REMOTE SENSING TECHNIQUE FOR SEAGRASS BEDS CLASSIFICATION AT KHUNG KRABEN BAY, CHANTHABURI PROVINCE

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ABSTRACT

The seagrass ecosystem is an important marine ecosystem that has recently come under serious threats mainly caused by human disturbances. Sustainable seagrass management plan is then urgently needed. To support decision making, accurate seagrass habitat maps, with geo-reference, are required. This research therefore aims to investigate appropriate remote sensing techniques for seagrass bed classification. It is the first time that satellite imagery - Landsat TM image – has been used in classifying seagrass habitats in the Khung Kraben Bay, Chanthaburi Province.

The supervised classification approach (i.e. minimum distance to means, parallelepiped and maximum likelihood methods) was mainly implemented in the research. All three techniques seemed to provide good results in classifying the dense canopy of seagrass. However, there was a limitation in identifying low density seagrasses. Among the three methods, the minimum distance to means technique provided the highest accuracy in classifying seagrasses. In addition, it provided fairly good results in classifying *H. pinifolia*. Nevertheless, the research did succeed in demonstrating how remote sensing techniques with the Landsat TM imagery can be used as a tool for the seagrass bed inventory.

KEY WORDS : SEAGRASS BED MAPPING / REMOTE SENSING / LANDSAT TM IMAGE / SUPERVISED CLASSIFICATION / KHUNG KRABEN BAY

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เทคนิคการสำรวจระยะไกลเพื่อการจำแนกแหล่งหญ้าทะเลอ่าวคุ้งกระเบน จังหวัดจันทบุรี
(REMOTE SENSING TECHNIQUE FOR SEAGRASS BEDS CLASSIFICATION AT KHUNG KRABEN BAY, CHANTHABURI PROVINCE)

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บทคัดย่อ

ระบบนิเวศหญ้าทะเลเป็นระบบนิเวศชายฝั่งที่มีความสำคัญ และอยู่ในภาวะซึ่งถูกคุกคามจากกิจกรรมของมนุษย์ ด้วยเหตุนี้ประเทศไทยจึงควรมีแผนการบริหารจัดการทรัพยากรหญ้าทะเลอย่างยั่งยืน โดยแผนที่แสดงแหล่งหญ้าทะเลที่มีความถูกต้องและอ้างอิงพิกัดทางภูมิศาสตร์ได้ จะเป็นข้อมูลที่สำคัญอย่างยิ่งต่อกระบวนการตัดสินใจและวางแผนบริหารจัดการทรัพยากรดังกล่าว งานวิจัยนี้จึงมีวัตถุประสงค์เพื่อศึกษาเทคนิคการสำรวจระยะไกลที่เหมาะสมสำหรับการจำแนกแหล่งหญ้าทะเล โดยเป็นงานวิจัยแรกที่ได้นำข้อมูลดาวเทียม LANDSAT TM มาใช้ศึกษาแหล่งหญ้าทะเลอ่าวคุ้งกระเบน จังหวัดจันทบุรี

ในการวิเคราะห์ข้อมูลดาวเทียมได้ใช้หลักการจำแนกข้อมูลแบบ supervised classification ซึ่งประกอบด้วยเทคนิค minimum distance to means, parallelepiped และ maximum likelihood ทั้งนี้ งานวิจัยพบว่า เทคนิคการจำแนกข้อมูลทั้ง 3 แบบให้ผลดีสำหรับการจำแนกแหล่งหญ้าทะเลที่ค่อนข้างมีพื้นที่การปกคลุมหนาแน่น โดยจะมีข้อจำกัดในการจำแนกแหล่งหญ้าทะเลขนาดเล็กหรือบริเวณที่มีหญ้าทะเลน้อย ซึ่งเทคนิคที่ให้ผลการจำแนกโดยรวมถูกต้องที่สุด คือ เทคนิค minimum distance to means นอกจากนี้ เทคนิคดังกล่าวยังให้ผลการจำแนกหญ้าทะเลชนิด *Halodule pinifolia* ถูกต้องและน่าเชื่อถือสูงที่สุดด้วย ผลการวิจัยครั้งนี้ได้แสดงถึงศักยภาพของเทคนิคการสำรวจระยะไกล และข้อมูลดาวเทียม LANDSAT TM ที่สามารถนำมาประยุกต์ใช้ในการสำรวจและจำแนกแหล่งหญ้าทะเลของประเทศไทยต่อไปได้

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CHAPTER 1
INTRODUCTION

1.1 Problem Statement

Seagrasses are marine angiosperms widely distributed in tropical and temperate intertidal and subtidal zones. These grass-like plants are usually found in beds or meadows patterns on mud or sand in shallow water (den Hartog, 1970; Phillips and Meñez, 1988; Short *et al*., 2001). A seagrass bed is a complex ecosystem. It is an important source of primary production. It provides food and shelter for marine fauna (e.g. dugongs, turtles, and waterfowls) and nursery grounds for juveniles. In addition, the seagrass ecosystem helps in stabilizing nutrient cycles, enriching bottom sediments and improving water quality. It also helps in protecting shorelines from erosion by storms and waves (Phillips and Meñez, 1988; Kemp, 2000; Duarte, 2002; Spalding *et al*., 2003).

Twelve species of seagrasses found in nineteen provinces of Thailand i.e. along the coastlines of the Gulf of Thailand and Andaman Sea (Lewmanomont *et al*., 1991; 1996; Poovachiranon *et al*., 1994; OEPP, 1998a; Supanwanid and Lewmanomont, 2003), have recently come under serious threat. Despite the seriousness of natural hazards (e.g. storms, floods, and diseases), human disturbances are their main threats. These include for example dredging, inappropriate fishing, anchoring, coastal constructions, coastal aquacultures and pollution from inland (Sudara *et al*., 1994; Poovachiranon *et al*., 1994; OEPP, 1998a; 2000; 2001; Satumanatpan, 2000; ONEP, 2003; Satumanatpan and Plathong, 2003; UNEP, 2005). Because of these threats an appropriate action plan for sustainable seagrass management is urgently needed. Such a plan should include a program to monitor changes in the seagrass ecosystem (OEPP, 1997; OEPP, 1998b; Satumanatpan, 2000). For such a program geo-referenced maps that present accurate information regarding

seagrass habitats are required (Fortes, 1989; Kirkman, 1996; 2000; Satumanatpan, 2000, Duarte, 2002).

Remote sensing technology is widely applied in marine habitats mapping including seagrass bed mapping. Such methods provide many advantages over other techniques especially in terms of efficiency and cost-effectiveness (Kirkman, 1996; 2000; Mumby *et al*., 1999; Green *et al*., 2000; McKenzie *et al*., 2001). In the case of Thailand, there are however very few studies regarding seagrass bed mapping. Most researches focus on ecological issues e.g. taxonomy, community structure and biomass (Fortes *et al*., 1994; Satumanatpan, 2000). The problem of a lack of accurate seagrass maps to support any management plan is then evident.

1.2 Research Aim

Because of the need for accurate maps showing the distribution of seagrass beds for the benefit of seagrass management, this research aims to investigate methods for implementing remote sensing techniques for seagrass bed classification. The Khung Kraben Bay on the eastern coast of the Gulf of Thailand was selected as a research site.

1.3 Conceptual Framework

Because the seagrass resources of Thailand are under threat, an appropriate management plan is urgently needed. Accurate maps with geo-referencing presenting distribution of seagrasses are important keys for managing such a plan. Although the remote sensing techniques have shown advantages in habitat mapping, there is still a knowledge gap in applying such methods in seagrass bed mapping in Thailand. This research therefore aims to investigate appropriate methods that apply the techniques in seagrass bed classification. The conceptual framework of the research is summarized in Figure 1.1.

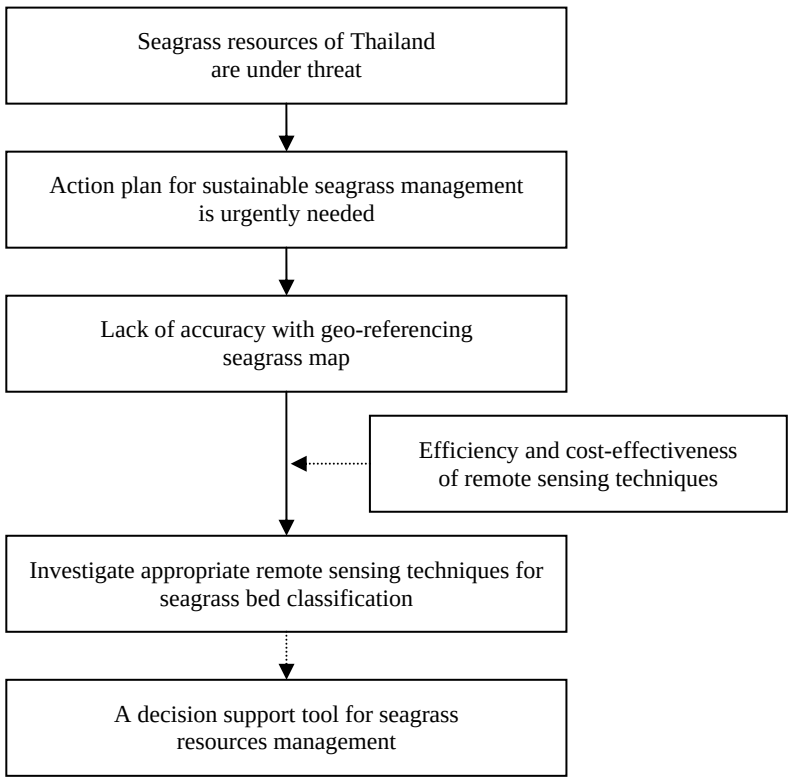


Figure 1.1 The conceptual framework of the research.

