April, 2013).

For overall results of water variables, most variables did not exceed the Thailand Marine Water Quality Standard. In exception for pH and DO at some studied stations, these values were slightly exceeded the standard but they still encouraged the benthic macrofauna growth. The sediment types of sampling stations were neutral to acidic with variation of nutrients and organic matter content. Sediment particle sizes also varied among the sampling beaches. In Krabi province, the substrates were determined to be very fine sand and fine sand. Sampling beaches in Trang province had very fine sand and medium sand whereas in Satun province had fine sand and medium sand. In the case of all station similarity based on ecological variable data, the results exhibited high similarity (83% similarity).

Benthic macrofauna from 8 beaches were also sampled during the 3 seasons. A total of 116 species were accounted belonging to 51 families, 20 orders, 5 classes of 4 phyla (Polychaeta, Mollusca, Arthropoda and Brachiopoda). The highest number of species was polychaetes followed by mollusks, crustaceans and brachiopods, respectively. The mean densities of benthic macrofauna in the sampling beaches were in the range of 23-935 individuals/2.25m^2. The similarity based on benthic macrofauna communities grouped sampling stations in Krabi and Trang provinces into the same group and it revealed the homogeneity of these sampling stations whereas sampling stations in Satun province were separated from those stations. The percentage of similarity was moderate at 21%. The highest species richness in each province was at Pak Meng beach station 1 in Trang, Nam Mao beach station 3 in Krabi and Pak Bara beach station 1 in Satun which the highest species richness of all sampling stations was at Pak Meang beach station 1. The lowest species richness in each province was at Yong Ling beach station 3 in Trang, Nopparatthara beach station 2 in Krabi and Pak Bang beach station 6 in Satun and the least species richness was at Yong Ling beach station 3.

The 11 common polychaetes species in the sampling beaches were *Glycera alba*, *Goniadopsis incerta*, *Scoloplos* (*Scoloplos*) *tumidus*, *Prionospio* (*Prionospio*) *steenstrupi*, *Axiothella obockensis*, *Lumbrineris* sp. 2, *Scoletoma* sp. 3, *Glycera natalensis, Paraprionospio* sp., *Mediomastus* sp. and *Dendronereis arborifera*. The 4 common mollusks were *Donax incarnates*, *Donax faba*, *Umbonium vestiarium* and *Pitar* sp. The 5 common crustaceans were *Matuta victor, Dotilla intermedia, Diogenes dubius*, *Diogenes klassi* and *Ocypode macrocera*.

The dominant species accounted 15 species including 4 polychaete species i.e. *Scoloplos* (*Leodamas*) *gracilis*, *Lumbrineris* sp. 2, *Lumbrineris heteropoda*, *Scoloplos* (*Scoloplos*) *tumidus*, *Prionospio* (*Prionospio*) *steenstrupi*, *Glycera alba* and *Dendronereis arborifera*. The 6 dominant mollusk species were *Umbonium vestiarium*, *Donax incarnatus*, *Donax cuneatus*, *Pitar* sp. *Donax faba* and *Pillucina* sp. Only 2 crustacean species including *Diogenes dubius* and *Dotilla intermedia* were dominated.

The principal component analysis extracted minor variables and could illustrate major variables of sampling stations. The ecological variables and biological indices fitting models on the stepwise multiple linear regression analysis revealed that the water variables; phosphate concentration in water, nitrate concentration in water, salinity and temperature correlated to 4 biotic indices; Margalef richness index (D), Shannon-Wiener diversity index (H), Species equitability or Evenness index (J) and Species dominance index (C) ($p<0.05$). The phosphate concentration in sediment and sediment pH related to the indices ($p<0.05$). The sediment particle sizes 0.71 mm, 0.3 mm and 0.075 mm also related to the indices ($p<0.05$). These variables were important parameters determining assemblage structure of macrobenthos in natural or slightly disturbed beach status.

The application of benthic macrofauna community to interpret the ecological habitats based on AMBI classification program manifested that all sampling stations were defined into 2 ecological groups. Group I as undisturbed habitats included 11 sampling stations in Krabi and Satun provinces. The stations in Krabi province were at Nopparathara beach station 1, all 3 stations of Ao-Nang beach, Nam Mao beach station 1 and 2 whereas in Satun province were Pak Bara beach station 2 and 3, Pak

Bang beach station 3, 5 and 6. Group II which were classified as slightly disturbed habitats included 15 sampling stations in Krabi, Trang and Satun provinces. The stations in Krabi province were Nopparatthara beach station 2 and 3 and Nam Mao beach station 3. In Trang province, all 8 assessed stations were interpreted in this group and in Satun province, Pak Bara beach station 1, Pak Bang beach station 1, 2 and 4 were also interpreted as slightly disturbed habitats. However, in longer study period, these stations must be analysed by their own benthic community datasets.

5.2 Recommendations

5.2.1 Long-term monitoring of benthic macrofauna community of the beaches can help pinpoint the presence of natural or human-made phenomena that are leading to ecological variation of the beach.

5.2.2 Expansion in studied scope of ecological variation (i.e. beach slope, settlement of benthic habitat, adjacent to riverine) should be considered. This may manifest the natural physical variables which affect to the benthic community.

5.2.3 Typology of local benthic macrofauna species in environmental sensitivity should be assigned and generated own ecological groups of the Andaman Sea coast.

5.2.4 The biological monitoring of the beach environments should be added to annual physical and chemical monitoring to reveal the complete picture of the beach health.

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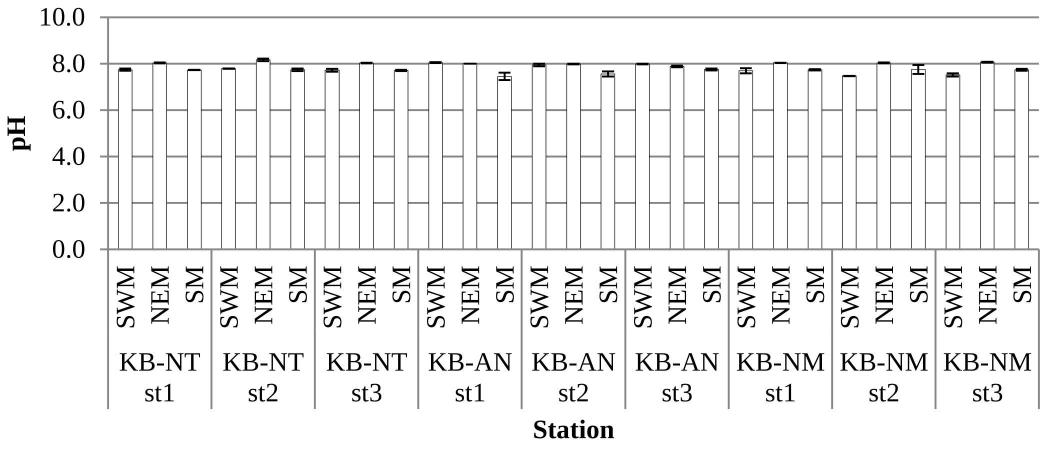
APPENDIX A

FIGURES OF WATER, SEDIMENT AND SEDIMENT PARTICLE SIZE VARIABLES MEASURED DATA



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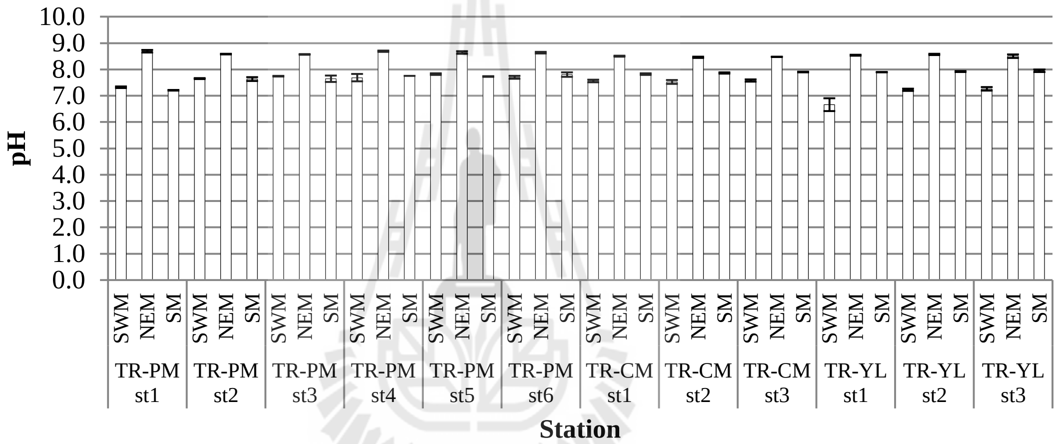

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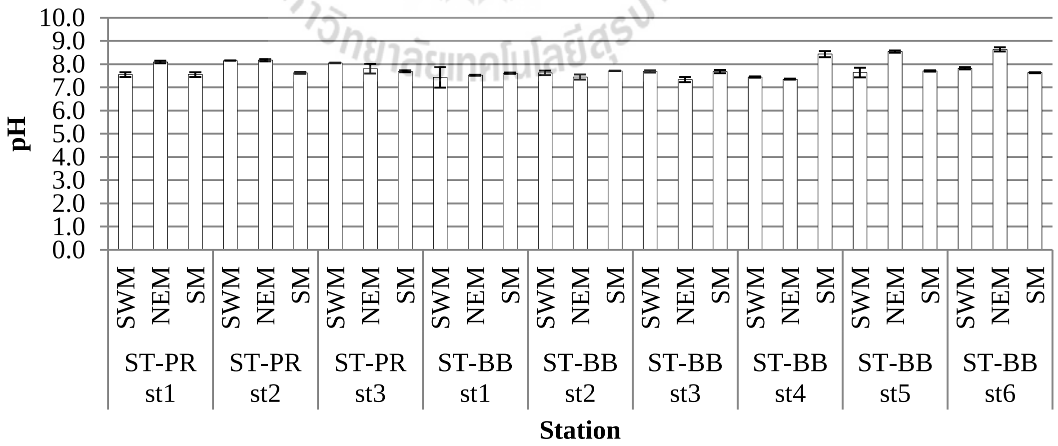
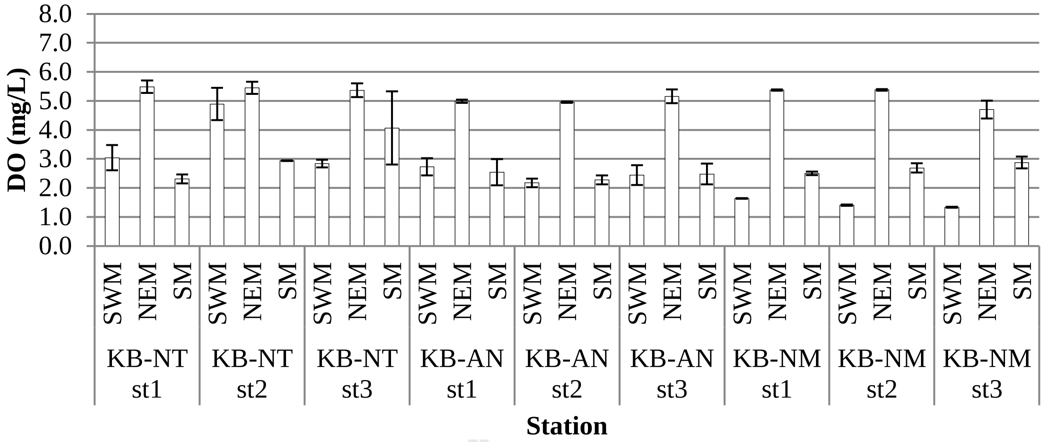
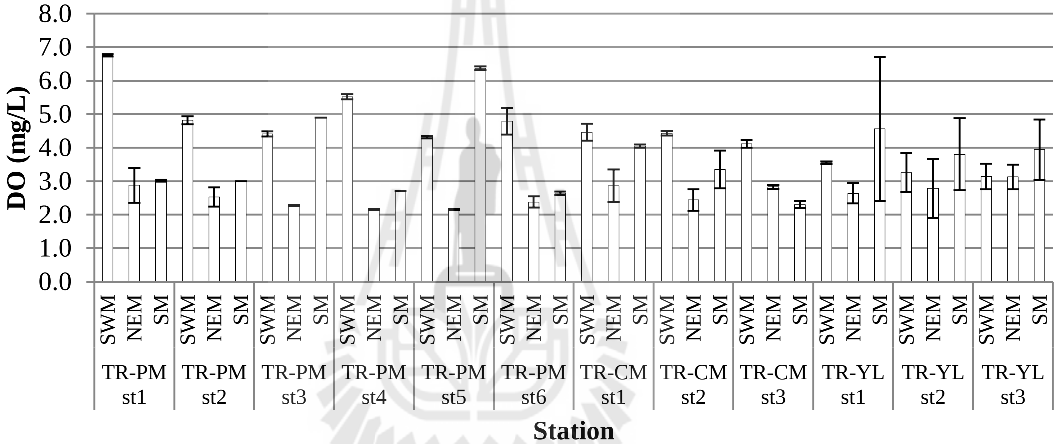


(c)

Figure A1.1 Water pH of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.



(a)



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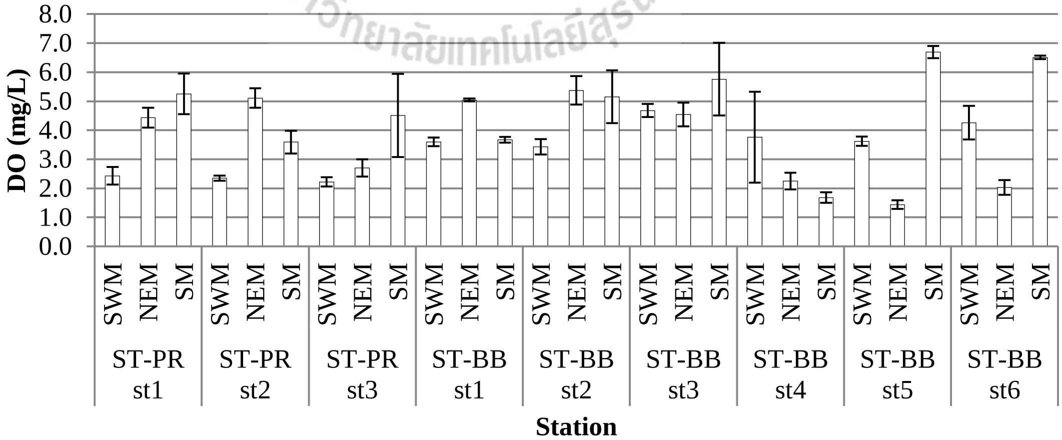


(c)

Figure A1.2 Dissolved oxygen of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.