1.4 Thesis Outline

An outline of the thesis is explained as follows. Relevant literatures are reviewed in two main sections of Chapter 2. First, an overview of seagrass species, distribution and their importance are presented. Then, applications of remote sensing technology in seagrass beds classification are described. Development of seagrass mapping in Thailand is also highlighted.

Chapter 3 describes characteristics of the study area – the Khung Kraben Bay in Chanthaburi Province, on the eastern coast of the Gulf of Thailand. Previous studies of seagrass bed mapping in the site are also presented. Following that, in Chapter 4, the research methods are explained in two main steps. First, preliminary studies including secondary data collection and visual interpretation of aerial photographs are

explained. Outcomes of such processes are used for the field surveying in the next step where seagrass bed classification is undertaken through the satellite image classification.

Chapter 5 presents the results of the satellite image processing. To evaluate the techniques, an error assessment is undertaken. In the discussion and conclusion, Chapter 6 presents an overall discussion of the research results. Then the contribution of the research and the progress that the research has made in advancing seagrass bed classification in Thailand are discussed.

CHAPTER 2
LITERATURE REVIEW

This chapter aims to present information on seagrass resources and the application of remote sensing technology for seagrass habitat mapping. In order to clearly understand seagrass resources and their situation, this chapter firstly summarizes seagrass species and their distribution worldwide. Next, the importance of seagrass is described. Then, it focuses on the situation of seagrass of Thailand including seagrass species and distribution, as well as threats to seagrass. Following that, the need for seagrass bed mapping is explained. This chapter also describes how remote sensing technology is useful for seagrass habitat mapping. The principles of this technology are firstly described. Then, the application of remote sensing technology for seagrass habitat mapping is reviewed.

2.1 Seagrasses

2.1.1 Global Overview of Seagrass Species and Distribution

Seagrasses are marine angiosperms, which grow fully submerged and rooted in estuarine and marine environments. They are not true grasses. These grass-like plants have the structural features of the leaves and rhizomes/roots adapted to soft substrates (muddy or sandy) of nearshore environments. Seagrasses can form extensive monospecific stands or areas of mixed stands. Such areas are known as seagrass beds or meadows (den Hartog, 1970; Phillips and Meñez, 1988; Fortes, 1989; Short *et* al., 2001; Spalding *et al*., 2003). A global overview of seagrass species and distribution are as follows:

2.1.1.1 Seagrass Species

There are relatively few species of seagrass globally, only 59 species. These are classified into 12 genera and 5 families (Spalding *et al*, 2003). Five genera (i.e. genus *Amphibolis*, *Cymodocea*, *Halodule*, *Syringodium* and *Thalassodendron*) are classified in family Cymodoceaceae. Three genera (i.e. *Enhalus*, *Halophila* and *Thalassia*) are classified in family Hydrocharitaceae. Two genera (i.e. *Zostera* and *Phyllospadix*) are classified in family Zosteraceae. Genus *Posidonia* and *Ruppia* are classified in family Posidoniaceae and Ruppiaceae respectively.

2.1.1.2 Distribution of Seagrass

Seagrasses are widely distributed in tropical and temperate intertidal and subtidal areas (den Hartog, 1970; Phillips and Meñez, 1988; Short *et al*., 2001; Spalding *et al*., 2003). The environmental condition controls on seagrass distribution are light, water depth, bottom substrates, tide and current, salinity and temperature (Phillips and Meñez, 1988; Short *et al*., 2001). Human negative impacts (both land and water-based activities) and global climate change can also affect the distribution of seagrass (Short *et al*., 2001; Spalding *et al*., 2003).

Due to seagrasses' needs for relatively high light for sustaining photosynthesis, they are commonly found in shallow, clear water (Spalding *et al*., 2003). Although normally found in shallow water, some of them can grow at depths of 30 m, for example in the Great Barrier Reef (Coles *et al*., 1989). Seagrasses thrive in waters where there is shelter from wave action and strong currents, which could create turbulent and muddy water, or where there is entrapment of water at low tide, to protect them from heat exposure, drying or freezing (Short *et al*., 2001). Seagrass ecosystems are often associated with coral and mangrove ecosystems (Spalding *et al*., 2003).

Seagrass habitats occur in the northern and southern hemispheres, in more than 120 countries and territories (Short *et al*., 2001; Spalding *et al*., 2003). According to Spalding *et al*. (2003), the countries with greatest seagrass diversity are countries which extend into both tropical and temperate climates, including Australia (29 species), the United States (23 species including all overseas territories) and Japan (16 species). Tropical countries with the highest seagrass species diversity include India and the Philippines (both with 14 species) and Papua New Guinea and Indonesia (both with 12 species). The Indo-West Pacific region is considered to be the center of generic richness and diversity of seagrass in the world (Heck and McCoy, 1978; Spalding *et al*., 2003).

2.1.2 Importance of Seagrass

Seagrass beds or seagrass meadows have recently been recognized as an important marine habitat (Phillips and Meñez, 1988). The importance of seagrass both in terms of their ecological functions and value to humanity are categorized as follows:

1) Fisheries

Seagrass beds form complex and highly productive ecosystems. The beds serve as a shelter and food source for associated animals and also provide a nursery ground for juvenile marine animals. Many of them are of economic importance for offshore fisheries (e.g. fish, mollusks and crustaceans) (Phillips and Meñez, 1988; Kemp, 2000; Duarte, 2002; Spalding *et al*., 2003). Additionally, Kemp (2000) stated that abundance and production of fish and invertebrate populations tend to be higher in seagrass habitats than in adjacent non-vegetated areas.

2) Sediment Stabilization and Coastal Protection

Through their rhizome systems, seagrasses help to stabilize bottom sediments. They perform important physical functions of attenuating wave and tidal energy, resulting in protection for the shoreline, enrichment and prevention of the

resuspension of sediments and particulates. These maintain water clarity and contribute to associated habitats, particularly coral reef ecosystems (Phillips and Meñez, 1988; Kemp, 2000; Duarte, 2002; Spalding *et al*., 2003).

3) Nutrient Cycling and Water Purification

Seagrasses promote the nutrient cycling within the ecosystem (Phillips and Meñez, 1988; Duarte, 2002). By enhancing processes of sedimentation, and through the relatively rapid uptake of nutrients, seagrasses and their epiphytes remove nutrient from the water (Spalding *et al*., 2003). Such nutrients can be released slowly through a process of decomposition and consumption.

Furthermore, seagrasses can also absorb toxic metals from the water. Ward (1989) reported that *Zostera mucronata*, *Posidonia australis* and *P. sinuosa* can be found growing at their usual depths near the Port Pirie smelter in Spencer Gulf, southern Australia where sediments are highly contaminated by Cd, Pb and Zn. Seagrasses may isolate the metals by storing them in structural components where they have little metabolic effect.

4) Mitigating Global Climate Change

Through photosynthesis and respiration, seagrasses provide oxygen to water and remove carbon dioxide from the atmosphere. Thus, seagrasses could play some role in the mitigation of global climate change impacts (Duarte, 2002).

5) Maintaining Biodiversity and Threatened Species

Seagrasses have been well known to the public as a food source for the dugong. They also play a role in safeguarding a number of threatened species such as sea turtles and seahorses. The wider functions of biodiversity include the maintenance of genetic variability, with its biochemical potential and possible role in supporting ecosystem function and resilience. Seagrass ecosystems with high biodiversity can also serve as recreational and educational areas (Spalding *et al*., 2003).

6) Others

There are other important roles of seagrass, particularly human use values. In the southeastern Asia region, including Thailand, seagrasses are used for many purposes, e.g. food and medicine for people, woven for handicrafts, extracted for some beneficial chemicals and compost for fertilizer (Fortes, 1989; Sudara *et al*., 1994; OEPP, 1998a).

2.1.3 Situation of Seagrass in Thailand

2.1.3.1 Seagrass Species and Distribution

Along the approximately 2,600 km coastline of Thailand, 12 species of seagrass in 7 genera (Table 2.1) occur in 19 provinces, with variation in the number of species.

Of 13 provinces in the Gulf of Thailand, on the eastern coast, seagrass sites are found at Chonburi (e.g. Sattahip Bay and Khram Island), Rayong (e.g. Khao Laem Ya, Baan Phe and Makhampom Bay), Chanthaburi (e.g. Khung Kraben Bay) and Trat (e.g. Khao Lan - Laem Klat, Chang and Kradat Island). On the western coast of the Gulf of Thailand, large areas of seagrass sites are found at Chumphon (i.e. Thung Ka - Sawi Bay at Chumphon National Park), Surat Thani (i.e. Samui and Pha Ngan Islands) and Pattani (i.e. Pattani Bay). In addition, seagrass sites with small areas are found at Phetchaburi, Prachuap Khiri Khan, Nakhon Si Thammarat, Phatthalung, Songkhla and Narathiwat (Lewmanomont, *et al*., 1991; 1996; OEPP, 1998a; UNEP, 2005).

In the Andaman Sea, which is more abundant in seagrass than the Gulf of Thailand, seagrass sites are found at 6 provinces including Ranong, Phang Nga, Krabi, Phuket, Trang and Satun (Lewmanomont, *et al*., 1991; 1996; Chansang and Poovachiranon, 1994; Poovachiranon *et al*., 1994; OEPP, 1998a). The largest seagrass site in Thailand is at Hat Chao Mai National Park and Ta Libong Island in Trang

(Supanwanid and Lewmanomont, 2003) where dugongs are frequently seen (Nateekanjanalarp and Sudara, 1994; UNEP 2005).

Table 2.1 A list of seagrass species in Thailand.