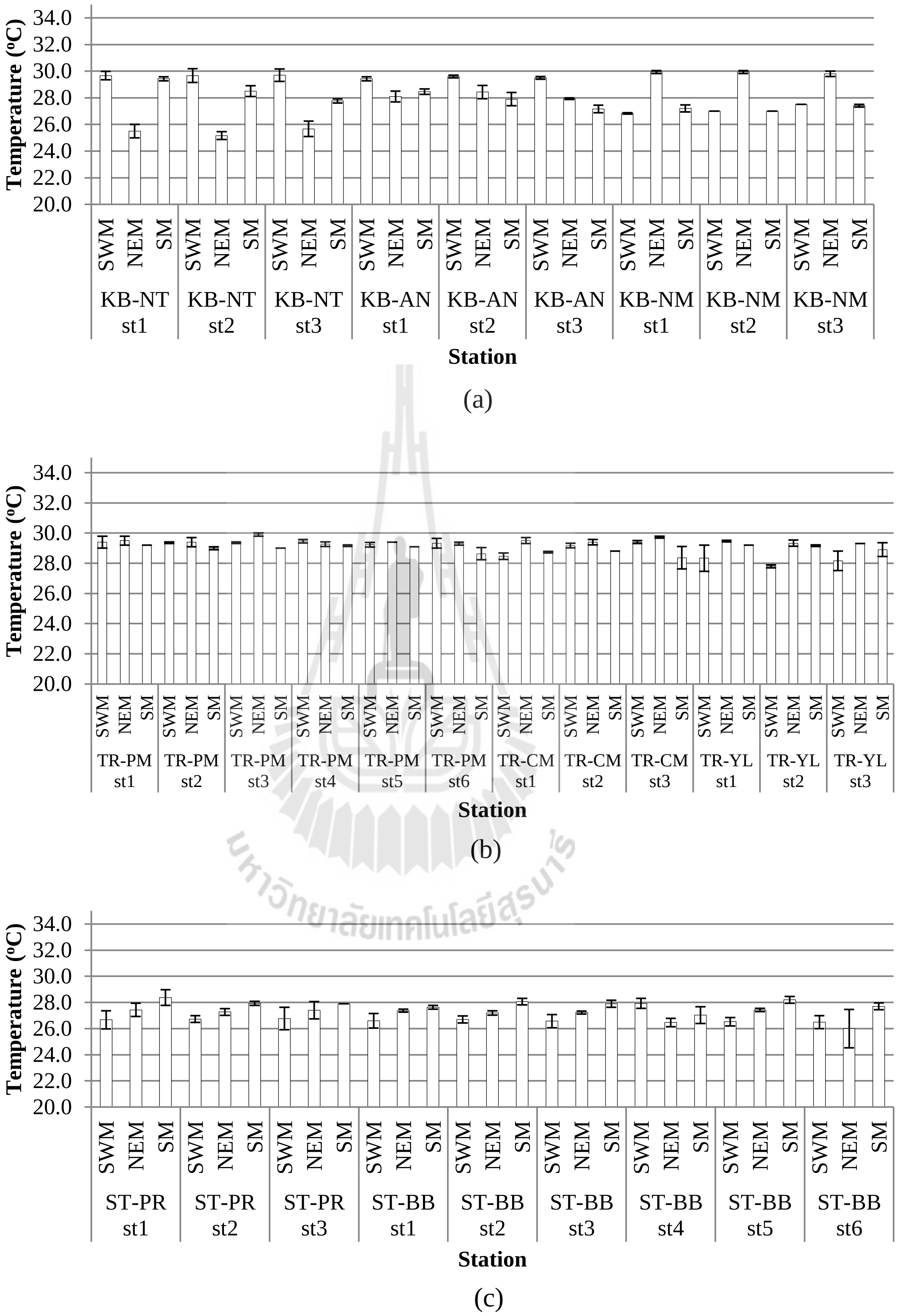
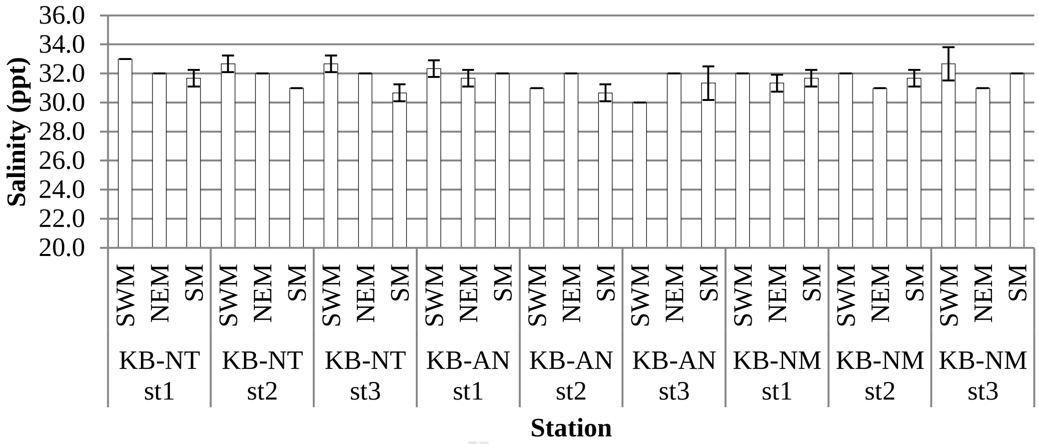
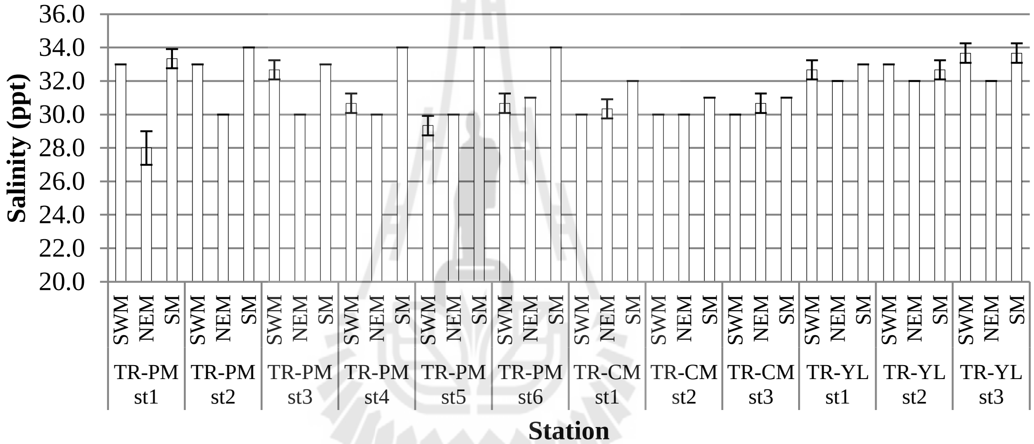


Figure A1.3 Water temperature of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.



(a)



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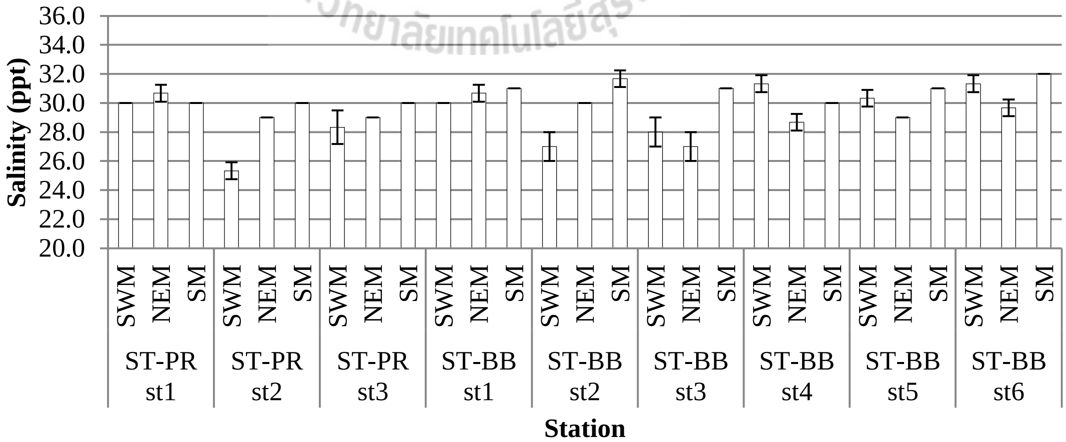
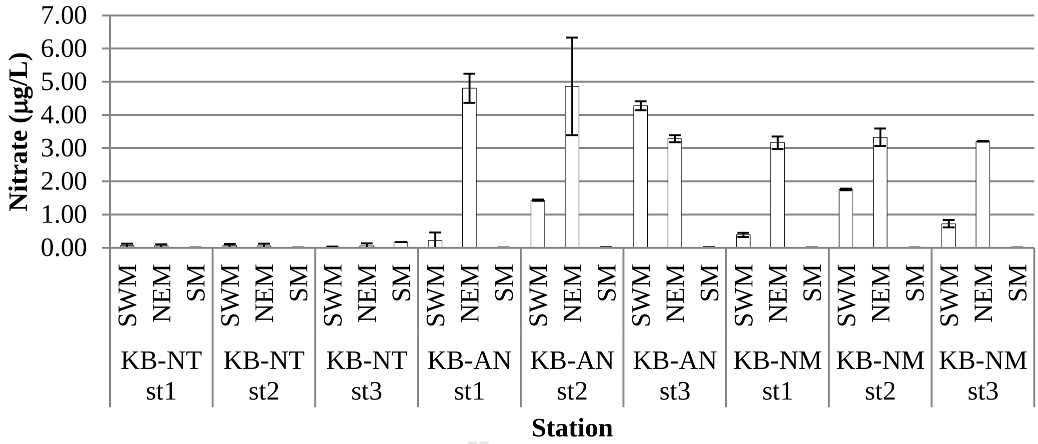


(c)

Figure A1.4 Salinity of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.



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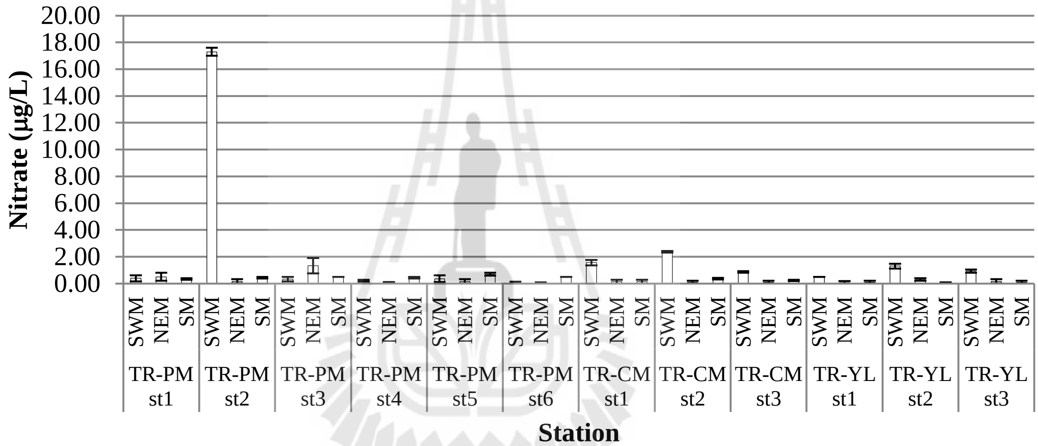

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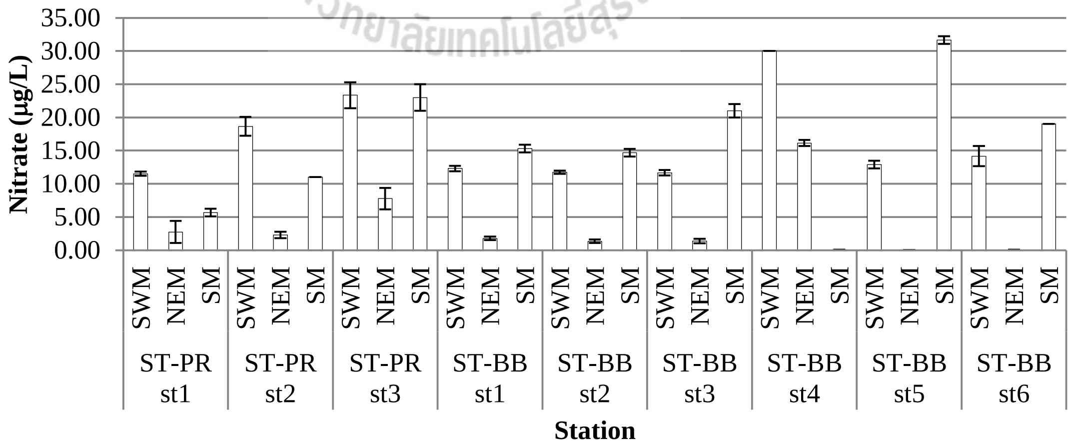
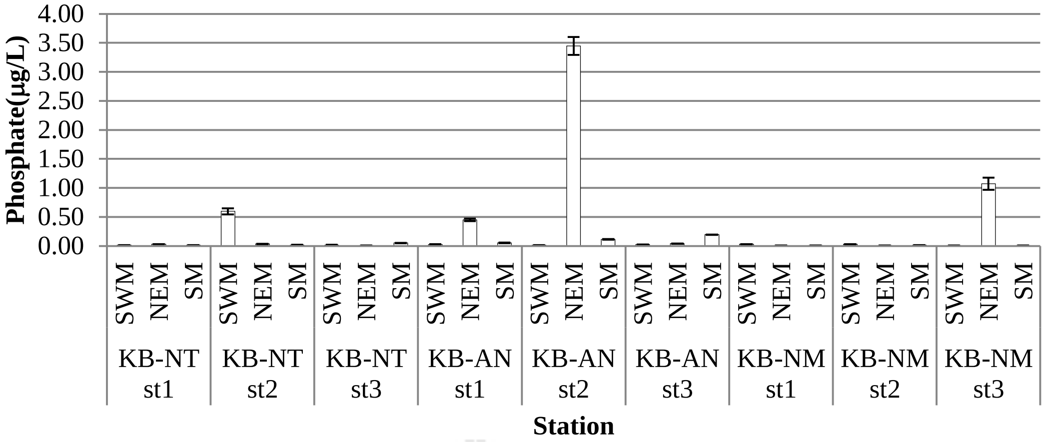
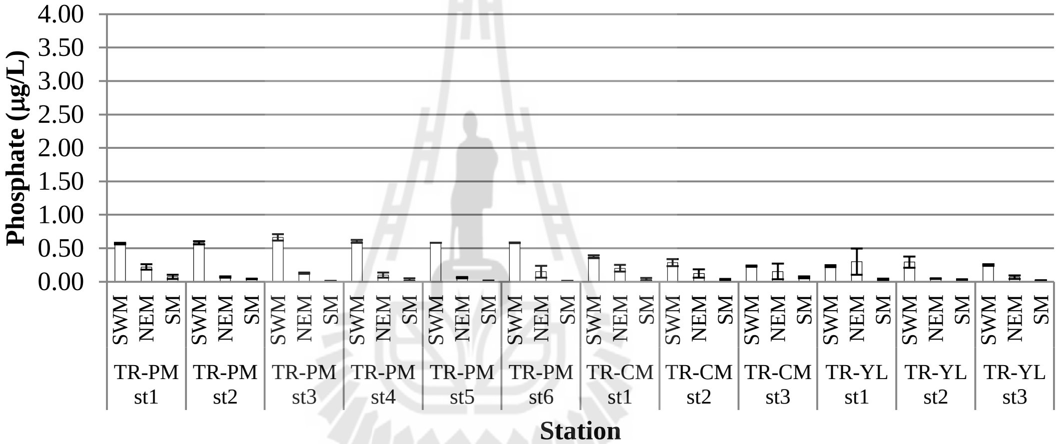


(c)

Figure A1.5 Nitrate in water of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.



(a)



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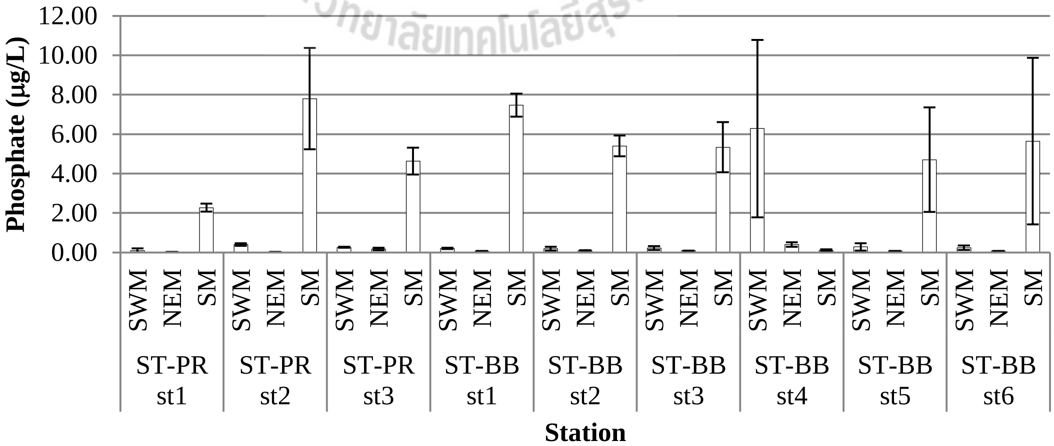
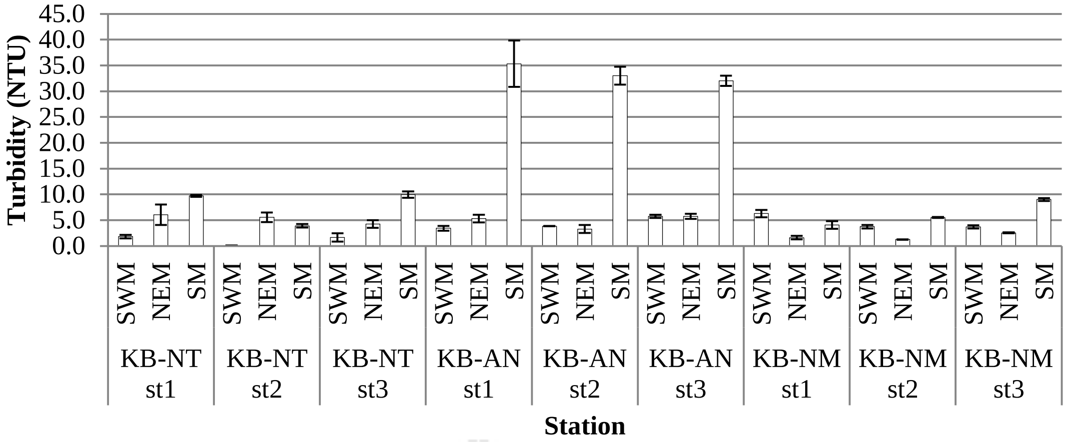
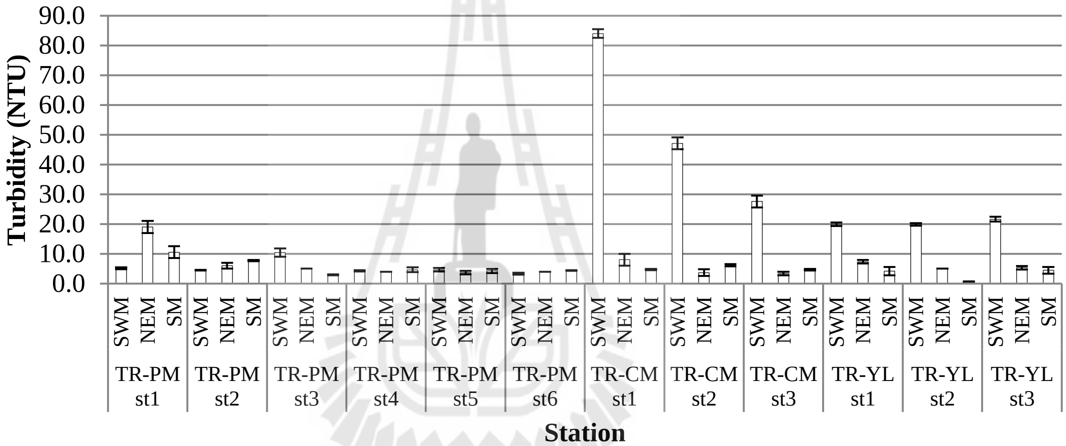


(c)

Figure A1.6 Phosphate in water of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.