Genus	Species	Author
Hydrocharitaceae		
Enhalus	*acoroides*	(Linnaeus f.) Royle
Halophila	*beccarii*	Ascherson
Halophila	*decipiens*	Ostenfeld
Halophila	*minor*	(Zollinger) den Hartog
Halophila	*ovalis*	(R.Brown) Hooker f.
Thalassia	*hemprichii*	(Ehrenberg) Ascherson
Cymodoceaceae		
Cymodocea	*rotundata*	Ehrenberg and Hemprich ex Ascherson
Cymodocea	*serrulata*	(R.Brown) Ascherson
Halodule	*pinifolia*	(Miki) den Hartog
Halodule	*uninervis*	(Forsskål) Ascherson
Syringodium	*isoetifolium*	(Ascherson) Dandy
Ruppiaceae		
Ruppia	*maritima*	Linnaeus

Sources: Lewmanomont *et al*., 1991; 1996; Poovachiranon *et al*., 1994; OEPP, 1998a; Supanwanid and Lewmanomont, 2003

Of the 12 species of seagrass reported in Thailand, two species, *Syringodium isoetifolium* and *Cymodocea rotundata,* are only found on the Andaman Sea coast, while *Ruppia maritima* is only present in estuarine areas in the Gulf of Thailand (Poovachiranoon *et al*., 1994). About associated habitats, Poovachiranon (2000) reported that there are 3 types of seagrass beds along the Andaman Sea coast which are mangrove-associated seagrass beds, seagrass beds on shallow sandy bottoms and seagrass beds associated with coral reefs.

2.1.3.2 Threats on Seagrasses

Seagrasses are critical ecosystems (Spalding *et al*., 2003). As noted in Chapter 1, most seagrass habitats both in the Gulf of Thailand and the Andaman Sea have faced threats over the past decades, leading to the loss and degradation of seagrasses. These have been caused by natural impacts and human disturbances.

1) Natural Impacts

The seagrass habitats with small areas (see Section 2.1.3.1) have natural variability (OEPP, 1998a). Strong disturbances, such as damage by storms and waves can uproot them and increase siltation, leading to massive loss of seagrass and change in community structures (Duarte, 2002). The tsunami attack along the Andaman Sea coast on the 26th December 2004 resulted in a 20 per cent reduction of seagrass cover at Hat Chao Mai National Park in Trang and 50 per cent of reduction at Phra Thong Island in Phang Nga (MNRE, 2005). Overflow from severe inland flooding also leads to siltation on seagrass beds. Moreover, greater freshwater discharges can cause a reduction in salinity close to nearshore, which may create osmotic stress to seagrasses (Short *et al*., 2001; Duarte, 2002).

Additionally, grazing by dugongs and sea turtles can impact seagrasses. However, Supanwanid (1996) estimated a recovery rate of *Halophila ovalis* at Hat Chao Mai National Park from dugong grazing by making artificial trails, and found that the biomass of *H. ovalis* recovered within 2 months. Dramatically, Nakaoka and Aioi (1999) reported that recovery of *H. ovalis* after grazing by dugongs was estimated to be less than 20 days.

2) Human Disturbances

Similarly to the threats to seagrasses worldwide (Short and Wyllie-Echeverria, 1996; Green and Short, 2003), intensive human activities in coastal areas of Thailand cause major disturbances and decline in seagrass habitats. These are due to the lack of knowledge and realization of the significance of seagrass. The

disturbances to seagrasses include mechanical damage, the construction of infrastructure and changes of land use in coastal areas, discharges from coastal activities and eutrophication.

Mechanical damage by dredging, inappropriate fishing (e.g. push nets, trawling) and anchoring causes direct physical destruction of seagrass habitats, resulted in uprooting and removal of seagrasses. Inappropriate fishing has been reported at Makhampom Bay in Rayong (Eastern Marine and Coastal Resources Research Center, 2003 – Pers. Comm.), Thung Ka - Sawi Bay in Chumphon (WFT, 2003), Pattani Bay in Pattani (Intharasook, 1999) and seagrass sites along the Andaman Sea (Chansang and Poovachiranon, 1994; Poovachiranon *et al*., 1994) The construction of infrastructure (e.g. port and road) and changes of land use in coastal areas can increase siltation. These lead to the burial of seagrasses and reduction of water transparency and light penetration. Seagrass habitats impacted by such activities are Samui and Pha Ngan Islands in Surat Thani (OEPP, 1998a; Satumanatpan, 2000), Pattani Bay in Pattani (Intharasook, 1999) and many seagrass sites at the Andaman Sea (Chansang and Poovachiranon, 1994; Poovachiranon *et al*., 1994).

Wastewater discharges from land-based and off-shore activities (e.g. coastal aquacultures, industrial and residential areas) can pollute coastal water and seagrass areas. Loading of discharges with enrichment from nutrients can also cause eutrophication phenomena over seagrass habitats as is obviously seen at Pattani Bay in Pattani (Intharasook, 1999). In the past decades, seagrass beds at Khung Kraben Bay have suffered from the discharges from the expansion of shrimp ponds (OEPP, 1998a). A seawater irrigation system has been constructed since 1989 to mitigate these effects (Khung Kraben Bay Fisheries Development Study Center, no date).

However, OEPP (1998a) reported that there are some seagrass habitats, which tend to have less impact from human disturbances. This is due to their falling under the responsibility of the military (i.e. Sattahip Bay and Khram Island in Chonburi, Manao Bay in Prachuap Khiri Khan) or private sector (i.e. Kradat Island in Trat, Tan Island in Surat Thani).

2.1.3.3 The Need for Seagrass Bed Mapping

Due to the fact that seagrass habitats are usually found in shallow water, they can be affected easily by various disturbances. As stated above, the seagrass habitats of Thailand are degraded and under serious threat. Consequently, integrated management and systematic monitoring are urgently needed.

Agenda 21, drawn up by the United Nations Conference on Environment and Development (UNCED) in 1992, declared that coastal and marine resources (including seagrass habitats) shall be protected. Integrated coastal and marine environment management plans, prevention of pollution from land-based and off-shore activities and implementation of the regional seas program should receive priority in national and regional activities (Quarrie, 1992; ESCAP, 1997). Similarly, in Thailand, the Policy and Prospective Plan for Enhancement and Conservation of National Environmental Quality 1997-2016 also stated that seagrass habitats shall be protected (OEPP, 1997), while the Management Plan for Environmental Quality 1999-2006 specified that degraded seagrass habitats shall be rehabilitated (OEPP, 1998b). In addition, ONEP (2003) suggested that seagrass bed mapping and zoning should be carried out. It also mentioned that the environmental impact assessment for coastal development activities should be improved; the public, particularly local people, should be encouraged and strengthened to realize seagrass importance and participate in monitoring changes in seagrass resources; research on seagrass rehabilitation and protection should be funded.

In order to achieve good seagrass management planning and change monitoring, seagrass maps are important keys for decision-making support purposes. Fortes (1989) stated that no management practices could be effectively implemented without knowledge of where the seagrass beds are located. In Thailand, however, most researches on seagrass resources have focused on seagrass taxonomy and distribution, community structure and biomass. Very few have been related to seagrass bed mapping. To deal with this problem, remote sensing technology should be applied for the inventory and classification of seagrass habitats of the country.

2.2 Remote Sensing for Seagrass Bed Classification

2.2.1 Remote Sensing: Definition and Processes

Remote sensing is defined as "the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation" (Lillesand *et al*., 2004). More sharply and precisely defined, remote sensing is "the noncontact recording of information from the ultraviolet, visible, infrared, and microwave regions of the electromagnetic spectrum by means of instruments such as cameras, scanners, lasers, linear arrays, and/or area arrays located on platforms such as aircraft or space aircraft, and the analysis of acquired information by means of visual and digital image processing" (Jensen, 2000).

Lillesand *et al*. (2004) explained that there are two main processes, data acquisition and data analysis (Figure 2.1). The elements of the data acquisition are energy sources (e.g. sun) (a), propagation of energy through the atmosphere (b), energy interactions with earth surface features (c), re-transmission of energy through the atmosphere (d), detections of energy by airborne and/or satellite sensors (e), resulting in the generation of sensor data in pictorial and/or digital form (f). For the data analysis process, the data are interpreted and analyzed by 2 major techniques (i.e. visual interpretation and/or computer-assisted analysis) (g). Reference data (e.g. field survey data, thematic maps) are used to assist in the data analysis. The information is then compiled (h), generally in the form of hard copy maps, tables or as computer files that can be merged with other layer of information in a geographic information system (GIS). Finally, the information is presented to users (i) who apply it to their decision-making process.

Remote sensing together with GIS has been widely used as a tool in resource management planning and support decision-making. Numerous applications includes cartography, land use analysis, geology, soils, water resources, agriculture, forestry, landscape planning, habitat mapping, environmental monitoring, evaluation of natural

hazards, conservation and oceanography (Jensen, 2000; Althausen, 2002; Pattanakiat, 2002; Lillesand *et al*., 2004).

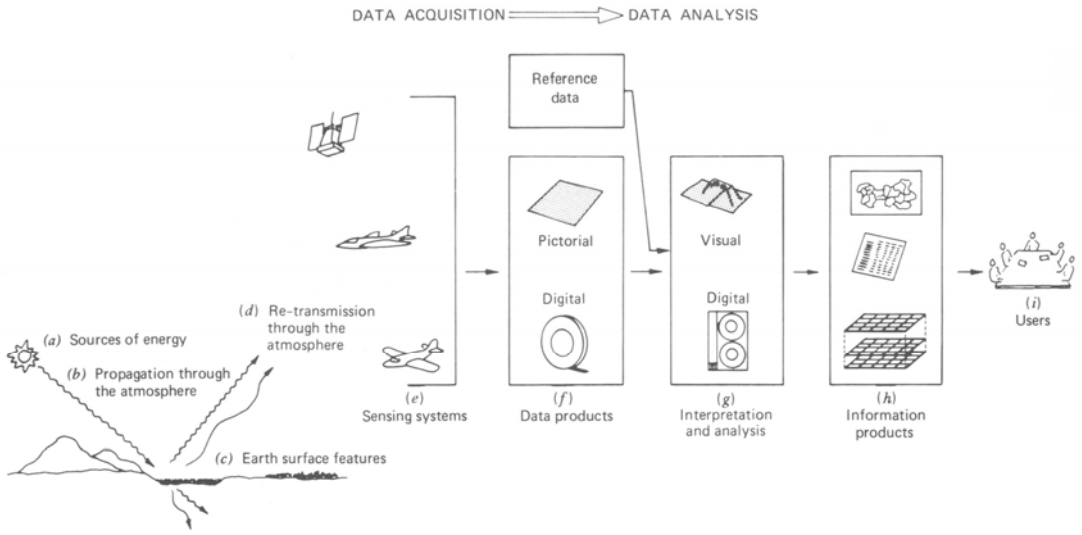


Figure 2.1 The illustration of general processes and elements involved in remote sensing of earth resources (from Lillesand *et al*., 2004).

Remote sensed data can be divided into 2 main types, aerial photographs and satellite images (Althausen, 2002). Currently, to obtain satellite images, many of the earth resource satellites have been launched. For example, the satellites with high resolution images include QuickBird and IKONOS. QuickBird has 1 panchromatic band at 0.61 m spatial resolution and 4 multispectral bands at 2.44 m resolution. IKONOS also has 1 panchromatic band and 4 multispectral bands but at 1 m and 4 m spatial resolution respectively. Such high resolution imageries are useful for application in cartography, urban planning, fine-scale resource inventory and coastal applications. The moderate resolution imageries include Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper Plus (ETM+) and SPOT 5. Landsat TM has 3 visible bands (30 m spatial resolution), 3 short-wave infrared bands (30 m spatial resolution) and 1 thermal band (120 m spatial resolution). Landsat ETM+ also has 3 visible bands and 3 short-wave infrared bands with spatial resolution of 30 m. The improvement of ETM+ over the previous TM is the thermal and panchromatic bands with spatial resolutions of 60 m and 15 m respectively. SPOT 5 has 1

panchromatic band at 2.5 to 5 m spatial resolution and 4 multispectral bands at 10 m spatial resolution. These moderate resolution images can be used for resource inventory, coastal applications, environmental monitoring and change detection (Green *et al*., 2000; Althausen, 2002).

One of the most used satellite imageries is Landsat TM. It was launched into orbit (at an altitude of 705 km) on the 1st March 1984. It has a sun-synchronous orbit, with 16 days repeat cycle (Jensen, 2000; Althausen, 2002; Lillesand *et al*., 2004). With multispectral bands, their characteristics are shown in Table 2.2.

Table 2.2 Characteristics of the Landsat Thematic Mapper spectral bands

Band	Wavelength (μm)	Spectral Location	Applications
1	0.45-0.52	Blue	Designed for water body penetration, making it useful for coastal water mapping. Also useful for soil/vegetation discrimination, forest type mapping.
2	0.52-0.60	Green	Designed to measure green reflectance peak of vegetation for vegetation discrimination and vigor assessment.
3	0.63-0.69	Red	Designed to sense a chlorophyll absorption region aiding in plant species differentiation.
4	0.76-0.90	Near-infrared	Useful for determining vegetation types, vigor and biomass content, for delineating water bodies and for soil moisture discrimination.
5	1.55-1.75	Mid-infrared	Indicative of vegetation moisture content and soil moisture. Also useful for differentiation of snow from clouds.
6	10.4-12.5	Thermal infrared	Useful in vegetation stress analysis, soil moisture discrimination and thermal mapping application.
7	2.08-2.35	Mid-infrared	Useful for discrimination of mineral and rock types. Also sensitive to vegetation moisture content.

Sources: Adapted form Lillesand *et al*., 2004

2.2.2 Remote Sensing for Marine Habitats Mapping

Both types of remote sensed data, aerial photographs and satellite imageries, have been used for coastal marine habitat mapping and monitoring in many places (Green *et al*., 1996; 2000; Chauvaud *et al*., 1998; Riegl and Piller, 2000; Mumby and Edwards, 2002; Ekebom and Erkkilä, 2003). On the cost-effectiveness of remote sensing for coastal habitat mapping, Mumby *et al*. (1999) reported that remote sensing is a more cost-effective technique than alternative field survey methods. For mapping small coastal areas (<60 km in any direction) in coarse detail, SPOT XS is the most cost-effective satellite sensor, but for larger areas Landsat TM is the most cost-effective and accurate sensor. Detailed habitat mapping should be undertaken using digital airborne scanners or interpretation of color aerial photography. Mumby and Edwards (2002) also reported that IKONOS (with 4 m multispectral spatial resolution) may be a cost-effective option if habitat patches or habitat dynamics are to be identified and monitored.

To map such coastal habitats, the visual interpretation approach is usually taken for the aerial photographs, whereas digital image processing, the computer-assisted approach, is taken for satellite images. Through the visual interpretation approach, the features in photographs are identified visually based on the experience of the analysts. Fundamental elements help to distinguish features in the photograph include shape, size, pattern, height (depth), shadow, tone (color), texture, site and association (Jensen, 2000; Narumalani, 2002; Lillesand *et al*., 2004). For the digital image processing used for underwater mapping applications, there are some issues that have to be taken into consideration as described below:

2.2.2.1 Band Selection

The visible spectral bands are considered useful for underwater feature mapping due to the fact that some spectral regions, particularly blue spectral region, are high in transmittance through water. With longer wavelengths, the transmittance rapidly declines (Figure 2.2) (Verbyla, 1995; Lillesand *et al*., 2004). Therefore, the

visible spectral bands are suitable for underwater mapping applications. For Landsat TM, band 1 (blue band) was designed for underwater mapping applications (see Table 2.1).

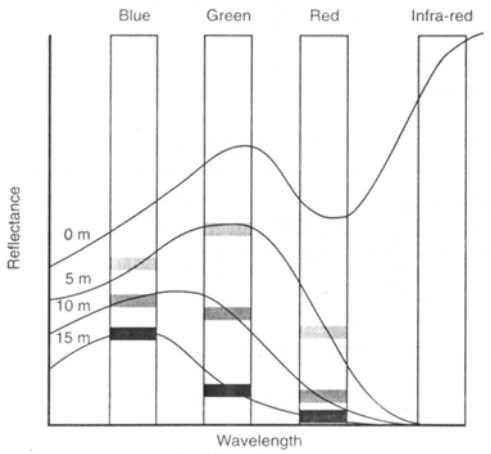


Figure 2.2 The changes of reflectance with increasing depth for the four waveband (blue, green, red and near-infrared). Differential attenuation of the 4 wavebands in the water column results in both a decreased ability to discriminate between different habitats with increasing depth and different reflectance being recorded for the same habitats at different depths (from Green *et al*., 2000).

2.2.2.2 Atmospheric Correction

Atmospheric correction should be undertaken in order to compensate for atmospheric absorption and scattering phenomena that can affect the radiance detected at the satellite sensor (Green *et al*., 2000; Rees, 2001; Narumalani 2002). Such a correction approach is useful when multiple scenes of imagery need to be analyzed, e.g. change monitoring studies (Narumalani 2002). Among several existing models, atmospheric modeling, 5S radiative transfer code (Simulation of the Sensor Signal in the Solar Spectrum) is used widely (Green *et al*., 2000). It includes a variety of standard options that allow this approach to be used with limited ancillary data (Tanre *et al*., 1990). The input data to the 5S radiative transfer code model include

viewing and illumination geometry, atmospheric profile, aerosol components, aerosol concentration, spectral band and ground reflectance. For the aerosol concentration parameter, a meteorological visibility (km) is required as an input data. For other parameters, the users can select appropriate inputs from the model (see Tanre *et al*., 1990 and Green *et al*., 2000).

2.2.2.3 Water Column Correction

As the light intensity decreases exponentially with increasing depth, it can cause confusion of the spectral radiances among underwater features (Figure 2.2). Therefore, compensation for the influence of water depth on bottom reflectance should be carried out (Green *et al*., 2000). The accuracy of habitat maps showed significant improvement when water column correction was undertaken (Mumby *et al*., 1998; Green *et al*., 2000). Lyzenga (1981) proposed a simple image-based approach to compensate such effect, the depth-invariant index algorithm.

$$\textit{depth-invariant index}_{ij} = \ln(L_i) - \left[\left(\frac{k_i}{k_j}\right) \cdot \ln(L_i)\right]$$

where $k_i / k_j = a + \sqrt{(a^2 + 1)}$

$$a = \frac{\sigma_{ii} - \sigma_{jj}}{2\sigma_{ij}}$$

and $\sigma_{ij} = \overline{X_i X_j} - \left(\overline{X_i} \cdot \overline{X_j}\right)$

($X_i = \ln(L_i)$, where L_i is the pixel radiance in band *i*. σ_{ii} is the variance of band *i*, σ_{ij} is the covariance between band *i* and *j*. k_i / k_j is the ratio of attenuation coefficients).

2.2.2.4 Classification Techniques

The digital image classification algorithms can be simply categorized as unsupervised and supervised classification techniques. Unsupervised classification automatically assigns unknown pixels in the image and aggregates them into a group or class based on their similarity to the spectral characteristics of the classes that are defined by the analysts (Narumalani *et al*., 2002; Lillesand *et al*., 2004). In contrast, supervised classification requires input from the analysts, training sites. The training site, which is an area that represents the homogeneous example of specific features or habitats to be mapped from the imagery, is needed for use in subsequent analysis. Thus, the analysts should be familiar with the study site and have a priori information about the site for extracting such the training sites (Narumalani *et al*., 2002; Lillesand *et al*., 2004). Once the characteristics of training sites have been obtained, it is possible to use a pattern recognition algorithm to classify the imagery into specific classes of feature. Three classification algorithms for spectral pattern recognition that are the most frequently used include minimum distance to means, parallelepiped and maximum likelihood classifier (Narumalani *et al*., 2002).