(a)



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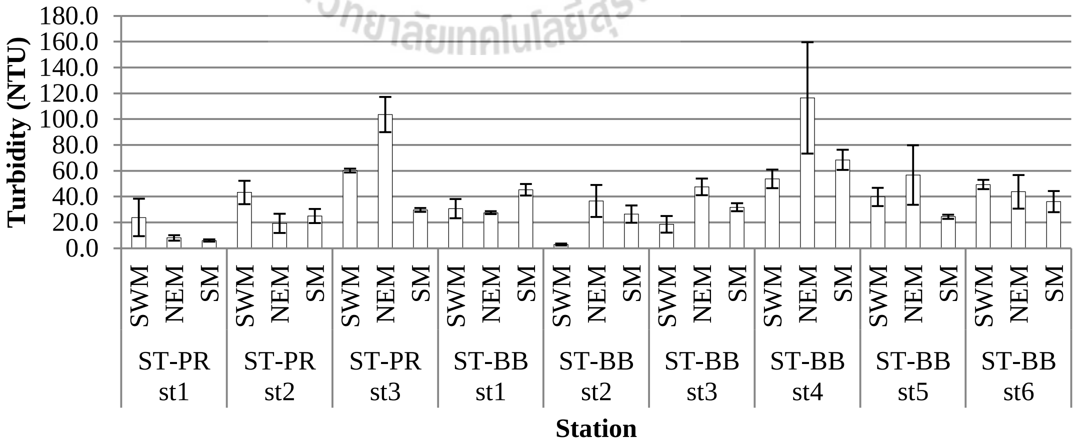
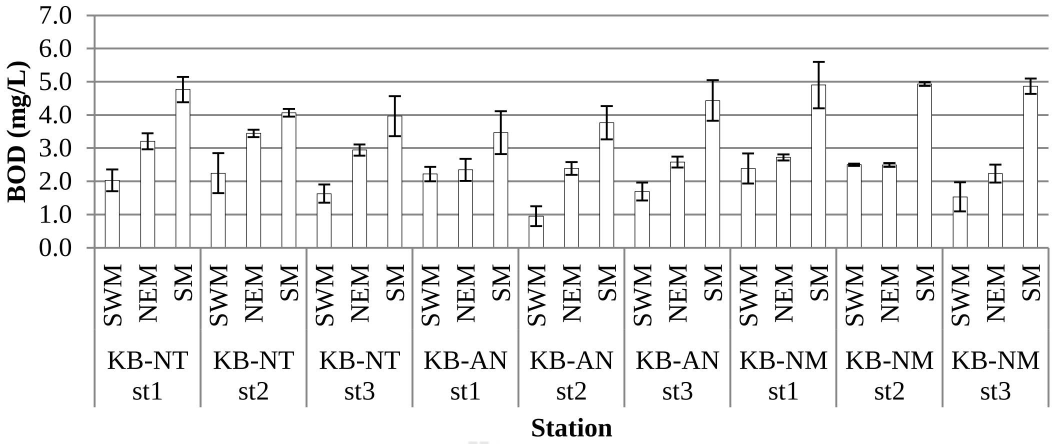
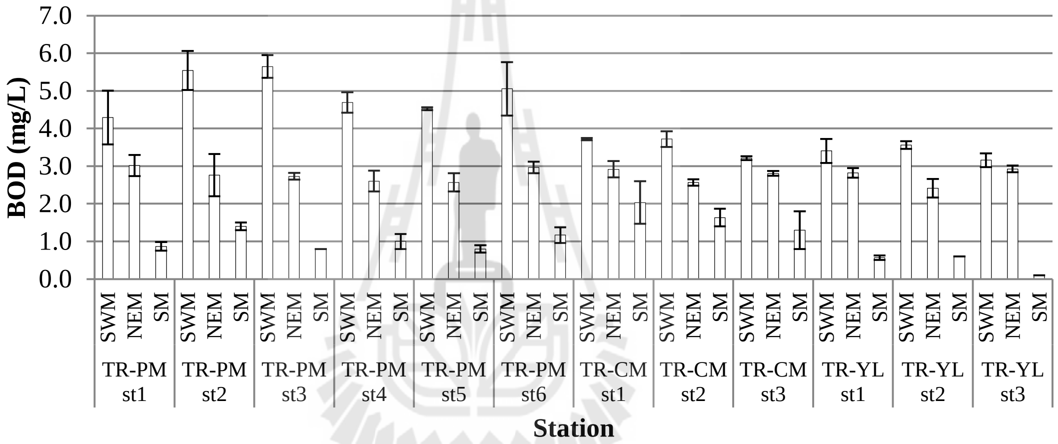


(c)

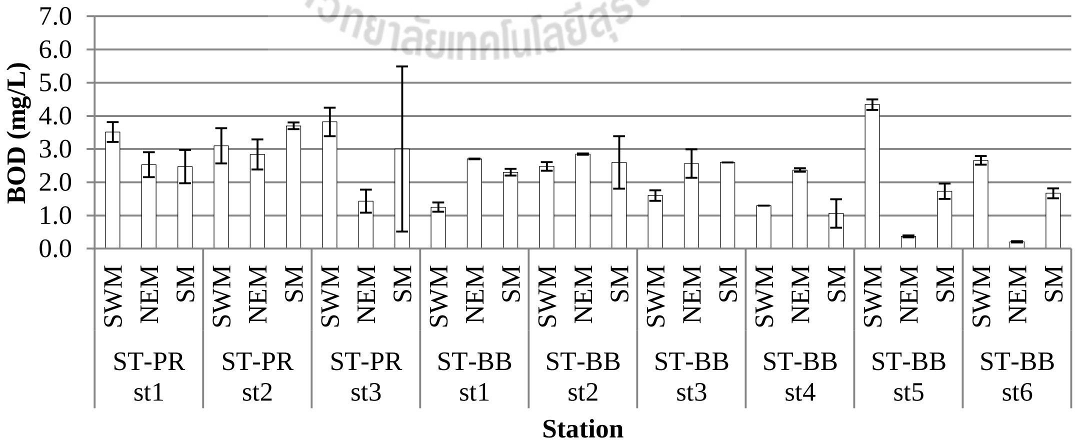
Figure A1.7 Water turbidity of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.



(a)

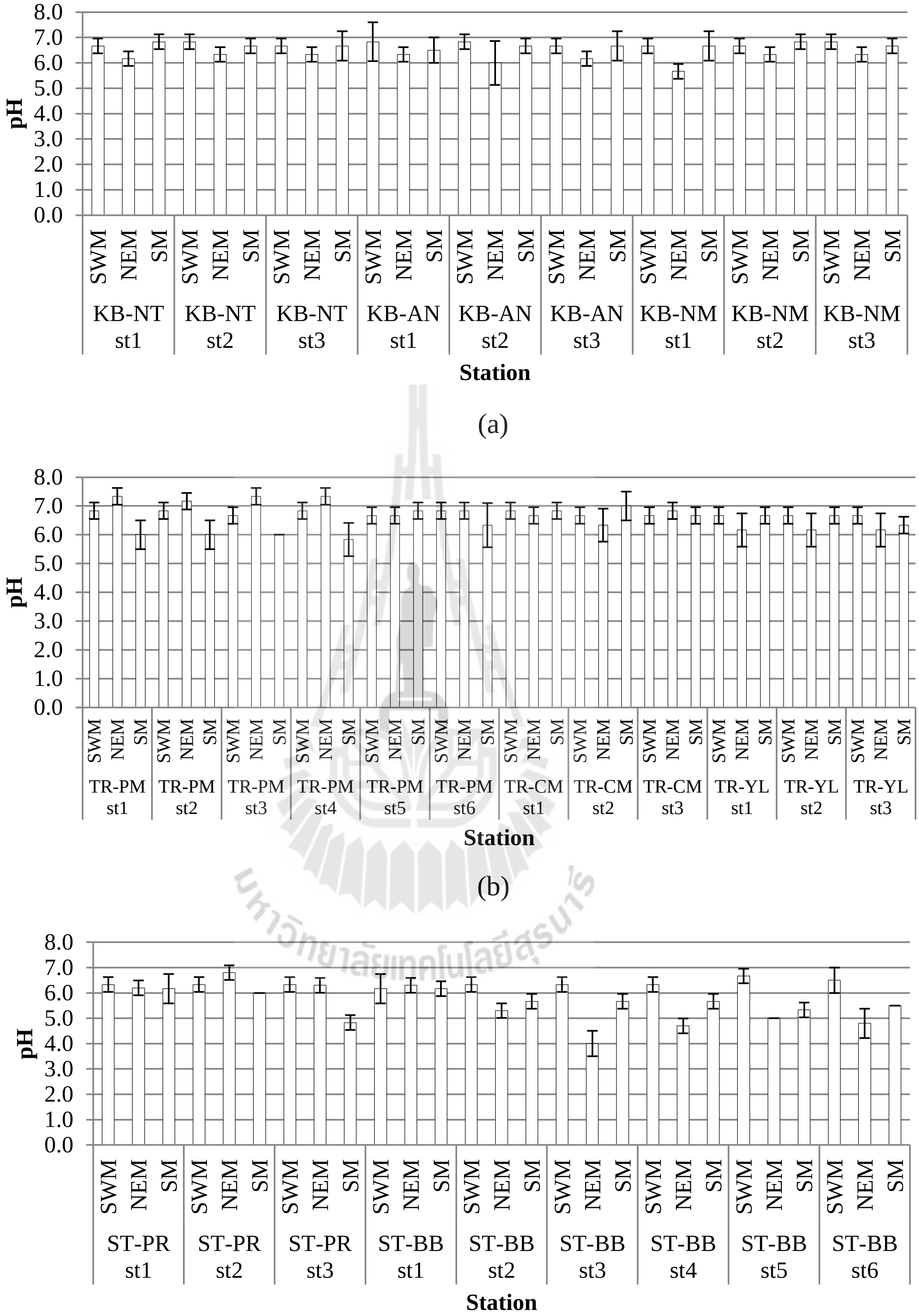


(b)



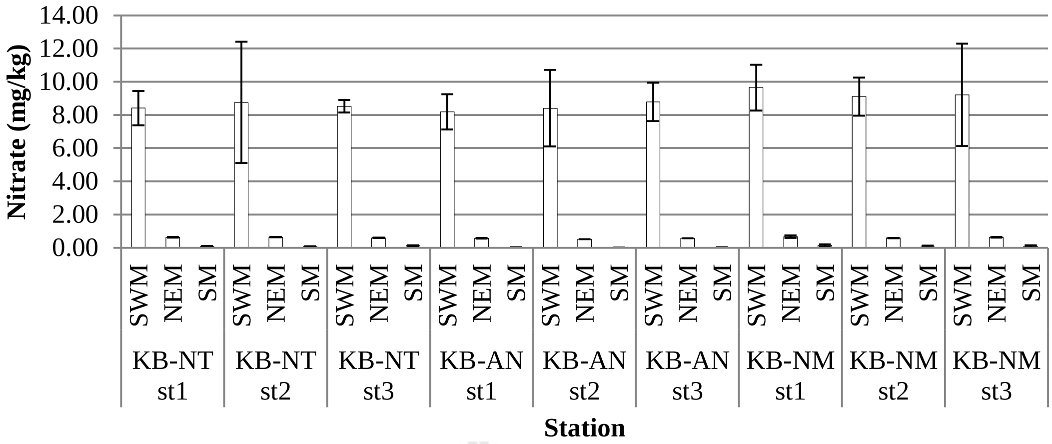
(c)

Figure A1.8 Water turbidity of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.

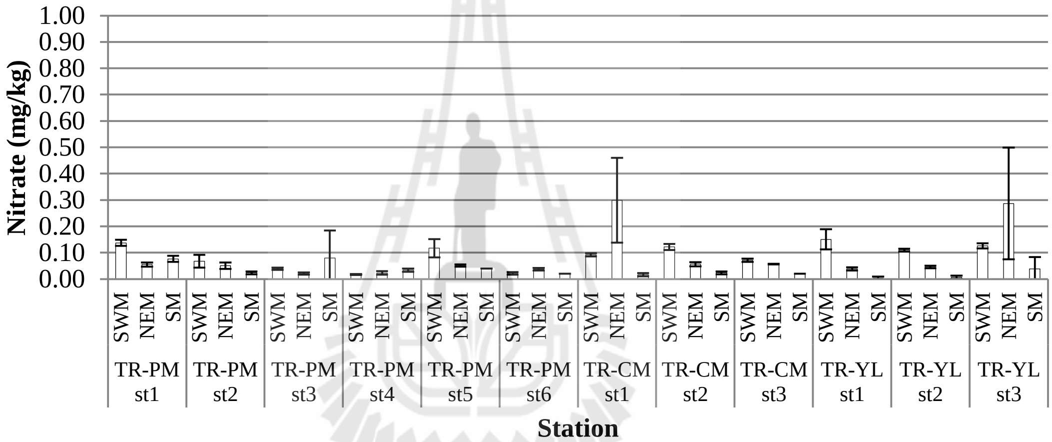


(c)

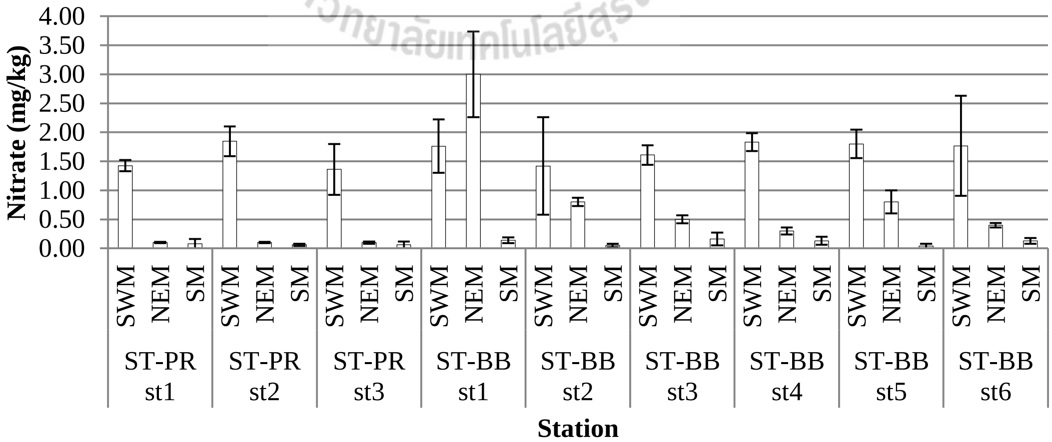
Figure A2.1 Sediment pH of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.



(a)



(b)



(c)

Figure A2.2 Nitrate in sediment of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.

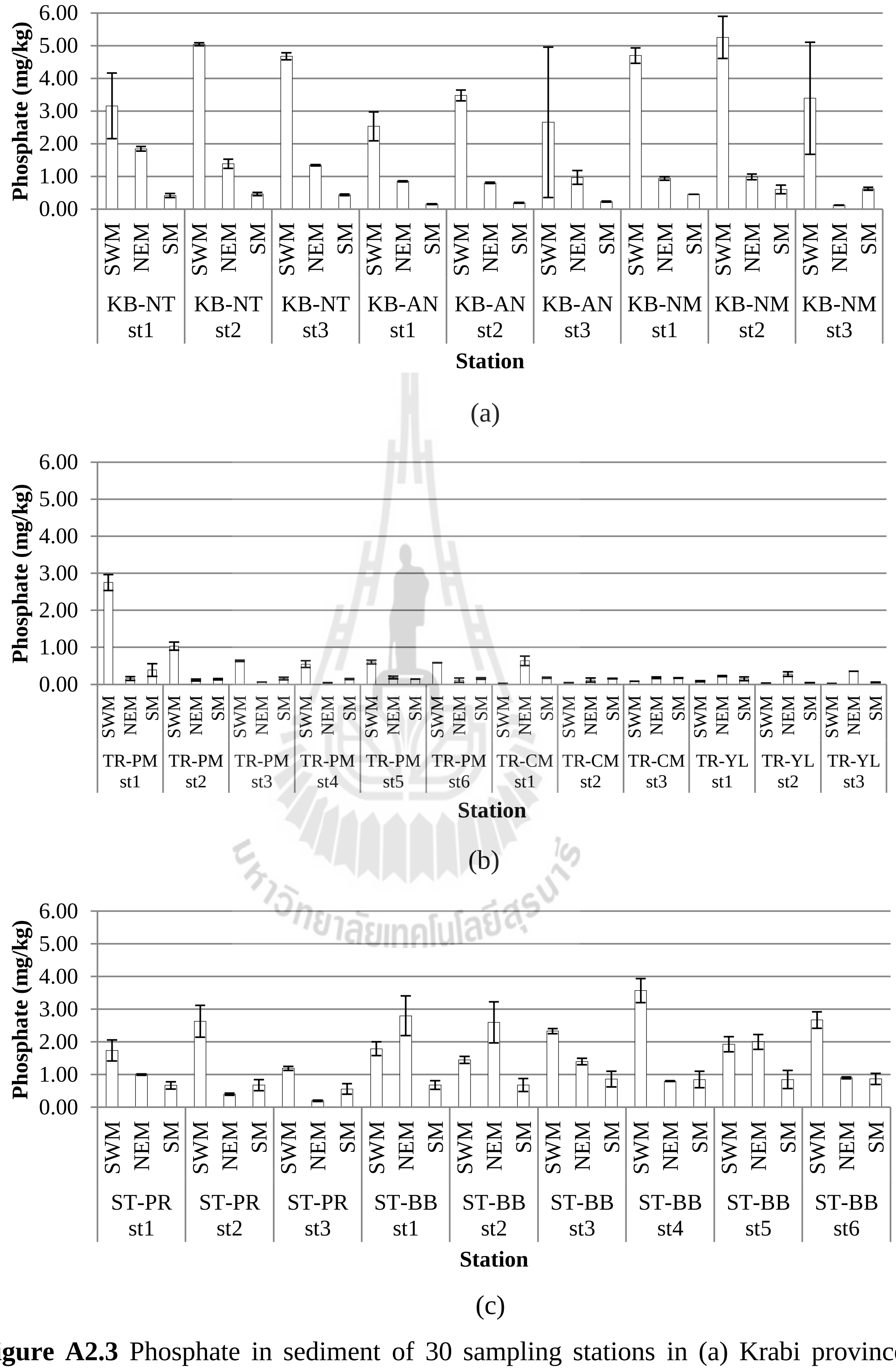
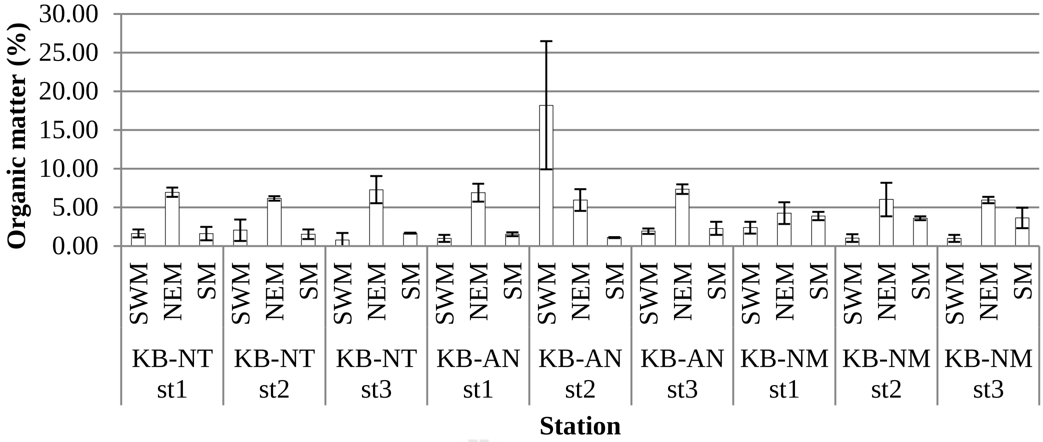
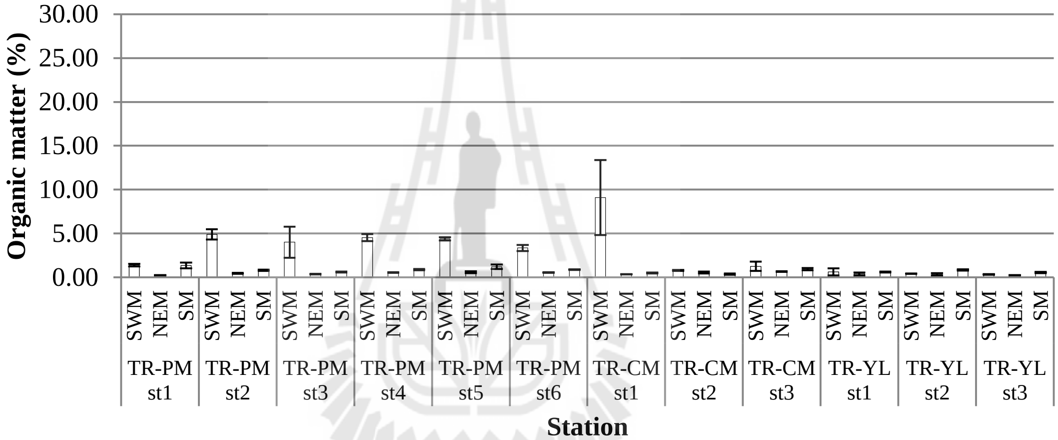


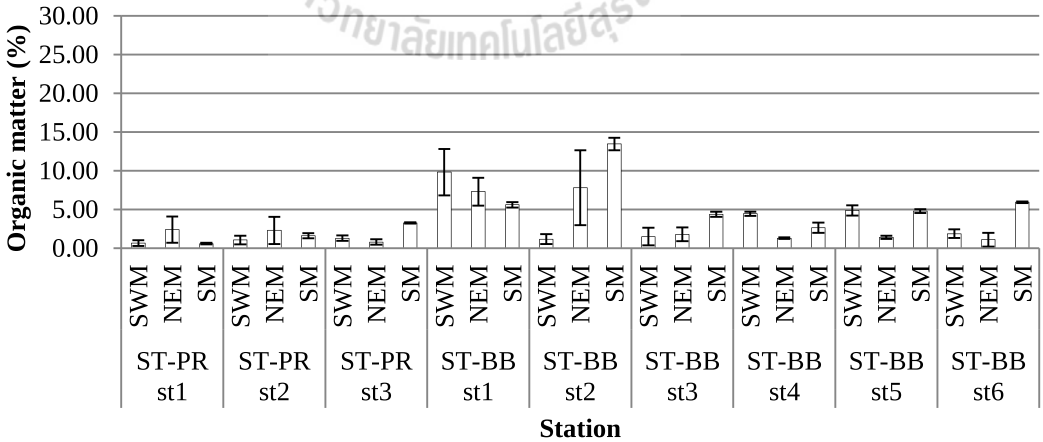
Figure A2.3 Phosphate in sediment of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.



(a)



(b)



(c)

Figure A2.4 Organic matter content of 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.

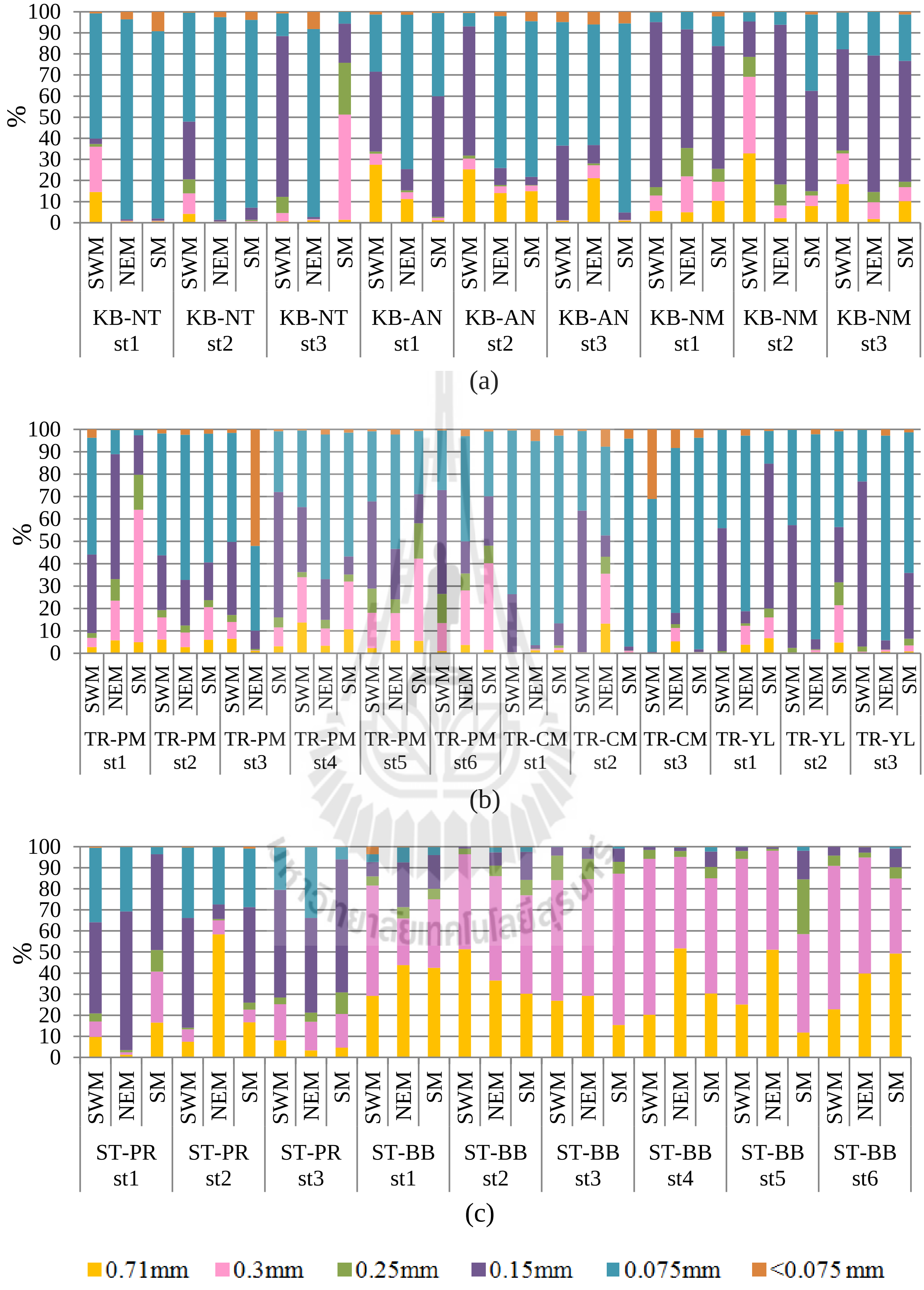
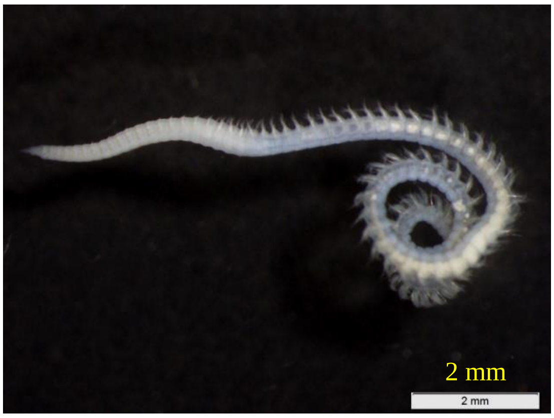


Figure A3.1 Percentages of sediment particle sizes at 30 sampling stations in (a) Krabi province, (b) Trang province, and (c) Satun province.

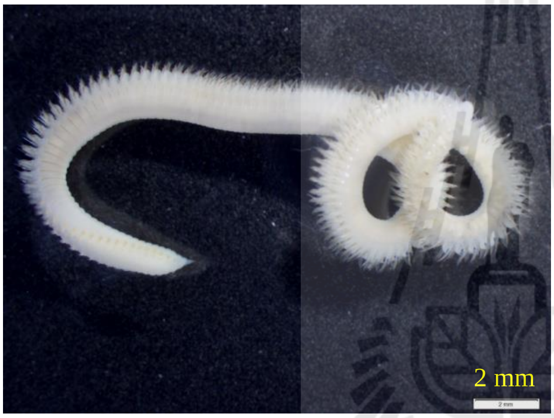
APPENDIX B

FIGURES OF BENTHIC MACROFAUNA FOUND IN THE 30 SAMPLING STATIONS

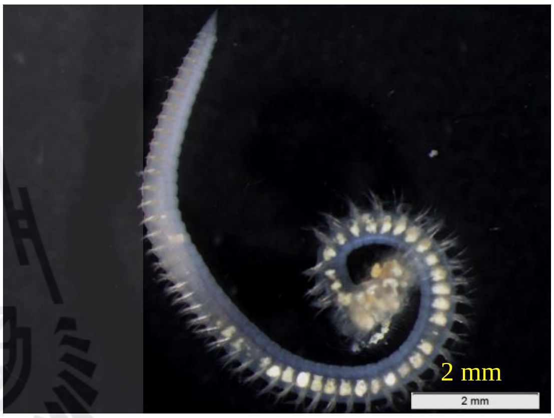
Scoloplos (*Leodamas*) *gracilis*



Scoloplos (*Scoloplos*) *marsupialis*



Scoloplos (*Scoloplos*) *tumidus*



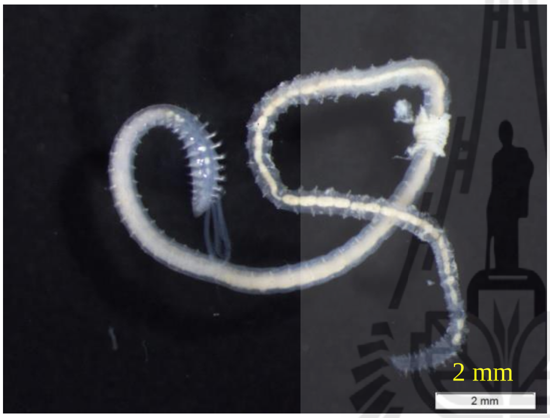
Scoloplos (*Scoloplos*) sp. 1

Scoloplos (*Scoloplos*) sp. 2

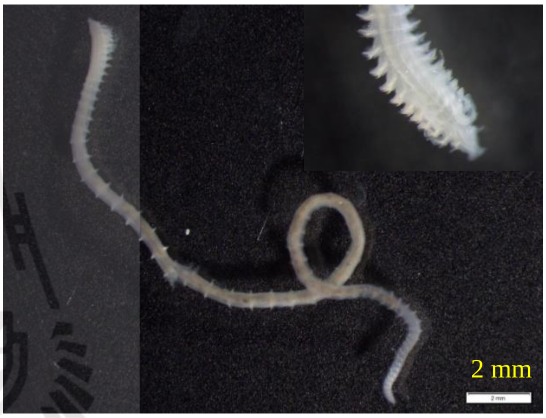
Scoloplos (*Scoloplos*) sp. 3

Scolelepis (Scolelepis) sp.

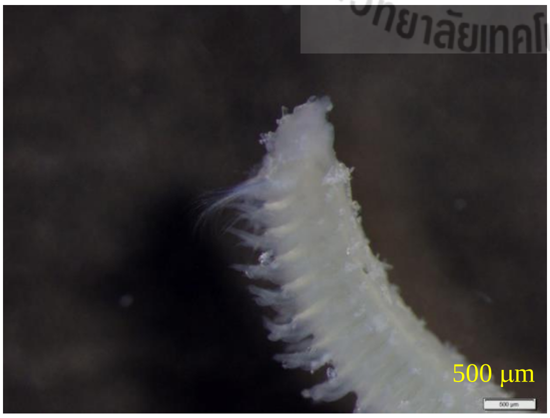
Paraprionospio cf. *oceanensis*



Paraprionospio sp.



Prionospio (*Prionospio*) *steenstrupi*

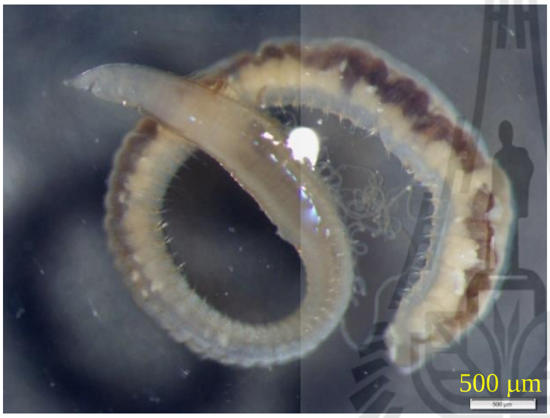


Dispio latilamella

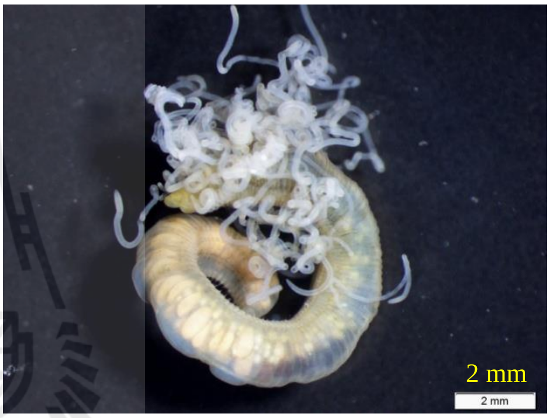
Magelona cf. *cincta*

Magelona conversa

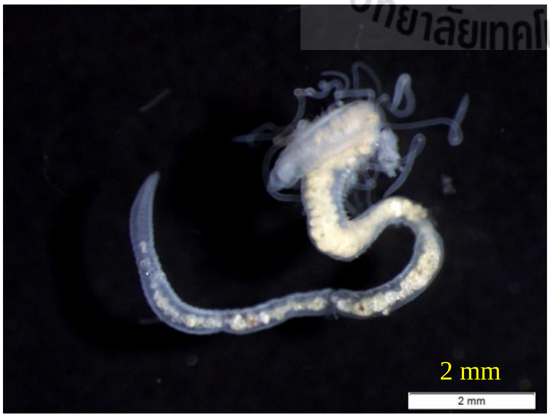
Magelona sacculata



Aphelochaeta sp.