The minimum distance to means classification algorithm is mathematically simple (Lillesand *et al*., 2004). Based on the training site data, it characterizes each class by its mean position on each band. To classify an unknown pixel, it examines the distance from that pixel to each class and assigns it the identity of the nearest class (Figure 2.3 (a)) (Eastman, 2001b). The parallelepiped classification algorithm is very fast and efficient computationally (Lillesand *et al*., 2004). The parallelepiped procedure characterizes each class by the range of expected values on each band. This range may be defined by the minimum and maximum values found in the training site data for that class or by some standardized range of deviations from the mean. With multispectral image data (e.g. Landsat TM), these ranges form an enclosed box-like polygon of expected values known as a parallelepipeds (Figure 2.3 (b)). Unclassified pixels are then given the class of any parallelepiped box they fall within. If a pixel does not fall within any box, it is left unassigned (Eastman, 2001b). The maximum likelihood is based on Bayesian

probability theory. It uses the means and variance/covariance data of the training site to estimate the posterior probability that a pixel belongs to each class (Figure 2.3 (c)) (Eastman, 2001b).

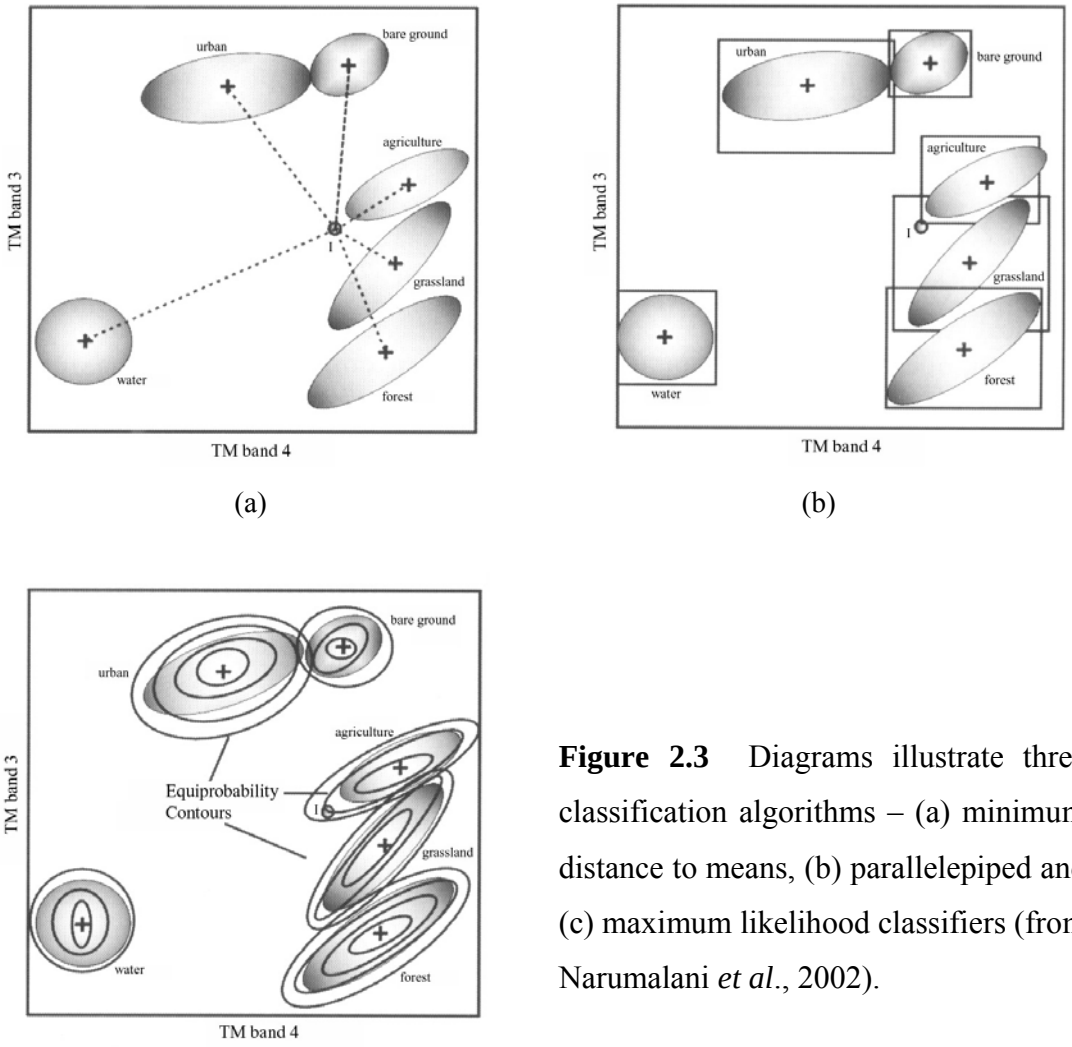


Figure 2.3 Diagrams illustrate three classification algorithms – (a) minimum distance to means, (b) parallelepiped and (c) maximum likelihood classifiers (from Narumalani *et al*., 2002).

2.2.2.5 Accuracy Assessment

Inaccurate maps may result in poor management decisions (McKenzie *et al*., 2001). Therefore, accuracy assessment should be undertaken in order to evaluate the accuracy and reliability of the classified data (Green *et al*., 2000; Congalton and Plourde, 2002; Lillesand *et al*., 2004).

The Kappa index can be computed for the classified image. It represents an overall accuracy of the classification with a possible range from 0 to 1 (Green *et al*., 2000). However, the overall accuracy ignored the commission and omission errors. An error matrix then is the way to effectively compare two maps quantitatively. It consists of a square array of numbers set out in rows and columns that express the number of sample units assigned to each land cover type as compared to what is on the actual ground. It also provides accuracy for each land cover type as well as both errors of exclusion (omission error) and errors of inclusion (commission error) present in the classification. The omission error can be referred to as producer's accuracy, because from this error the producer of the classification will know how well a certain area was classified. The commission error can be referred to as the user's accuracy, indicating for the user of the map the probability that a pixel classified on the map actually represents that land cover type on the ground (Congalton and Plourde, 2002).

Green *et al*. (2000) stated that there are few guidelines existing on the accuracy requirements of habitat maps for particular coastal management applications. Nevertheless, they mentioned that an accuracy of 60 per cent is probably as useful as 80 per cent for the habitat maps are used to provide a general inventory of resources as background to a management plan. However, applications such as estimating the loss of seagrass cover due to coastal development activities would require the highest accuracies possible (about 90 per cent).

2.2.3 Applications of Remote Sensing for Seagrass Habitat Mapping

2.2.3.1 Development of Seagrass Bed Mapping in Thailand

In Thailand, there is a gap of knowledge in applying remote sensing techniques for seagrass bed mapping. Of the studies of seagrass resources in Thailand, most of them have focused on seagrass taxonomy and distribution, structure of seagrass community and biomass, and seagrass beds have been mapped by hand. Some maps have presented the seagrass resources in points, while some have

presented them as extensive areas. Such maps are in hard copy (analog format) and lack geo-referencing. According to McKenzie *et al*. (2001), it should be noted that a paper map is in a format that does not allow manipulation and transformation. This makes it difficult for future seagrass mapping studies to be compared, queried and analyzed.

In 1998, however, there was a study on seagrass bed classification and a national management and action plan for seagrass resources in Thailand. Seagrass maps, which were cited from the previous studies together with the visual interpretation of 1:50,000 aerial photographs, were presented in hard copy. Additionally, the ground truthing (accuracy assessment) for the interpreted maps were not undertaken (OEPP, 1998a).

In 2004, the UNEP/GEF project on Reversing Environmental Degradation Trends in the South China Sea and the Gulf of Thailand, through the seagrass component of Thailand, reviewed the previous studies on seagrass in the Gulf of Thailand and transformed the maps into digital format (UNEP, 2004). The limitation of the report is the lack of up-to-date data and that the seagrass beds in some areas are still presented in point. However, this study can be useful for general management planning, policy and decision-making support.

As this review shows, it is clear that there is a gap of knowledge in implementing remote sensing technology for seagrass habitat mapping in Thailand. Some of researches show that such technology has been used only for mangroves (Charuppat, 1998) and coral reefs (Thamrongnawasawat, 1991; Jensiripikul, 2002; Ninsawat, 2002). Jensiripikul (2002), by using Landsat TM image to classify coral reefs at Kradat Island in Trat, found that the principal component analysis (PCA) and supervised classification with Mahalanobis distance and Minimum distance to means classifiers can be used for shallow water coral reef survey and classification. The overall accuracies from these 2 classifiers were 55.15 and 51.80 per cent respectively. Ninsawat (2002) used the Mahalanobis classifier to classify the coral reef habitats at Phi Phi Island in Krabi Province. The fused image (5.8 m spatial resolution) of

panchromatic band and LISS III multispectral bands of IRS-1D satellite was used. This classification technique provided an overall accuracy of 76.67 per cent.

2.2.3.2 Relevant Researches

For seagrass resources, the reviewed researches can be divided into 3 groups according to the remote sensed data that they used. The researches deal with aerial photographs (Robbins, 1997; Chauvaud *et al*., 1998; Pasqualini *et al*., 1998; 2001; Seddon *et al*., 2000; Kendrick *et al*., 2000, 2002; Agostini *et al*., 2003a; 2003b), satellite images (Dahdouh-Guebas *et al*., 1999; Mumby *et al*., 1999; Mumby and Edwards, 2002; Lundén and Gullström, 2003; Bouvet *et al*., 2003; Pasqualini *et al*., 2005) and aerial photographs together with satellite images (Ward *et al*., 1997; Ferguson and Korfmacher, 1997).