Timarete sp.

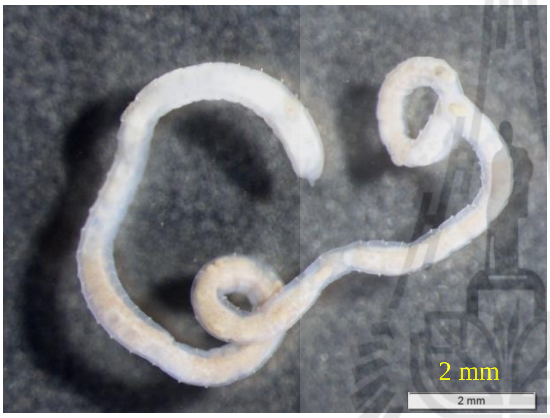


Chaetozone sp. 1

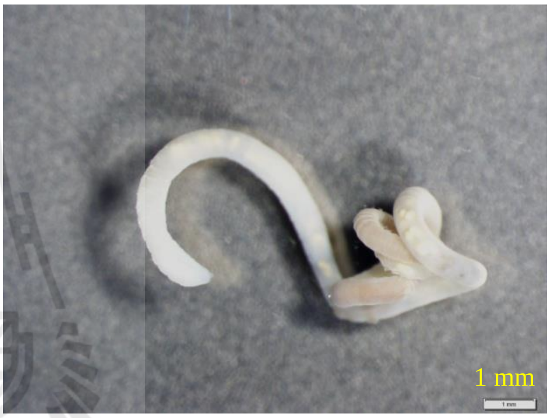
Chaetozone sp. 2

Monticellina sp.

Mediomastus sp.



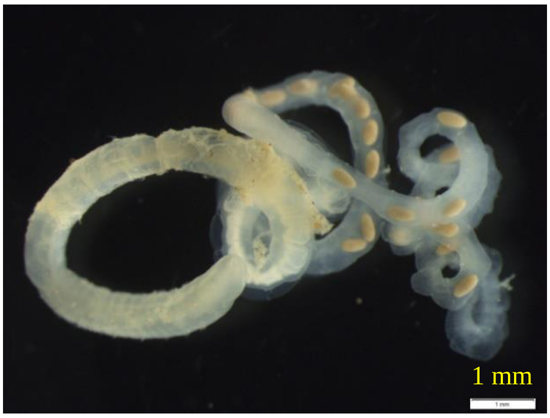
Heteromastus filiformis



Heteromastus sp. 1

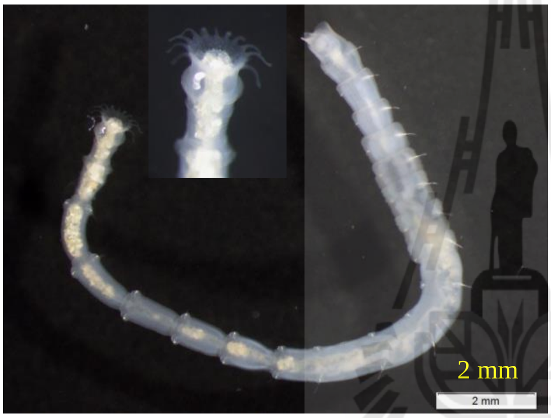
Heteromastus sp. 2

Heteromastus sp. 3

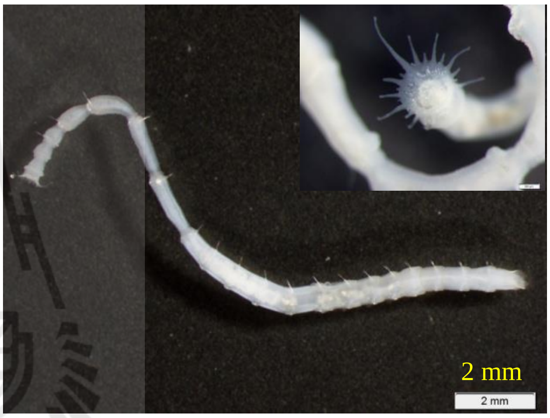


Heteromastus sp. 4

Capitellus branchiferus



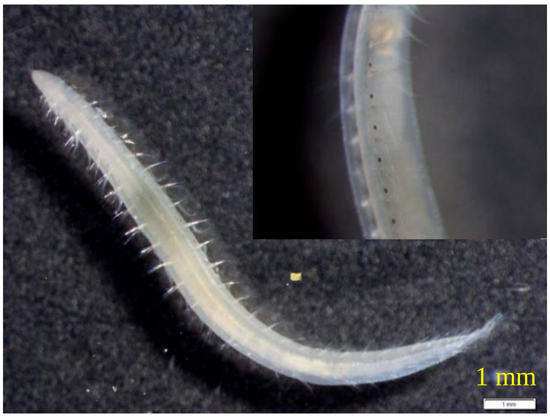
Euclymene annandalei



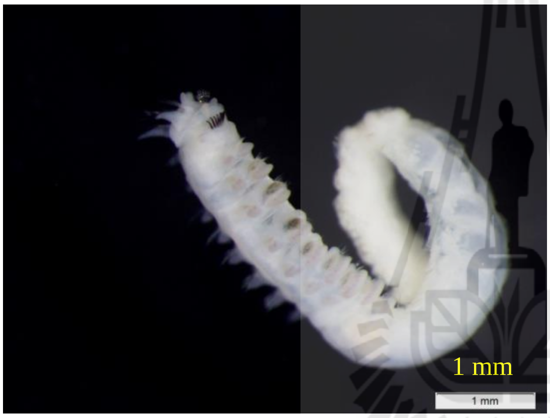
Axiothella obockensis

Ophelina sp. 1

Ophelina sp. 2

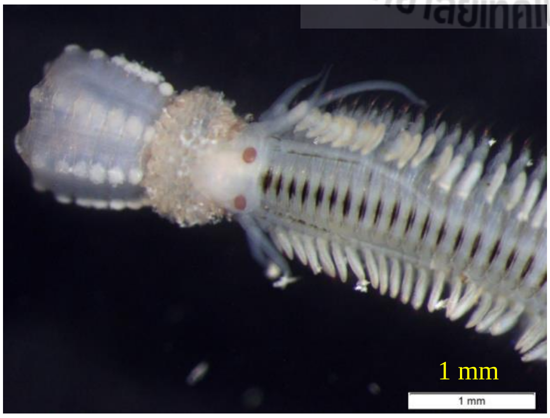


Armandia sp.



Asclerocheilus sp.

Anaitides sp.

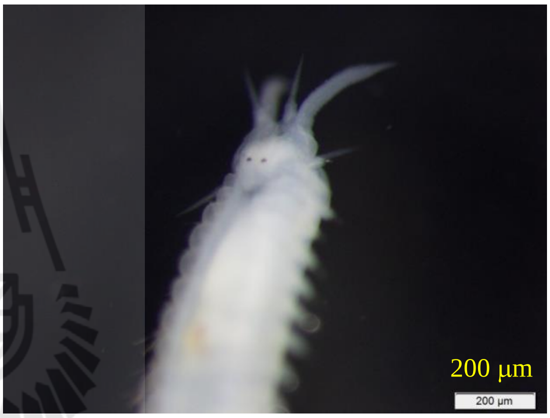


Phyllodoce sp.

Eteone sp.

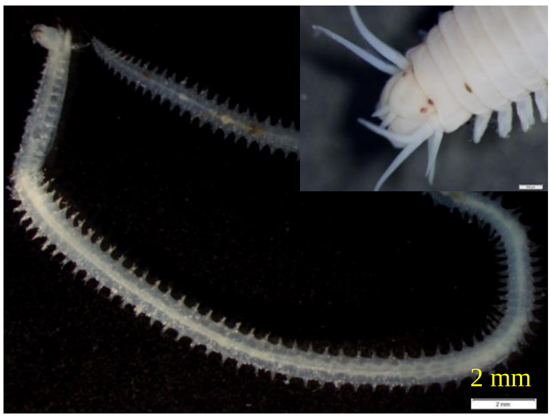
Grubeulepis geayi

Lepidonotus sp.



Pisione sp.

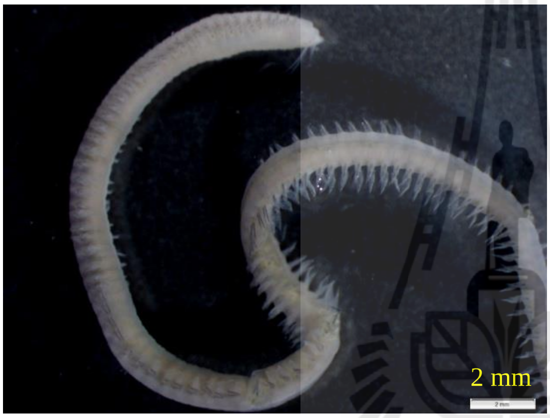
Sigambra pettiboneae



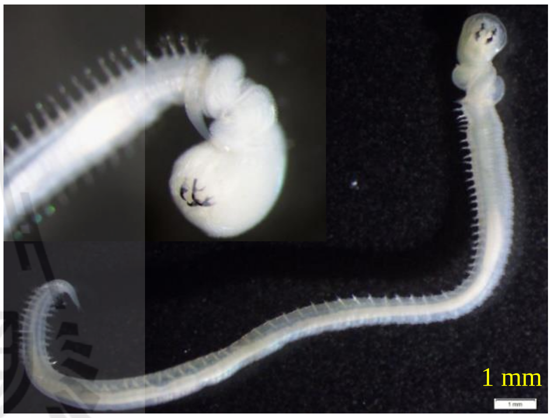
Neanthes caudata

Neanthes sp.

Dendronereis arborifera



Tylonereis heterochaeta



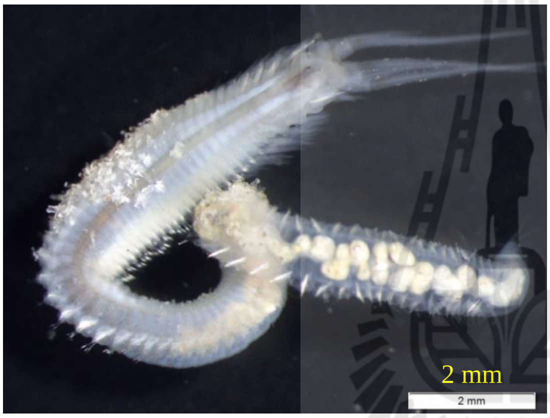
Glycera alba

Glycera natalensis

Glycera sp.

Goniadopsis incerta

Linopherus canariensis

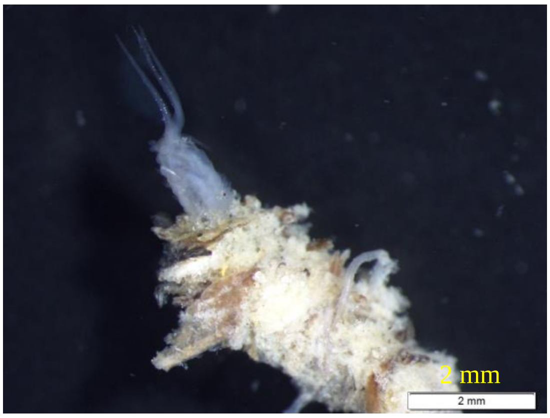


Diopatra amboinensis

Diopatra semperi

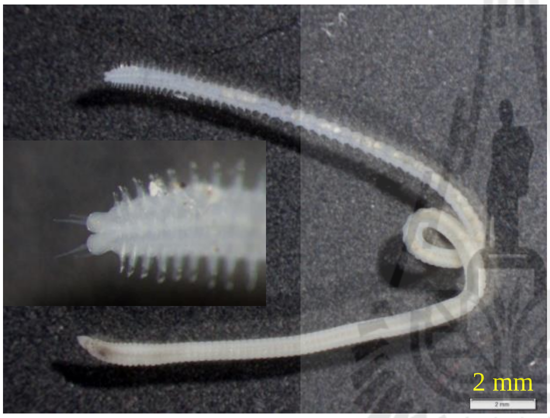
Diopatra sugokai

Diopatra sp. 1



Diopatra sp. 2

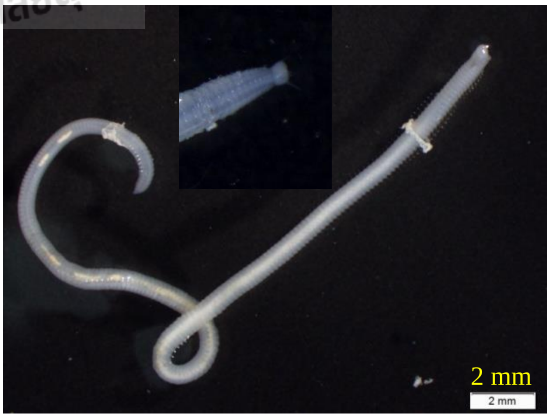
Marphysa macintoshi



Lumbrineris heteropoda

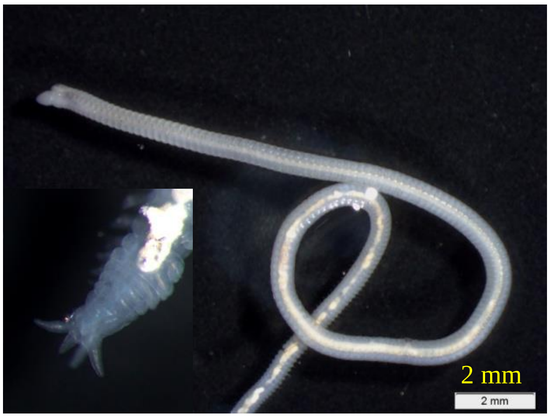
Lumbrineris sp. 1

Lumbrineris sp. 2



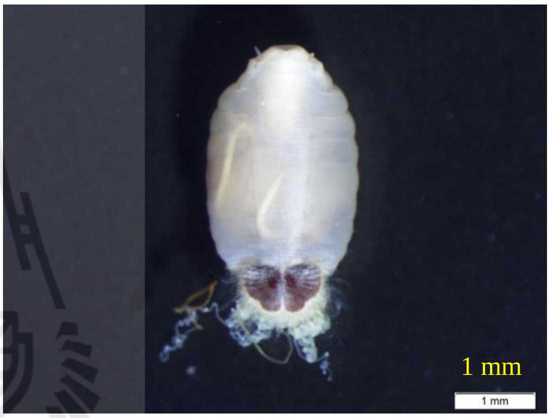
Scoletoma sp. 1

Scoletoma sp. 2

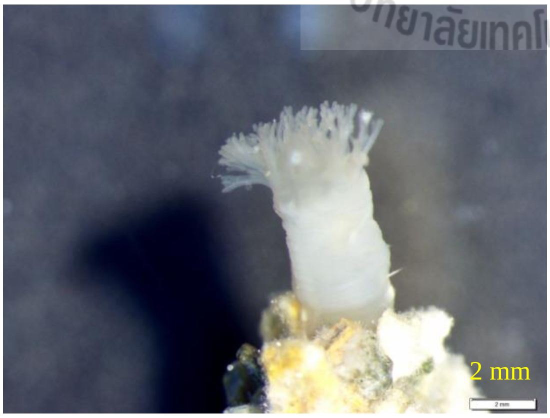


Scoletoma sp. 3

Sternaspis andamanensis

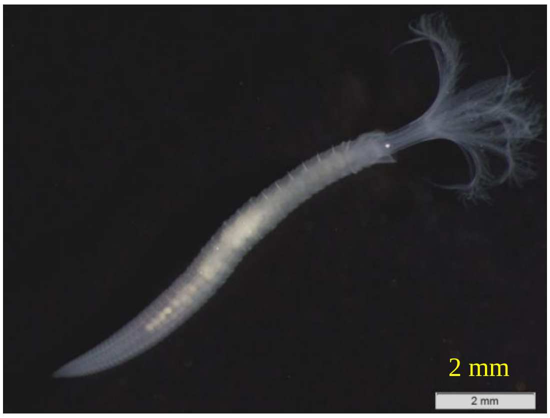


Petersenaspis sp.

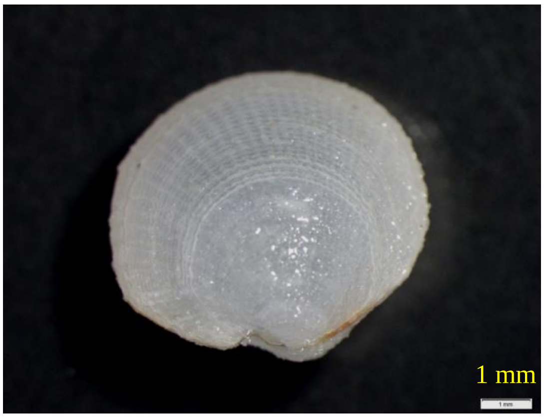


Owenia fusiformis

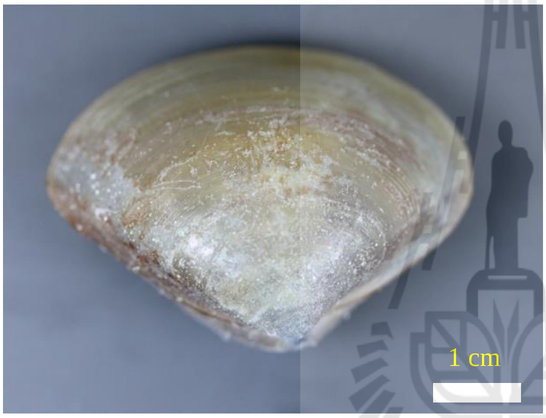
Lanice conchilega



Chone sp.