1) Aerial Photographs Applications

Aerial photographs can be used for seagrass bed mapping; for example, Chauvaud *et al*. (1998) used digitized aerial photographs to map coral reefs, mangroves and seagrass beds in the Bay of Robert at Martinique Island, French West Indies. Aerial photographs, at a scale of 1:25,000, were first subjected to true-color digitization by using a color scanner. The resolution used was 5 m pixel. After separation of the red, green and blue bands, an unsupervised classification was achieved. After geo-rectification and terrestrial masking out were carried out, the new images obtained were analyzed by using supervised classification with the maximum probability algorithm. The technique can identify the percentage coverage of seagrass beds in various substrates, as well as corals and mangroves. To assess reliability of the thematic map, an error matrix was produced. An overall accuracy was 94 per cent, which indicates reasonable accuracy. The research concluded that the technique was suited to the monitoring of coastal ecosystems.

Similar to Chauvaud *et al*. (1998), the study by Pasqualini *et al*. (1998) also used digitized color photographs (a scale of 1:20,000) to map the beds of seagrass

(*Posidonia oceanica*) at Corsica Island, Mediterranean Sea. Computerized image processing techniques, the Principal Component Analysis (PCA) and supervised classification by hypercube were applied to the photograph. Four assemblages and bottom types (i.e. soft sediments, photophilous algae on rock, patchy seagrass beds and continuous seagrass beds) were taken into account. The study found that the image processing technique offered relatively reliable interpretation of the main benthic assemblages in shallow water (0 to 20 m of depth) along 100 km of the Corsican coastline.

At the same place as Pasqualini *et al*. (1998), Corsica Island in the Mediterranean Sea, Agostini *et al*. (2003a) used digitized color aerial photographs (scale of 1:25,000) taken in 1997 to estimate the distribution of *Cymodocea nodosa*, *Zostera noltii* and *Ruppia cirrhosa* in the Urbinu Lagoon (about 10 m of depth). Principal component analysis (PCA) was applied to identify the main benthic assemblages and bottom types into sand, mud, pebbles, mixed meadows of seagrass and the dead shoots of *Posidonia oceanica*. The study found that the meadows of *C. nodosa* and *Z. noltii* were dominant in the area strong influenced by seawater (near the sea), while the meadows of *R. cirrhosa* were dominant in the area influenced by freshwater (near the river). The classified map is estimated to be reliable at 76 per cent for the whole lagoon.

To monitor the changes in seagrass, Robbins (1997) used color aerial photographs of 1988, 1990 and 1992, at a scale of 1:24,000, to identify seagrass coverage (i.e. *Halodule wrightii*, *Thalassia testudinum*, *Syringodium filiforme* and *Ruppia maritima*) at the shallow estuary, Tempa Bay in Florida. The results were compared with the data in 1982 to estimate the coverage of changes of seagrass. Although the interpretation could not identify seagrass cover by species, it found that the overall seagrass coverage at Tempa Bay had increased 87 per cent during the decade of 1982 to 1992.

Seddon *et al*. (2000) used aerial photographs to map the extent and location of dieback of intertidal and subtidal seagrasses along the north eastern coast

of Spencer Gulf, South Australia. Two periods (1987 and 1994) of the photographs (scale of 1:40,000) were enlarged to scale about 1:20,000, colour and texture characteristics were used to help to distinguish the habitat features. The study found that the dieback of *Amphibolis antarctica* and *Zostera* spp. was associated with a hot El Niño summer. The factor of extreme climatic conditions, combined with low sea levels, resulted in a sudden and wide-scale loss of seagrasses rather than a gradual regression.

In Western Australia, Kendrick *et al*. (2000) used aerial photographs from 1965, 1972, 1982 and 1995 to determine the temporal and spatial changes in seagrass distribution at Success and Parmelia Banks. These photographs were rectified, and then manually interpreted for seagrass areas and non-vegetated sands. The mapping of seagrass covers at a scale of 1:10,000 was only feasible for species of seagrass with a dense leaf canopy, *Amphibolis* spp. and *Posidonia* spp., while it was not possible to map *Halophila ovalis*, *Heterozostera tasmanica* and *Syringodium isoetifolium*. The results indicated that the percentage of seagrass cover on Success Bank had increased from 21 per cent in 1965 to 43 per cent in 1995, whereas on Parmelia Bank the percentage of seagrass cover had remained relatively constant with 46 per cent in 1965 and 44 per cent in 1995.

In Cockburn Sound in Western Australia, Kendrick *et al*. (2002) studied changes of seagrass coverage from 1967 to 1999. Color aerial photographs taken in 1967, 1972, 1981, 1994 and 1999 were used. The computerized, grayscale segmentation mapping method (Spann-Wilson segmentation) was employed to map submerged vegetation. A towed underwater video was used in ground truthing surveys. The results found that seagrass coverage in the area had declined by 77 per cent since 1967. The study formed an accurate baseline of seagrass changes between 1967 and 1999 for further monitoring and management of seagrass in the Cockburn Sound.

Agostini *et al*. (2003a), Agostini *et al*. (2003b) used these research results together with previous works to examine the temporal and spatial changes of seagrass cover in the Urbinu Lagoon, Mediterranean Sea from 1990 to 1997. The

maps of seagrass in 1990, 1994 and 1997 that were interpreted from image processing using 1:25,000 color aerial photographs were compared by using Adobe Photoshop software. The overall change was 12 per cent decrease between 1990 and 1994, and a 16 per cent increase between 1994 and 1997. The study concluded that regressions were not irreversible over that period of 7 years and seagrass meadows in the area had been stable despite environmental perturbations.

2) Satellite Image Applications

For the application of satellite data, Dahdouh-Guebas *et al*. (1999) used the 3 visible bands of Landsat TM to map the distribution of seagrass and algae along the southern Kenyan coast in East Africa. The process of density slicing (in the NIH Image 1.52 program) was used for the image. For the results, 2 distinct zones of vegetation can be recognized. Ground truthing revealed that they are rocky substrates with mostly algae and seagrasses. This study provided a preliminary map illustrating the wide extent of such plants.

Lundén and Gullström (2003) also used the 3 visible bands of Landsat TM to monitor the vanishing of seagrass along the Swedish coast. A natural color composite of the 1989 and 2000 TM images were created. Contrast stretching was undertaken to enhance the distribution of eelgrass (*Zostera marina*). The TM imags clearly indicated the potential for mapping and monitoring of eelgrass over the Swedish coast.

For the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) sensor, the capacity of the sensor to classify the shallow benthic ecosystems of New Caledonia in the South Pacific was investigated by using unsupervised classification method (Bouvet *et al*., 2003). The results showed that the classification of the main benthic habitats in shallow water (<5 m of depth) was possible, at a geomorphological scale for coral reef structure and at a habitat scale for seagrass beds. However, the process required local validation to avoid confusion between coral slopes and shallow dense seagrasses.

Recently, Pasqualini *et al*. (2005) used the SPOT 5 image with spatial resolution of 2.5 and 10 m for mapping *Posidonia oceanica* at Laganas Bay in the Mediterranean Sea. Supervised classification by generalized hypercube was applied to both types of image. Overall accuracies of SPOT 2.5 m and SPOT 10 m were 73 and 96 per cent respectively. Although SPOT 2.5 m provides lower overall accuracy than SPOT 10 m, it was very useful for mapping *P*. *oceanica*, as it allowed the patchiness of the formations to be better taken into account.

3) Aerial Photographs together with Satellite Image Applications

Ward *et al*. (1997) studied the spatial change in eelgrass meadows (*Zostera marina*) from 1978 to 1995 at Izembek Lagoon, Alaska. The study area is a shallow water embayment, which is believed to contain one of the largest beds of eelgrass in the world. The 1978 Landsat multi-spectral scanner (MSS) image and 1987 black and white photographs were compared to evaluate the change between 1978 and 1987. A ground survey in 1995 was used to assess spatial change from 1987 to 1995. The 4 MSS Landsat bands, acquired on July 1978, were firstly geo-referenced, and then processed by unsupervised classification technique with the ISODATA clustering algorithm into 4 classes, i.e. water, eelgrass, non-vegetated or upland habitats. The aerial photographs at a scale of 1:36,000, taken on July 1987, were visually interpreted into 4 classes in the same way as the classification of Landsat image. Then, the polygons of all classes were digitized into geographic information system (GIS) format to compare with the maps of 1978. Ground surveying, accessed by small boat and foot, was conducted in September 1995 to investigate changes in area of eelgrass habitats between 1987 and 1995. The results showed that the image classification and photographs interpretation revealed eelgrass habitats in the Izembek Lagoon. During the 17-year period (1978 to 1995), there was no large-scale change in eelgrass cover at this lagoon.

On the North Carolina coast, Ferguson and Korfmacher (1997) also used remote sensed data together with GIS to detect the seagrass meadows of *Zostera marina*, *Halodule wrightii* and *Ruppia maritima* at Core Sound and Back Sound. The

Landsat TM images at low tide in December 1988 and June 1992, and high tide in October 1992 were chosen. The land masked-out subimages, include band 1 to 5 and 7, were analyzed by using the principal component analysis (PCA) and cluster analysis. The classified maps were compared to the reference seagrass meadow data from aerial photographs. The results showed that the Landsat classification with reference data was as high as 72.6 per cent for the June 1992 image and lowest for October 1992 (63.4 per cent). Seagrasses adjacent to the mainland (Core Sound) were less widely distributed than seagrasses adjacent to the barrier island. The study noted that the efficiency of Landsat TM data provided relatively useful data for contemporary and retrospective spatial inventories and changes detection for seagrass meadows. Access to ancillary environmental data (e.g. wind and tidal data) was critical to the image selection and the data analysis and interpretation process.

2.3 Summary

This chapter has sought to introduce the general information of seagrasses, particularly the threats that they have faced, as well as the need of accurate and geo-referenced maps of seagrass as an important key for the effective management planning and systematic change monitoring. Regarding remote sensing technology, the relevant researches have shown the potential of such techniques for seagrass habitat mapping.

CHAPTER 3
THE STUDY AREA

For this research, the Khung Kraben Bay, an important seagrass site in the Gulf of Thailand, was selected as the study area. Characteristics of the area are described in this chapter. In the first part, physical and ecological features are explained. Activities recently undertaken in the area are also highlighted. Following that, relevant researches regarding seagrass bed mapping undertaken in the study area are reviewed.

3.1 Physical Characteristics

The Khung Kraben bay is located in Khlong Khut Sub-district, Thamai District, Chanthaburi Province on the eastern coast of the Gulf of Thailand (12° 37' to 12° 34' N and 101° 53' to 101° 55' E). It covers a total area of 6.4 sq km. The bay is a shallow semi-enclosed embayment (Figure 3.1). The open channel is about 600 m in width. Along the shoreline, there are mangrove forests. The areas next to the forests inland are shrimp ponds, agriculture areas and fisher-folk villages. There are eight canals (Khlong in Thai) that discharge treated effluents from shrimp ponds to the bay (i.e. Khlong Ta Ta, Khlong Hin, Khlong Ta Au, Khlong Ta Kuai, Khlong Mo Suk, Khlong Salut, Khlong Bang and Khlong Pla Chon).

In terms of climate, the Khung Kraben bay is influenced by two monsoons i.e. north-eastern and south-western monsoons. The main rainy season is from June to October where the south-western monsoon brings humidity and rain.

The current in the bay at a low tide period is in an anticlockwise direction. The tidal is diurnal (Hydrographic Department, 2004), with the depth range of 2 m (Sudara *et al*., 1991). In one tidal cycle, about 86 per cent of seawater in the bay will be replaced by (new) water flowing from the open sea (Sangrungruang *et al*., 1999). With respect to water quality, data collected at 500 m offshore comparing dry and wet seasons in 2004 shows that the temperature of the water was 31.7°C for the dry season and 30.1 °C for the wet season. Salinity varied from 29.3 to 23.4 ppt. Suspended sediments found were 78.2 and 77.7 mg/l. Nutrients however did not exceed the standard of coastal water quality for natural habitats conservation (class 3) (PCD, 2005). Bottom substrates found were sand and mud (Aryuthaka *et al*., 1992).

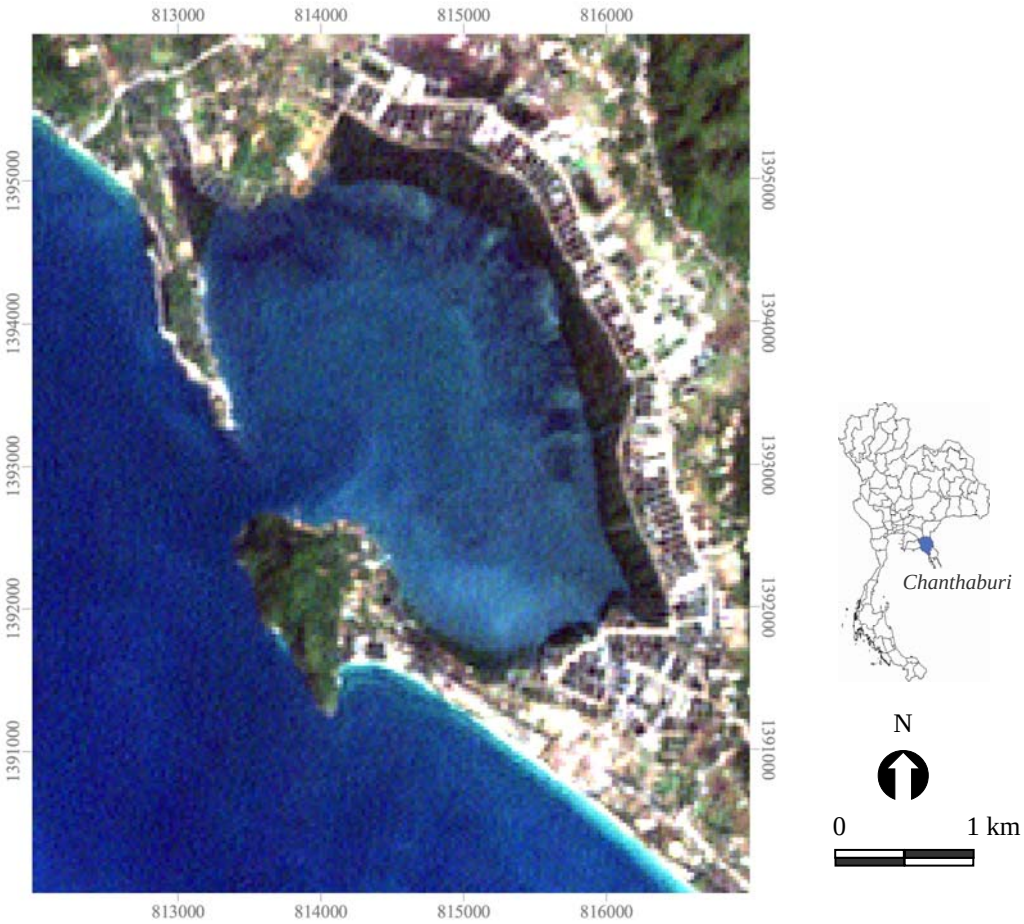
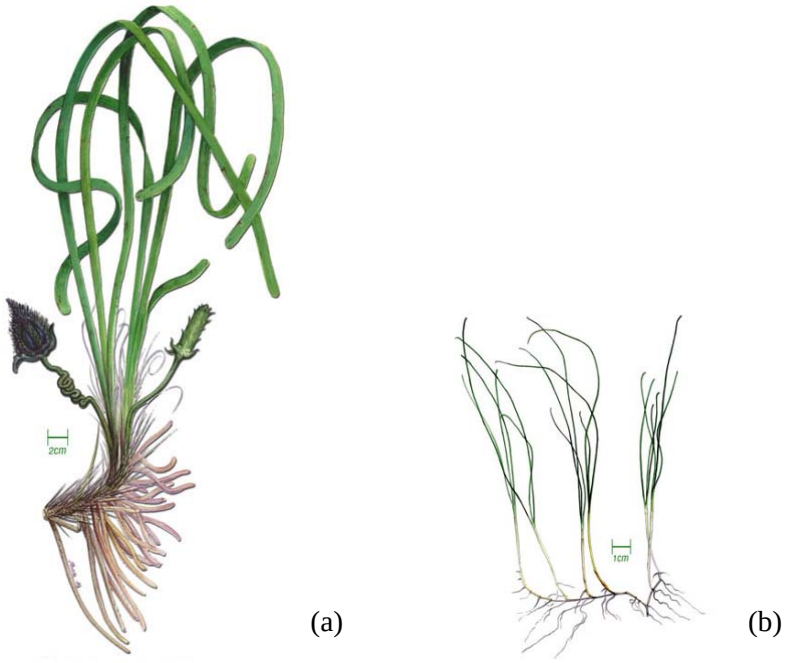


Figure 3.1 Satellite Image of the Khung Kraben Bay (true color composition of the Landsat TM image).

3.2 Ecological Characteristics

The Khung Kraben bay is regarded as a national wetland (OEPP, 1999). In the area, two main ecosystems are found. Seagrass beds are found in the bay while mangroves grow along the shoreline. There are five species of seagrass found. They are *Enhalus acoroides*, *Halodule pinifolia*, *Halophila decipiens*, *Halophila minor* and *Halophila ovalis*. *E. acoroides* and *H. pinifolia* are the dominant species (Sudara *et al.*, 1991; Aryuthaka *et al.*, 1992; Lewmanomont *et al.*, 1996; PMBC *et al.*, 1998). *E. acoroides* (see Figure 3.2a) has big rhizomes with a diameter up to 1.5 cm. The rhizomes are usually covered by the persistent fibrous strands of decayed leaves. The roots are numerous and not branches (10 to 20 cm long and 3 to 5 mm wide). The leaves are 30 to 150 cm long and 1.25 to 1.75 cm wide. In Figure 3.2b, *H. pinifolia*, it can be seen that there is rhizome creeping with 2 to 3 roots and a short erect stem at each node. Each internode is about 1-3 cm long. The leaf sheath is 1 to 4 cm long and the leaf blade is 5 to 20 cm long and 0.6 to 1.2 mm wide (den Hartog, 1970; Phillips and Meñez, 1988).



(a) (b)

Figure 3.2 General features of the dominant seagrasses at the Khung Kraben Bay – (a) *Enhalus acoroides* and (b) *Halodule pinifolia* (adapted from UNEP, 2005).

In the mangrove forests, about 30 tree species are found. *Rhizophora apiculata* is a dominant species. In addition, red mangrove (*R. mucronata*), black mangrove (*Bruguiera gymnorrhiza*), *Avicennia* spp., *Lumnitzera* spp. and *Sonnerratia alba* are found (Khung Kraben Bay Royal Development Study Center, 1998). The areas next to the mangrove forests inland are agriculture areas, and on the mountain, dry evergreen forests are found (OEPP, 1999).