Pillucina sp.



Mactra olorina

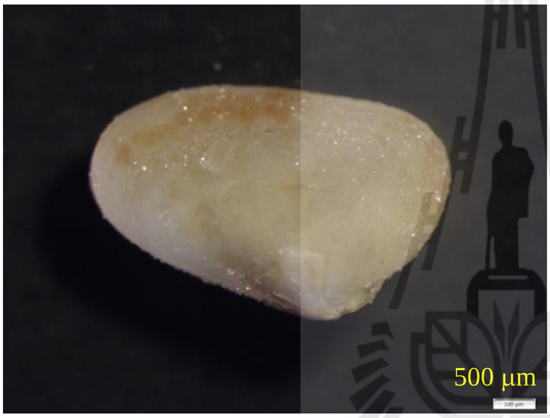
Mactra cuneata

Siliqua radiata

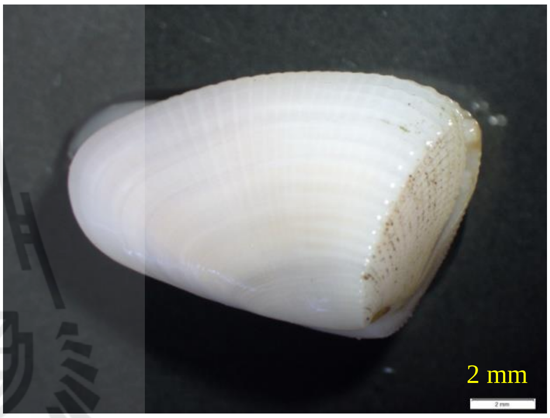
Siliqua fasciata

Chlamys sp.

Tellina sp. 1



Tellina sp. 2



Donax cuneatus

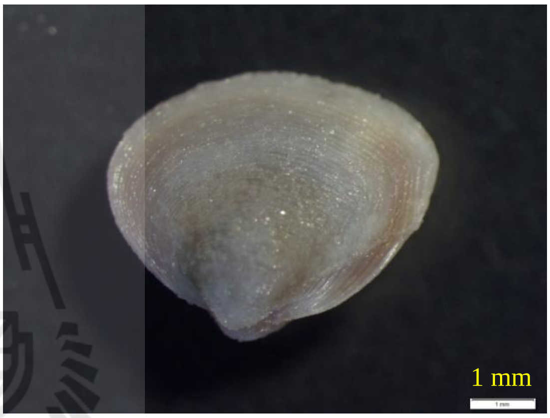
Donax incarnatus

Donax faba

Donax scortum

Gari (*Psammotaea*) *elongata*

Meretrix sp.

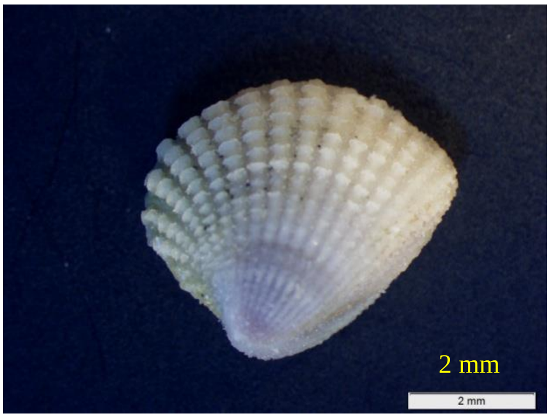


Pitar sp.

Anadora granosa

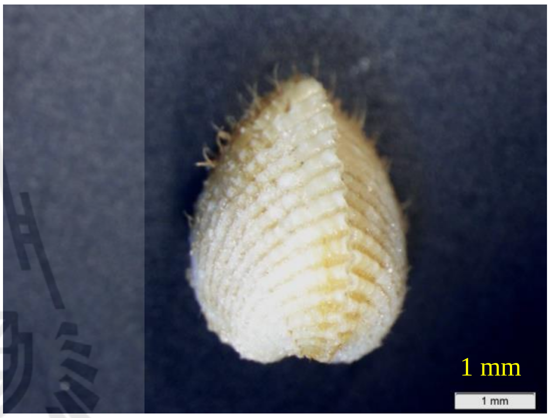
Paphia gallus

Timoclea scabra



Timoclea imbricata

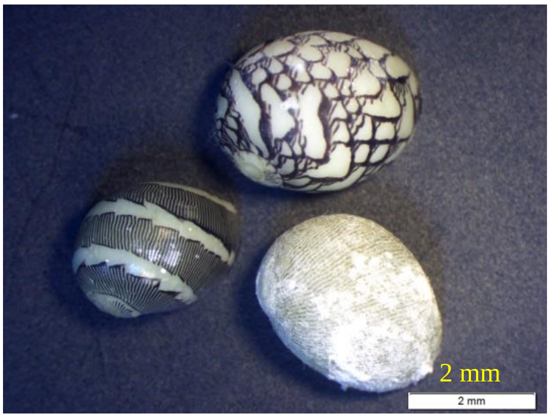
Circe scripta



Fragum fragum

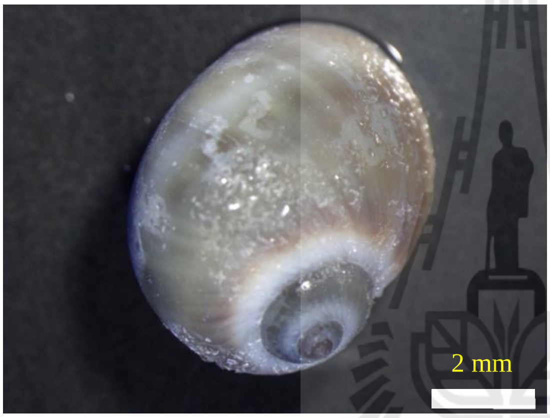
Umbonium vestiarium

Cerithium corallium

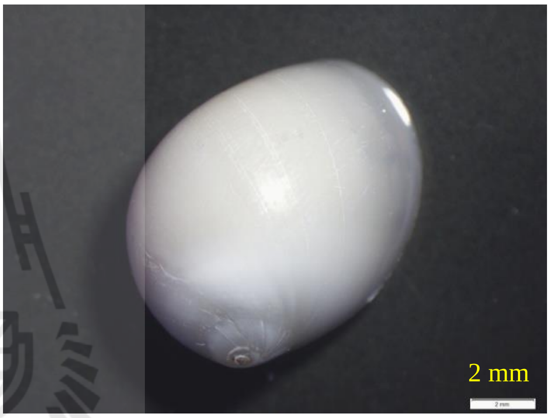


Clithon oualaniensis

Natica tigrina



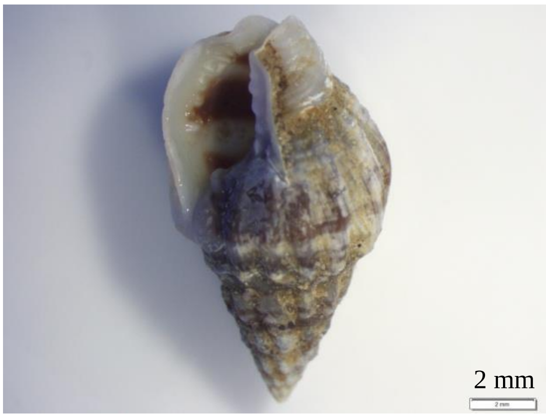
Natica vitellus



Polinices mammilla

Nassarius pullus

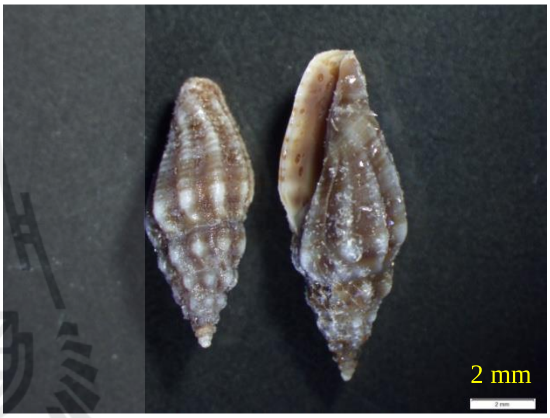
Nassarius livescens



Nassarius jacksonianus

Nassarius stolatus

Nassarius globosus



Vexillum sp.

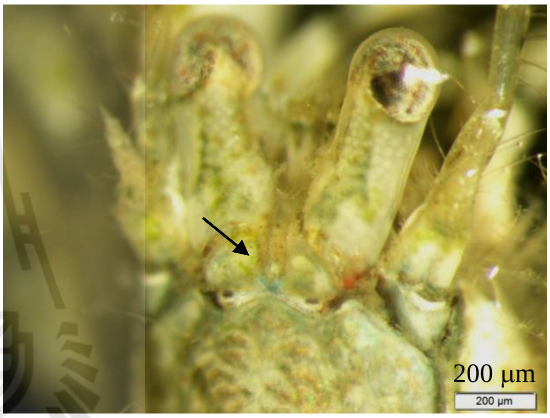
Turricula javana

Lodderia novemcarinata

Atys cylindricus

Diogenes klassi

Diogenes dubius



Diogenes planimanus

Philyra olivacea

Philyra platycheira

Matuta victor

Dotilla intermedia

Dotilla myctiroides

Ocypode ceratopthalma

Ocypode macrocera

Scopimera proxima

Macrophthalmus convexus

Camptandrium sexdentatum

Lingula sp.

APPENDIX C

LIST AND MEAN ANNUAL ABUNDANCE OF BENTHIC MACROFAUNA

Table C1.1 List and mean annual abundance of benthic macrofauna species in Krabi province.

No.	Species	Abundance of benthic macrofauna (individuals) Stations								
		KB-NT st1	KB-NT st2	KB-NT st3	KB-AN st1	KB-AN st2	KB-AN st3	KB-NM st1	KB-NM st2	KB-NM st3
	Polychaetes									
1	*Scoloplos* (*Leodamas*) *gracilis*	58	0	47	15	93	440	1	0	0
2	*Scoloplos* (*Scoloplos*) *marsupialis*	40	13	4	0	132	122	0	0	0
3	*Scoloplos* (*Scoloplos*) *tumidus*	0	7	23	0	0	0	3	34	31
4	*Scoloplos* (*Scoloplos*) sp. 2	0	21	0	0	0	0	4	0	0
5	*Scoloplos* (*Scoloplos*) sp. 3	0	0	0	0	151	130	0	0	0
6	*Scolelepis* (*Scolelepis*) sp.	3	0	2	5	3	0	0	2	0
7	*Prionospio* (*Prionospio*) *steenstrupi*	0	0	0	5	2	0	7	10	1
8	*Dispio latilamella*	0	0	0	1	9	0	1	0	0
9	*Magelona conversa*	0	0	0	0	0	5	0	0	0
10	*Aphelochaeta* sp.	0	0	0	0	0	0	2	0	3

Table C1.1 (Continued) List and mean annual abundance of benthic macrofauna species in Krabi province.

No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		KB-NT st1	KB-NT st2	KB-NT st3	KB-AN st1	KB-AN st2	KB-AN st3	KB-NM st1	KB-NM st2	KB-NM st3
11	*Capitellus branchiferus*	0	0	0	0	0	0	11	0	23
12	*Axiothella obockensis*	0	0	0	71	162	200	53	9	13
13	*Armandia* sp.	0	0	0	0	0	1	0	3	0
14	*Anaitides* sp.	0	0	0	0	0	0	0	0	3
15	*Phyllodoce* sp.	0	0	0	0	0	0	0	0	3
16	*Eteone* sp.	0	0	0	0	0	0	0	0	2
17	*Pisione* sp.	0	0	0	0	3	0	0	0	0
18	*Neanthes caudata*	7	0	0	0	0	0	0	4	12
19	*Tylonereis heterochaeta*	6	7	6	0	0	0	5	0	7
20	*Glycera alba*	31	50	36	53	18	28	16	18	14
21	*Glycera natalensis*	0	0	0	13	3	0	0	0	5
22	*Glycera* sp.	0	0	0	0	0	0	0	4	14

Table C1.1 (Continued) List and mean annual abundance of benthic macrofauna species in Krabi province.

No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		KB-NT st1	KB-NT st2	KB-NT st3	KB-AN st1	KB-AN st2	KB-AN st3	KB-NM st1	KB-NM st2	KB-NM st3
23	*Goniadopsis incerta*	11	12	18	0	0	0	0	4	4
24	*Linopherus canariensis*	0	0	0	0	0	0	3	0	0
25	*Diopatra sugokai*	0	0	0	0	0	2	0	0	9
26	*Diopatra* sp. 2	0	0	0	0	0	0	0	0	9
27	*Marphysa macintoshi*	0	0	0	0	0	0	0	0	1
28	*Lumbrineris heteropoda*	0	0	0	0	0	0	0	25	0
29	*Lumbrineris* sp. 2	10	5	0	0	0	0	29	136	155
30	*Scoletoma* sp. 2	0	0	0	0	0	0	0	0	7
31	*Scoletoma* sp. 3	22	0	12	6	6	0	0	23	24
32	*Owenia fusiformis*	0	0	0	0	0	0	0	2	1
	Total abundance of polychaetes	188	115	148	169	582	928	135	274	341

Table C1.1 (Continued) List and mean annual abundance of benthic macrofauna species in Krabi province.

No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		KB-NT st1	KB-NT st2	KB-NT st3	KB-AN st1	KB-AN st2	KB-AN st3	KB-NM st1	KB-NM st2	KB-NM st3
	Mollusks									
1	*Chlamys* sp.	2	0	0	0	1	0	0	0	0
2	*Pillucina* sp.	26	0	0	0	0	10	0	11	43
3	*Mactra olorina*	0	0	0	1	8	7	0	0	4
4	*Siliqua fasciata*	0	0	0	0	3	8	0	0	0
5	*Donax cuneatus*	27	0	2	87	112	37	0	0	1
6	*Donax incarnatus*	45	55	95	80	20	30	15	33	13
7	*Donax faba*	6	3	29	35	98	34	75	95	83
8	*Donax scortum*	0	0	0	0	0	1	0	0	0
9	*Anomalocardia squamosa*	0	0	0	0	0	1	0	0	0
10	*Paphia gallus*	0	0	0	0	0	0	0	3	0
11	*Timoclea scabra*	0	0	0	0	0	0	0	0	1

Table C1.1 (Continued) List and mean annual abundance of benthic macrofauna species in Krabi province.

No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		KB-NT st1	KB-NT st2	KB-NT st3	KB-AN st1	KB-AN st2	KB-AN st3	KB-NM st1	KB-NM st2	KB-NM st3
12	*Timoclea imbricata*	0	0	0	1	0	5	0	0	0
13	*Circe scripta*	0	0	0	0	0	0	1	0	0
14	*Cerithium coralium*	0	0	0	0	0	0	5	0	0
15	*Umbonium vestiarium*	19	58	11	26	36	26	0	15	21
16	*Clithon oualaniensis*	0	0	3	0	0	0	0	0	3
17	*Natica tigrina*	0	0	0	1	1	0	0	0	0
18	*Natica vitellus*	0	0	0	0	0	0	0	4	2
19	*Nassarius pullus*	0	0	0	0	0	0	8	0	0
20	*Nassarius livescens*	0	0	0	2	3	0	0	0	2
21	*Nassarius jacksonianus*	0	0	0	0	0	0	0	0	2
22	*Nassarius stolatus*	7	0	0	0	0	2	0	0	2
23	*Vexillum* sp.	0	0	0	0	0	0	0	1	0

Table C1.1 (Continued) List and mean annual abundance of benthic macrofauna species in Krabi province.

No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		KB-NT st1	KB-NT st2	KB-NT st3	KB-AN st1	KB-AN st2	KB-AN st3	KB-NM st1	KB-NM st2	KB-NM st3
24	*Turricula javana*	0	0	0	0	0	3	0	0	0
	Total abundance of mollusks	132	116	140	233	282	164	104	162	177
	Crustaceans									
1	*Diogenes klassi*	0	0	0	0	0	4	0	0	0
2	*Diogenes dubius*	23	7	0	45	369	162	2	24	22
3	*Philyra platycheira*	1	0	0	1	2	5	1	0	1
4	*Matuta victor*	2	2	2	5	4	2	0	0	0
5	*Dotilla intermedia*	39	54	36	10	0	0	5	37	15
6	*Dotilla myctiroides*	0	0	26	0	0	0	0	27	1
7	*Ocypode macrocera*	14	3	0	0	0	0	4	1	4
8	*Scopimera proxima*	0	0	0	0	0	0	4	2	5
9	*Macrophthalmus convexus*	4	0	0	0	0	0	0	2	1

Table C1.1 (Continued) List and mean annual abundance of benthic macrofauna species in Krabi province.

No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		KB-NT st1	KB-NT st2	KB-NT st3	KB-AN st1	KB-AN st2	KB-AN st3	KB-NM st1	KB-NM st2	KB-NM st3
	Total abundance of crustaceans	83	66	64	61	375	173	16	93	49
	Total abundance of all species	**403**	**297**	**352**	**463**	**1239**	**1265**	**255**	**529**	**567**
	Total number of species	**22**	**14**	**16**	**20**	**23**	**24**	**22**	**26**	**40**

Table C1.2 List and mean annual abundance of benthic macrofauna species in Trang province.

No.	Species	Abundance of benthic macrofauna (individuals) Stations											
		TR-PM st1	TR-PM st2	TR-PM st3	TR-PM st4	TR-PM st5	TR-PM st6	TR-CM st1	TR-CM st2	TR-CM st3	TR-YL st1	TR-YL st2	TR-YL st3
	Polychaetes												
1	*Scoloplos* (*Leodamas*) *gracilis*	0	7	0	0	35	25	122	9	23	0	0	0
2	*Scoloplos* (*Scoloplos*) *marsupialis*	0	0	0	1	14	8	99	20	3	6	6	0
3	*Scoloplos* (*Scoloplos*) *tumidus*	33	59	56	0	0	0	10	10	15	2	30	0
4	*Scoloplos* (*Scoloplos*) sp. 1	9	21	10	0	0	2	0	3	0	0	0	0
5	*Scoloplos* (*Scoloplos*) sp. 2	27	0	0	0	0	2	0	0	0	0	0	0
6	*Scoloplos* (*Scoloplos*) sp. 3	0	0	25	0	0	0	0	0	0	0	0	10
7	*Scolelepis* (*Scolelepis*) sp.	1	0	0	0	14	4	0	0	0	7	0	0
8	*Prionospio* (*Prionospio*) *steenstrupi*	4	64	28	82	60	160	6	11	13	0	0	0
9	*Dispio latilamella*	2	4	3	0	0	0	2	0	0	0	0	0

Table C1.2 (Continued) List and mean annual abundance of benthic macrofauna species in Trang province.

No.	Species	Abundance of benthic macrofauna (individuals)											
		Stations											
		TR-PM st1	TR-PM st2	TR-PM st3	TR-PM st4	TR-PM st5	TR-PM st6	TR-CM st1	TR-CM st2	TR-CM st3	TR-YL st1	TR-YL st2	TR-YL st3
10	*Magelona conversa*	0	0	0	0	4	0	0	0	0	0	0	0
11	*Magelona sacculata*	0	0	0	0	0	0	4	0	0	0	0	0
12	*Timarete* sp.	0	4	0	0	0	0	0	0	0	0	0	0
13	*Chaetozone* sp.1	0	0	0	0	2	0	0	0	0	0	0	0
14	*Chaetozone* sp.2	0	0	0	0	0	10	0	0	0	0	0	0
15	*Monticellina* sp.	0	0	0	0	0	0	2	0	0	0	0	0
17	*Heteromastus filiformis*	16	16	0	0	4	0	0	0	0	0	0	0
18	*Heteromastus* sp.4	6	8	0	0	0	4	0	0	0	0	0	0
16	*Capitellethus branchiferus*	51	4	0	0	0	0	0	0	0	0	0	0
19	*Axiothella obockensis*	20	35	0	0	30	6	0	0	0	6	0	0
20	*Ophelina* sp. 1	28	0	0	0	0	0	0	0	0	0	0	0

Table C1.2 (Continued) List and mean annual abundance of benthic macrofauna species in Trang province.

No.	Species	Abundance of benthic macrofauna (individuals)											
		Stations											
		TR-PM st1	TR-PM st2	TR-PM st3	TR-PM st4	TR-PM st5	TR-PM st6	TR-CM st1	TR-CM st2	TR-CM st3	TR-YL st1	TR-YL st2	TR-YL st3
21	*Phyllodoce* sp.	3	0	0	0	0	0	0	0	0	0	0	0
22	*Eteone* sp.	0	1	0	0	3	0	0	0	0	0	0	0
23	*Grubeulepis geayi*	5	1	0	0	0	0	0	0	0	0	0	0
24	*Tylonereis heterochaeta*	8	26	0	0	4	0	0	0	0	0	0	0
25	*Neanthes caudata*	0	0	0	0	5	0	0	0	0	0	0	0
26	*Neanthes* sp.	1	0	18	4	8	5	0	0	0	10	0	0
27	*Glycera alba*	35	45	38	0	29	15	19	56	33	43	20	16
28	*Glycera natalensis*	0	9	0	35	0	0	5	5	3	0	5	0
29	*Glycera* sp.	10	12	24	0	0	8	9	0	7	0	0	0
30	*Goniadopsis incerta*	41	21	19	9	0	13	0	0	6	16	0	5
31	*Diopatra amboinensis*	14	0	0	1	5	0	0	0	0	0	0	0

Table C1.2 (Continued) List and mean annual abundance of benthic macrofauna species in Trang province.

No.	Species	Abundance of benthic macrofauna (individuals)											
		Stations											
		TR-PM st1	TR-PM st2	TR-PM st3	TR-PM st4	TR-PM st5	TR-PM st6	TR-CM st1	TR-CM st2	TR-CM st3	TR-YL st1	TR-YL st2	TR-YL st3
32	*Diopatra sugokai*	0	0	0	0	0	0	0	12	0	0	0	0
33	*Marphysa macintoshi*	15	0	0	0	0	0	0	0	0	0	0	0
34	*Lumbrineris heteropoda*	31	186	0	0	0	10	0	0	0	0	0	0
35	*Lumbrineris* sp. 1	0	0	0	0	0	0	6	3	0	0	0	0
36	*Lumbrineris* sp. 2	24	131	25	0	26	0	5	0	0	0	0	0
37	*Scoletoma* sp. 1	90	0	0	0	0	0	0	0	0	0	0	0
38	*Scoletoma* sp. 2	18	43	36	0	0	0	0	0	0	0	0	0
39	*Scoletoma* sp. 3	88	41	22	0	0	20	12	0	9	0	0	0
40	*Owenia fusiformis*	1	0	0	0	0	0	0	0	0	0	0	0
41	*Chone* sp.	0	0	0	0	24	8	6	1	5	0	0	0
	Total abundance of polychaetes	581	738	304	132	267	300	307	130	117	90	61	31

Table C1.2 (Continued) List and mean annual abundance of benthic macrofauna species in Trang province.

No.	Species	Abundance of benthic macrofauna (individuals)											
		Stations											
		TR-PM st1	TR-PM st2	TR-PM st3	TR-PM st4	TR-PM st5	TR-PM st6	TR-CM st1	TR-CM st2	TR-CM st3	TR-YL st1	TR-YL st2	TR-YL st3
	Mollusks												
1	*Pillucina* sp.	401	117	0	0	67	0	1	0	0	0	0	0
2	*Mactra cuneata*	8	3	0	0	0	0	0	0	0	0	0	0
3	*Siliqua radiata*	0	0	0	0	0	0	15	0	0	0	0	0
4	*Tellina* sp. 1	5	0	0	0	0	0	0	0	0	0	0	0
5	*Tellina* sp. 2	4	3	0	0	0	0	0	0	0	0	0	0
6	*Donax incarnatus*	0	21	46	15	27	75	2	9	0	4	59	44
7	*Donax cuneatus*	0	0	10	7	6	0	0	0	0	0	0	0
8	*Donax faba*	0	0	23	11	23	33	0	0	0	0	0	0
9	*Meretrix* sp.	0	0	0	0	1	0	0	0	0	0	0	0
10	*Timoclea imbricata*	0	0	0	0	0	1	0	0	0	0	0	0

Table C1.2 (Continued) List and mean annual abundance of benthic macrofauna species in Trang province.

No.	Species	Abundance of benthic macrofauna (individuals)											
		Stations											
		TR-PM st1	TR-PM st2	TR-PM st3	TR-PM st4	TR-PM st5	TR-PM st6	TR-CM st1	TR-CM st2	TR-CM st3	TR-YL st1	TR-YL st2	TR-YL st3
11	*Pitar* sp.	0	0	0	0	0	0	0	0	0	0	0	0
12	*Fragum fragum*	2	0	0	0	3	0	0	0	0	0	0	0
13	*Umbonium vestiarium*	3	4	12	0	0	0	19	10	3	0	0	0
14	*Natica vitellus*	14	1	0	0	0	0	0	0	0	0	0	0
15	*Polinices mammilla*	0	0	0	0	0	4	0	0	0	0	0	0
16	*Nassarius pullus*	12	0	0	0	0	0	0	0	0	0	0	0
17	*Nassarius livescens*	0	0	0	0	0	0	3	0	3	0	0	0
18	*Nassarius jacksonianus*	10	9	0	9	4	1	0	0	0	0	0	0
19	*Nassarius stolatus*	6	15	0	0	0	0	0	0	0	0	0	0
20	*Vexillum* sp.	6	3	0	0	0	0	0	0	0	0	0	0
21	*Turricula javana*	0	0	0	0	0	3	0	1	0	0	0	0

Table C1.2 (Continued) List and mean annual abundance of benthic macrofauna species in Trang province.

No.	Species	Abundance of benthic macrofauna (individuals)											
		Stations											
		TR-PM st1	TR-PM st2	TR-PM st3	TR-PM st4	TR-PM st5	TR-PM st6	TR-CM st1	TR-CM st2	TR-CM st3	TR-YL st1	TR-YL st2	TR-YL st3
22	*Lodderia novemcarinata*	0	2	0	0	0	0	0	0	0	0	0	0
23	*Atys cylindricus*	0	0	0	1	0	0	0	0	0	0	0	0
	Total abundance of mollusks	471	178	91	43	131	117	40	20	6	4	59	44
	Crustaceans												
1	*Diogenes klassi*	13	12	0	0	0	8	0	0	0	0	0	0
2	*Diogenes dubius*	29	50	23	4	50	100	4	19	19	0	0	0
3	*Diogenes planimanus*	0	0	0	0	4	0	0	0	0	0	0	0
4	*Matuta victor*	0	9	0	7	0	0	6	0	0	0	0	0
5	*Dotilla intermedia*	47	8	37	175	38	46	5	0	0	123	42	59
6	*Ocypode macrocera*	26	0	0	0	0	1	0	5	5	0	0	0
7	*Scopimera proxima*	0	0	0	0	19	0	0	6	6	0	0	0

Table C1.2 (Continued) List and mean annual abundance of benthic macrofauna species in Trang province.

No.	Species	Abundance of benthic macrofauna (individuals)											
		Stations											
		TR-PM st1	TR-PM st2	TR-PM st3	TR-PM st4	TR-PM st5	TR-PM st6	TR-CM st1	TR-CM st2	TR-CM st3	TR-YL st1	TR-YL st2	TR-YL st3
8	*Macrophthalmus convexus*	1	23	0	0	0	0	0	0	0	0	0	0
	Total abundance of crustaceans	116	102	60	186	111	155	15	30	30	123	42	59
	Total abundance of all species	**1168**	**1018**	**455**	**361**	**509**	**572**	**362**	**180**	**153**	**217**	**162**	**134**
	Total number of species	**42**	**36**	**18**	**14**	**27**	**26**	**22**	**16**	**15**	**9**	**6**	**5**

Table C1.3 List and mean annual abundance of benthic macrofauna species in Satun province.

No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		ST-PR st1	ST-PR st2	ST-PR st3	ST-BB st1	ST-BB st2	ST-BB st3	ST-BB st4	ST-BB st5	ST-BB st6
	Polychaetes									
1	*Scoloplos* (*Scoloplos*) *tumidus*	25	29	26	12	0	0	0	5	0
2	*Scolelepis* (*Scolelepis*) sp.	3	1	0	0	0	0	3	2	0
3	*Paraprionospio* cf. *oceanensis*	0	0	0	0	7	5	0	6	0
4	*Paraprionospio* sp.	0	0	0	7	12	5	8	1	0
5	*Prionospio* (*Prionospio*) *steenstrupi*	1	6	0	9	0	0	4	0	0
6	*Magelona* cf. *cincta*	0	0	8	0	0	6	2	2	0
7	*Mediomastus* sp.	30	0	18	54	36	18	38	6	6
8	*Heteromastus filiformis*	5	0	0	0	0	0	0	0	0
9	*Heteromastus* sp. 1	0	0	0	10	7	0	0	0	0
10	*Heteromastus* sp. 2	0	0	0	0	0	0	9	0	0
11	*Heteromastus* sp. 3	0	0	0	0	0	0	8	0	0

Table C1.3 (Continued) List and mean annual abundance of benthic macrofauna species in Satun province.

No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		ST-PR st1	ST-PR st2	ST-PR st3	ST-BB st1	ST-BB st2	ST-BB st3	ST-BB st4	ST-BB st5	ST-BB st6
12	*Euclymene annandalei*	5	0	0	3	0	0	0	0	0
13	*Ophelina* sp. 1	3	0	0	0	0	3	0	0	0
14	*Ophelina* sp. 2	0	0	0	0	7	20	0	4	3
15	*Asclerocheilus* sp.	0	0	0	3	0	0	0	0	0
16	*Anaitides* sp.	0	3	0	0	0	4	0	0	0
17	*Phyllodoce* sp.	5	0	0	0	0	0	0	4	4
18	*Lepidonotus* sp.	0	0	0	3	0	0	0	0	0
19	*Sigambra pettiboneae*	0	0	0	3	12	19	18	0	0
20	*Neanthes caudata*	6	1	17	68	0	0	8	10	14
21	*Dendronereis arborifera*	0	0	0	20	100	110	205	100	45
22	*Glycera alba*	54	14	10	2	0	0	2	0	0
23	*Glycera natalensis*	0	0	0	0	0	0	0	6	0

Table C1.3 (Continued) List and mean annual abundance of benthic macrofauna species in Satun province.

No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		ST-PR st1	ST-PR st2	ST-PR st3	ST-BB st1	ST-BB st2	ST-BB st3	ST-BB st4	ST-BB st5	ST-BB st6
24	*Glycera* sp.	0	0	0	3	0	0	0	2	3
25	*Goniadopsis incerta*	23	2	0	0	1	0	0	0	0
26	*Linopherus canariensis*	3	0	3	0	0	2	0	2	0
27	*Diopatra amboinensis*	3	3	0	0	10	1	30	0	0
28	*Diopatra semperi*	0	0	0	5	0	0	2	46	0
29	*Diopatra* sp. 1	2	0	0	0	0	0	0	0	0
30	*Scoletoma* sp. 1	34	0	0	5	0	0	9	0	0
31	*Scoletoma* sp. 2	0	0	0	4	8	15	0	26	7
32	*Sternaspis andamanensis*	7	0	0	0	1	1	0	3	0
33	*Peternaspis* sp.	1	0	0	0	0	0	0	0	0
34	*Lanice conchilega*	3	0	0	0	0	0	0	0	0
	Total abundance of polychaetes	213	59	82	211	201	209	346	225	82

Table C1.3 (Continued) List and mean annual abundance of benthic macrofauna species in Satun province.

No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		ST-PR st1	ST-PR st2	ST-PR st3	ST-BB st1	ST-BB st2	ST-BB st3	ST-BB st4	ST-BB st5	ST-BB st6
	Mollusks									
1	*Anadora granosa*	0	0	1	0	0	0	0	0	0
2	*Tellina* sp.1	3	0	14	13	0	0	0	10	0
3	*Tellina* sp. 2	12	0	22	15	16	5	35	0	0
4	*Donax incarnates*	9	16	11	0	0	15	0	53	4
5	*Donax faba*	15	27	61	120	112	70	106	179	206
6	*Gari* (*Psammotaea*) *elongata*	0	0	0	0	0	0	3	0	0
7	*Meretrix* sp.	2	0	0	0	0	0	0	0	0
8	*Timoclea scabra*	2	2	0	0	0	3	0	0	0
9	*Pitar* sp.	0	0	12	89	83	132	44	5	9
10	*Umbonium vestiarium*	3	0	0	0	0	0	0	0	0
11	*Clithon oualaniensis*	5	0	0	0	0	0	0	0	0

Table C1.3 (Continued) List and mean annual abundance of benthic macrofauna species in Satun province.

No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		ST-PR st1	ST-PR st2	ST-PR st3	ST-BB st1	ST-BB st2	ST-BB st3	ST-BB st4	ST-BB st5	ST-BB st6
12	*Natica tigrina*	0	0	15	0	1	0	0	0	0
13	*Natica vitellus*	2	0	0	0	4	0	0	0	0
14	*Nassarius pullus*	4	0	0	0	0	0	0	0	0
15	*Nassarius livescens*	5	0	0	0	0	0	0	0	0
16	*Nassarius jacksonianus*	3	0	0	0	0	0	0	0	0
17	*Nassarius stolatus*	45	13	0	3	1	0	7	9	0
18	*Nassarius globosus*	0	0	0	1	0	0	0	0	0
19	*Turricula javana*	0	3	0	0	0	0	0	0	0
	Total abundance of mollusks	110	61	136	241	217	225	195	256	219
	Crustaceans									
1	*Diogenes klassi*	43	30	9	26	24	20	0	14	11
2	*Philyra olivacea*	2	0	0	0	2	3	3	0	0

Table C1.3 (Continued) List and mean annual abundance of benthic macrofauna species in Satun province.

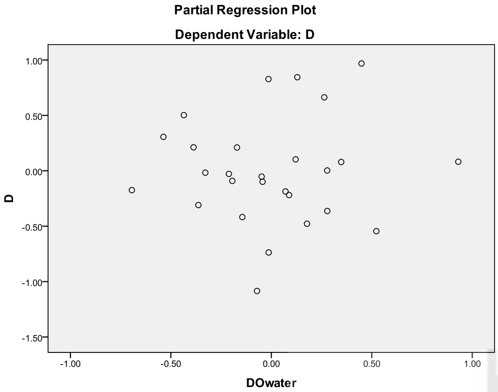
No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		ST-PR st1	ST-PR st2	ST-PR st3	ST-BB st1	ST-BB st2	ST-BB st3	ST-BB st4	ST-BB st5	ST-BB st6
3	*Matuta victor*	3	7	5	0	4	0	0	0	1
4	*Dotilla intermedia*	38	101	239	10	6	0	0	10	0
5	*Dotilla myctiroides*	2	0	0	0	0	0	0	0	0
6	*Ocypode macrocera*	22	5	1	0	11	11	5	3	4
7	*Ocypode ceratopthalma*	0	0	0	0	0	3	0	0	0
8	*Scopimera proxima*	0	0	0	5	0	6	13	6	5
9	*Macrophthalmus convexus*	4	0	0	0	0	0	0	0	0
10	*Camptandrium sexdentatum*	0	0	0	0	0	14	0	0	0
	Total abundance of crustaceans	114	143	254	41	47	57	21	33	21
	Brachiopods									
1	*Lingula* sp.	17	0	0	0	0	0	0	0	0
	Total abundance of all species	**454**	**263**	**472**	**493**	**465**	**491**	**562**	**514**	**322**

Table C1.3 (Continued) List and mean annual abundance of benthic macrofauna species in Satun province.

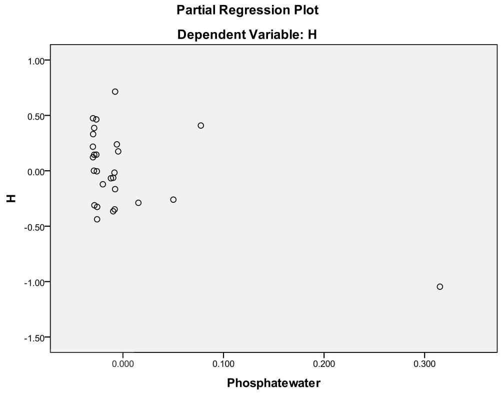
No.	Species	Abundance of benthic macrofauna (individuals)								
		Stations								
		ST-PR st1	ST-PR st2	ST-PR st3	ST-BB st1	ST-BB st2	ST-BB st3	ST-BB st4	ST-BB st5	ST-BB st6
	Number of species	**39**	**17**	**17**	**25**	**22**	**24**	**22**	**25**	**14**

APPENDIX D

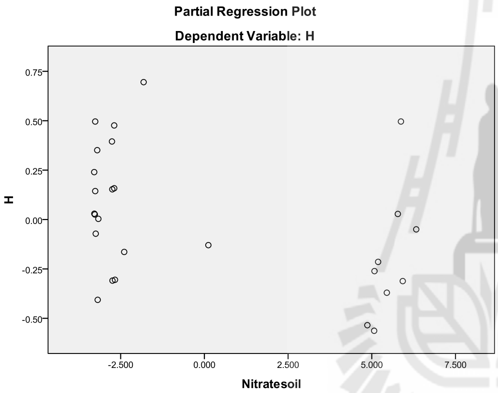
FIGURES OF PARTIAL PLOTS OF STEPWISE LINEAR REGRESSIONS



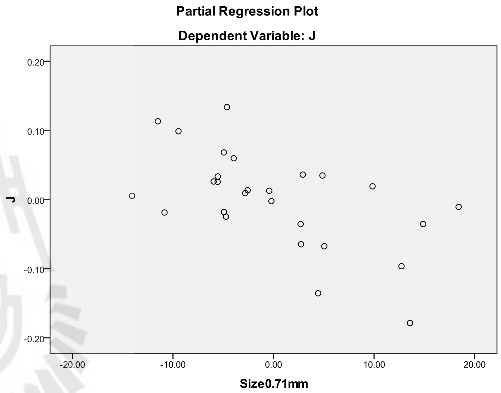
(a) D and dissolved oxygen



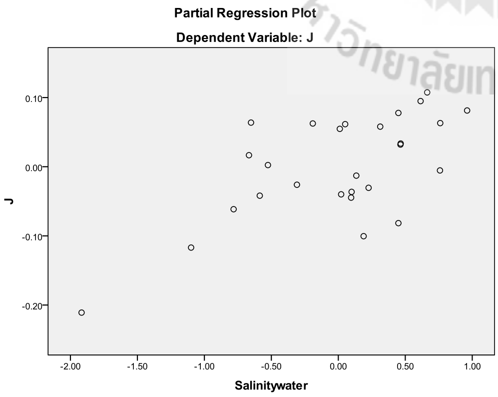
(b) H and phosphate concentration in water



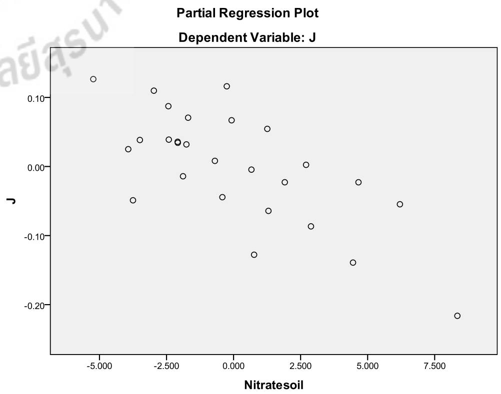
(c) H and nitrate concentration in sediment



(d) J and sediment size 0.71mm

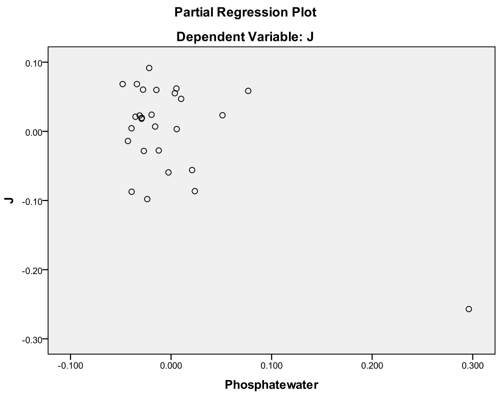


(e) J and water salinity

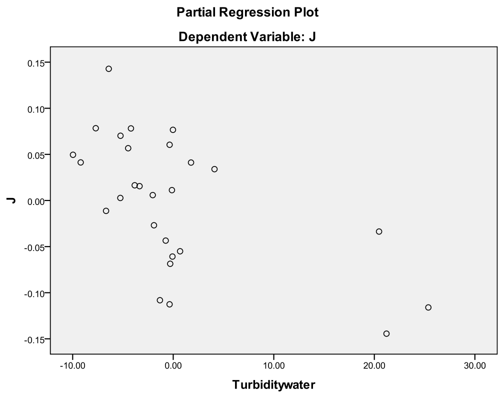


(f) J and nitrate concentration in sediment

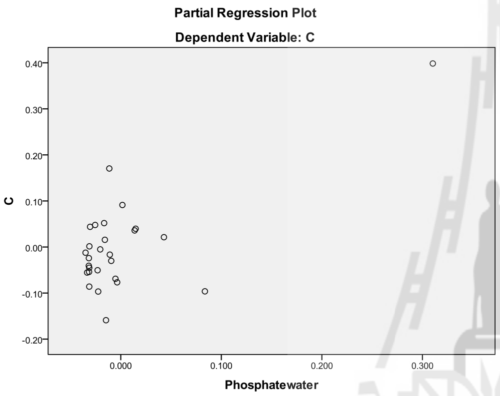
Figure D1.1 Partial plots of stepwise linear regressions between biological indices and environmental variables of sampling stations in Krabi province.



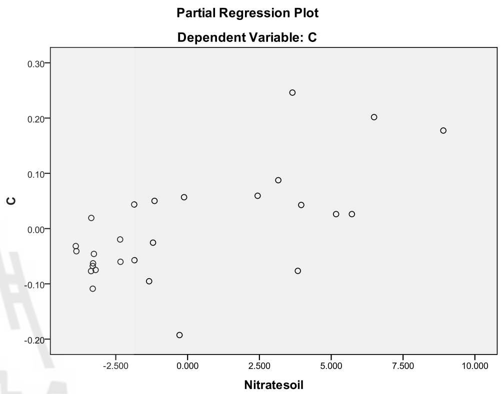
(g) J and phosphate concentration in water



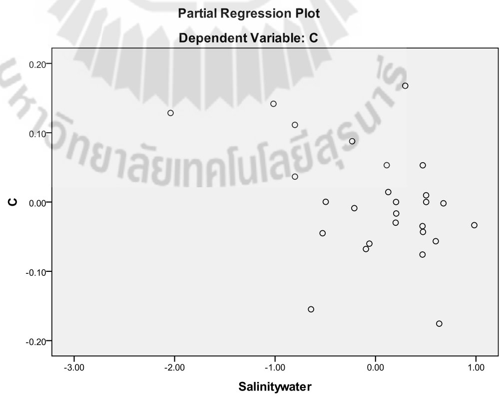
(h) J and water turbidity



(i) C and phosphate concentration in water

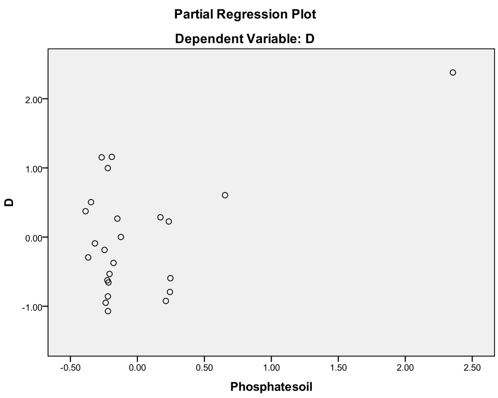


(j) C and nitrate concentration in sediment

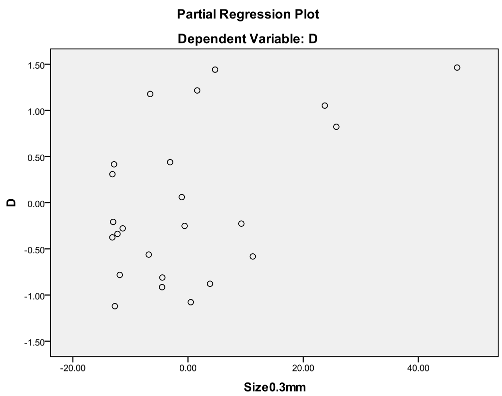


(k) C and water salinity

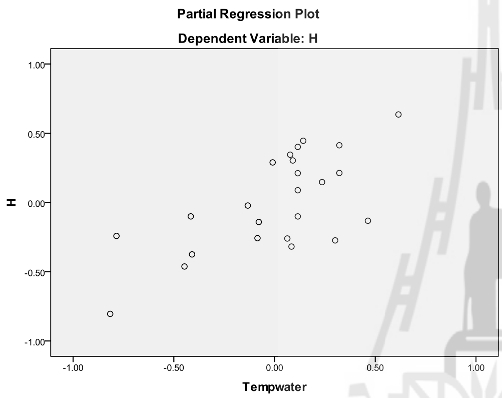
Figure D1.1 (Continued) Partial plots of stepwise linear regressions between biological indices and environmental variables of sampling stations in Krabi province.



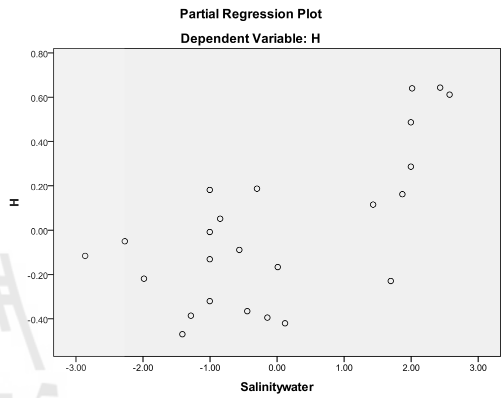
(a) D and phosphate concentration in sediment



(b) D and sediment size 0.3 mm

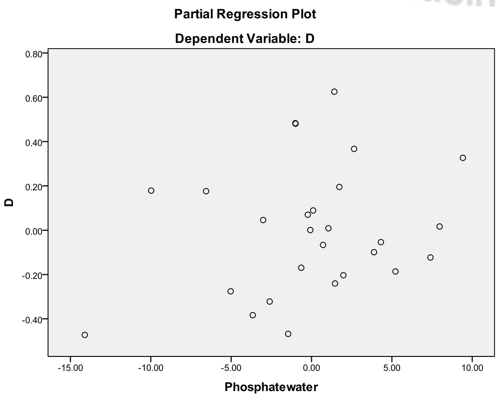


(c) H and water temperature

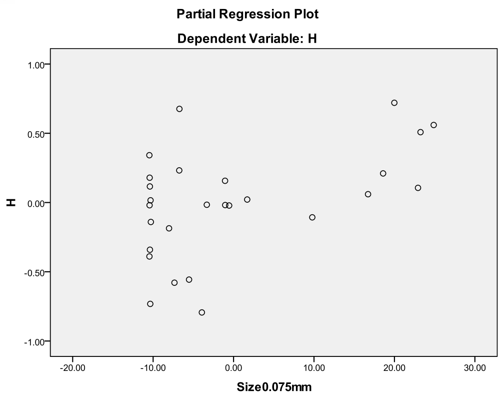


(d) H and water salinity

Figure D1.2 Partial plots of stepwise linear regressions between biological indices and environmental variables of sampling stations in Trang province.

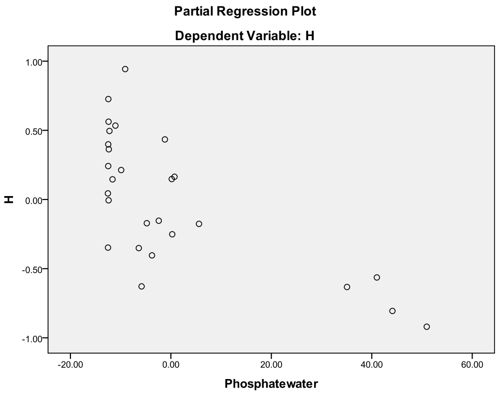


(a) D and phosphate concentrations in water

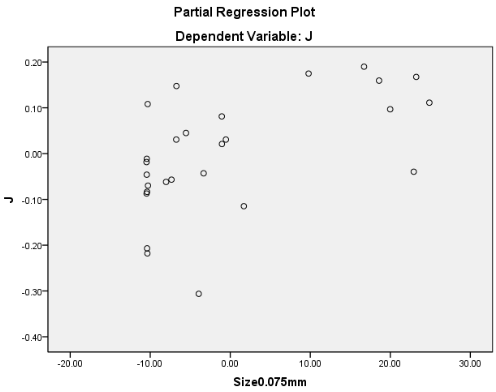


(b) H and sediment size 0.075 mm

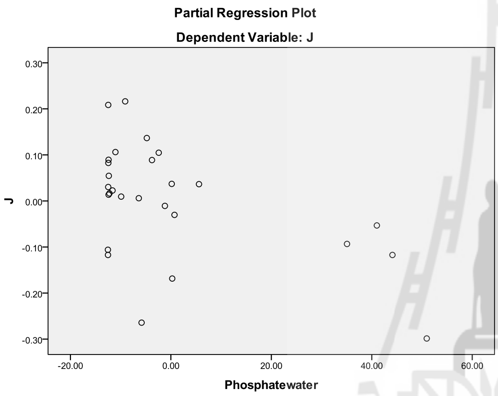
Figure D1.3 Partial plots of stepwise linear regressions between biological indices and environmental variables of sampling stations in Satun province.



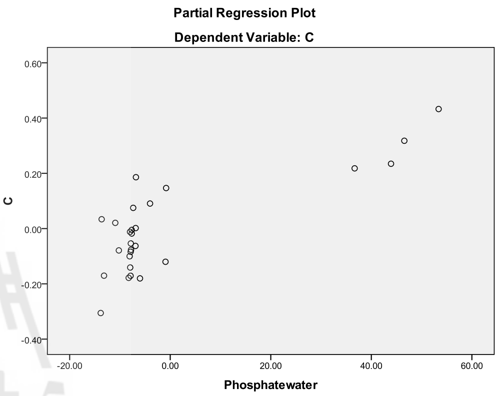
(c) H and phosphate concentrations in water



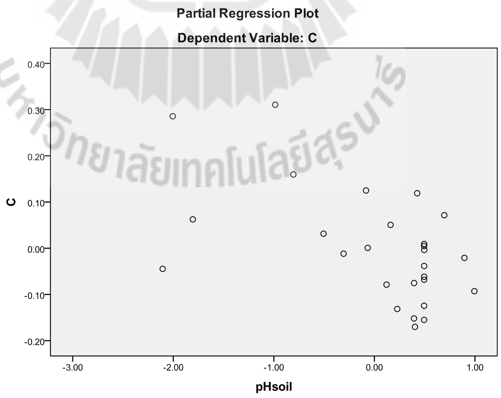
(d) J and sediment size 0.075 mm



(e) J and phosphate concentrations in water



(f) C and phosphate concentrations in water



(g) C and sediment pH

Figure D1.3 (Continued) Partial plots of stepwise linear regressions between biological indices and environmental variables of sampling stations in Satun province.

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