There are many marine animals that are important in terms of economics found in the seagrass beds. These include fishes e.g. greasy grouper (*Epinephelus coioides*) and snapper (*Lutjanus* spp.), shrimps (e.g. *Peneaus* spp., *Metapeneaus* spp., *Acetes* spp.) and crabs (e.g. *Portunus pelagicus*) (Sudara *et al*., 1991; Khakhai, 2002; UNEP 2005). These marine fauna are also regarded as important food sources for the local people. Dugongs (*Dugong dugon*), an endangered marine mammal have been found in this area (Nateekanjanalarp and Sudara, 1994). In addition, at least 35 bird species are found. A near threatened bird found is the watercock (*Gallicrex cinerea*) and common species found are the common mynah (*Acridotheres tristis*), black drongo (*Dicrurus macrocercus*) and Indian roller (*Coracias benghalensis*). Most of the birds are found in the mangrove forests (OEPP, 1999).

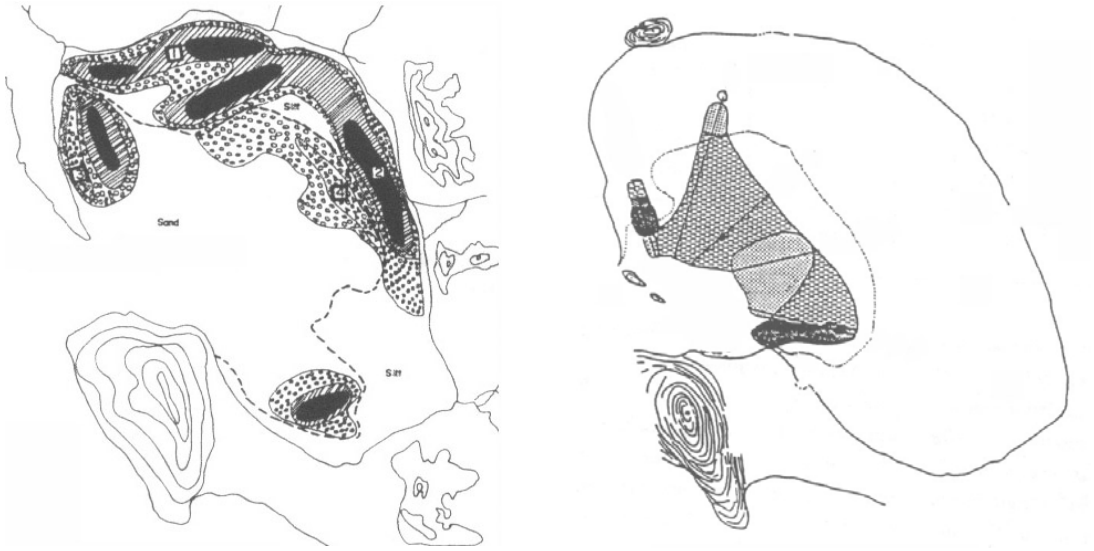
3.3 Activities Currently Undertaken

In 1982, through the great foresight of his Majesty the King, the Khung Kraben Bay Royal Development Study Center was established. It aims to demonstrate the activities for appropriate coastal management and encourage local people to conserve marine and coastal resources for the Khung Kraben Bay and surrounding areas. To achieve that end, an interdisciplinary strategy was implemented i.e. relevant departments from the government had to collaborate as a working team. The activities of the center recently undertaken emphasize mangrove conservation and rehabilitation, marine aquacultures, agriculture and research (Khung Kraben Bay Royal Development Study Center, 1998).

In order to mitigate the effluent from shrimp farms that was damaging the seagrass habitats, a seawater irrigation system was implemented. The effluents are stored in sedimentation ponds and are then aerated before being discharged into the bay. In addition, mangroves and seagrass beds are used as the natural treatment system in the final step (Khung Kraben Bay Fisheries Development Study Center, no date).

3.4 Relevant Researches on Seagrass Bed Mapping

The pioneer researches about seagrasses in the Khung Kraben Bay were presented by Sudara *et al*. (1991) and Aryuthaka *et al*. (1992). In both studies, the maps showing the distribution of seagrasses were produced by hand using the data from the field surveying. From Figure 3.3, the differences of the distribution of seagrass beds are apparent. However, both researches highlighted that *E. acoroides* was found at the northern and southern parts of the bay while *H. pinifolia* was found in the middle. However, up to now, no up-to-date map has been produced. Because of this these seagrass distribution maps are referred to in many studies, for example the projects of OEPP (1998a), KKB Center (2003), UNEP (2004).



(a) (b)

Figure 3.3 Hand-drawing maps of seagrass beds at the Khung Kraben Bay – the study of (a) Sudara *et al*. (1991) and (b) Aryuthaka *et al*. (1992).

With respect to academic concerns, the hand-drawn map made from field surveying can provide information on details such as distribution, density and percentage of cover. However, such a map is not very accurate. In addition, there are difficulties in comparing the paper-based maps for further analysis (in particular changes monitored over time).

3.5 Summary

The Khung Kraben Bay is an important seagrass site in the Gulf of Thailand. This area can be regarded as important for the local economy because much economically valuable marine fauna lives in the seagrass and mangrove areas of the bay. Focusing on seagrasses, *E. acoroides* and *H. pinifolia* are the dominant species found.

In 1982, the Khung Kraben Bay Royal Development Study Center was established to demonstrate activities for appropriate coastal management and to encourage local people to conserve marine and coastal resources. There were studies regarding the distribution of the seagrasses in the area; however, the distribution maps were produced by hand. There is no up-to-date research regarding this issue and no truly accurate map.

CHAPTER 4
RESEARCH METHODS

Digital image processing was the main approach applied in the study. There are two main procedures involved i.e. field survey and satellite image classification. These processes are explained in detail in this chapter. Firstly, relevant data and materials used are listed. Next, processes undertaken in the preliminary study and field surveying are explained. Steps in classifying satellite image including band selection, image preprocessing, water column correction and image classification are described. Lastly, processes to evaluate the outputs are explained.

4.1 Data and Materials

4.1.1 Field Survey

Data and materials used in the field survey are:

1) Color aerial photographs of the Khung Kraben Bay, scale of 1:25,000, taken on the 2nd January 2003
2) Topographical map, scale of 1:50,000, series L7018 sheet 5334 II
3) Global Positioning System (GPS) receiver
4) Compass
5) Small boat
6) Camera
7) Notebook

4.1.2 Satellite Image Classification

Data and materials used in this process are:

1) Landsat 5 TM image, acquired on the 16th December 2004
2) Topographical map, scale of 1:50,000, series L7018 sheet 5334 II
3) Personal computer with 800 MHz processor, 256 MB of RAM
4) Image processing software, IDRISI32

4.2 Visual Interpretation of the Aerial Photographs

To review background data for the research, relevant data and information such as relevant researches were collected (see Chapter 2). In addition, the color aerial photographs of the Khung Kraben Bay, scale of 1:25,000, taken on the 2nd January 2003, were interpreted (visual interpretation). In this process, fundamental features (e.g. shape, size, pattern and color) were used to help identify the distribution of seagrass beds.

The results of the visual interpretation (based on the experience of the analyst) showed that the seagrass beds were found in the bay along the shoreline while the small patches of seagrasses were in the northern and southern parts of the bay. These preliminary results were used in planning the field survey.

4.3 Field Survey

The field work was undertaken on the 10th to 12th December 2004, which was the closest possible period of time to the acquisition date of the satellite image. This was done to avoid effects from seasonal changes. In the planning stage, line transects with about 150 m distance between each line were drawn on a topographical map to locate the field sampling points. In the field, GPS receiver and compass were used to locate such points. At each point, data regarding species of seagrasses found were noted. These sets of data were used in the further processes (water column correction, satellite image classification and accuracy assessment).

4.4 Satellite Image Classification

4.4.1 Band Selection

The Landsat 5 TM image (30 m spatial resolution) acquired on the 16th December 2004 was used in this study. The acquisition time (10:17 am, the local time of Thailand) was in the high tide period, 2.4 m above the lowest receding level (predicted by Hydrographic Department, 2004). In addition, the amount of cloud shown in the image (least cloud is most appropriate) and clarity of seawater were also considered in selecting the image. In this research, three visible spectral bands were used in the classification because they are good for penetration through the water (see Chapter 2). Those bands are band 1 (blue band: 0.45-0.52 μm wavelength), band 2 (green band: 0.52-0.60 μm) and band 3 (red band: 0.63-0.69 μm).

4.4.2 Image Preprocessing

The image was radiometrically and geometrically corrected. The image was then rectified to a projection of UTM zone 47N and datum of WGS 84 by using image processing software, IDRISI32 (Eastman, 2001a; 2001b). The referenced co-ordinations (i.e. ground control points: GCPs) were obtained from the topographical map published by the Royal Thai Survey Department. A second-order polynomial method was used to transform the image to the geometry of the chosen map projection. The accuracy of the transformation was assessed by calculating the root mean square (RMS) error. The accuracy is accepted when the RMS error is less than a single pixel. In the next step, the nearest neighbor method was used to resample the image. This method is required when the image is used to discriminate the boundaries of habitats (Green *et al*., 2000).

Atmospheric correction was undertaken to compensate for effects from atmospheric absorption and scattering. The atmospheric modeling, 5S radiative transfer code (Simulation of the Sensor Signal in the Solar Spectrum), was used. A meteorological visibility of 8 km recorded near the acquisition time of the satellite image (Chanthaburi Meteorological Station, 2004 – Pers. Comm.) was used.

The final step of this section was masking the terrestrial area out by using spectral digitization. Near-infrared band (band 4 of TM) was used in such process because it show strong contrast between land and water (see Table 2.1). Only the selected (water) area was on focus for further analysis.

4.4.3 Water Column Correction

As the light intensity decreases exponentially when depth increases, confusion can be caused regarding the spectral radiances of the underwater features leading to difficulty in identifying features (refer to Chapter 2). Therefore, a depth-invariant algorithm was implemented to compensate for such effects (from the depth) on bottom reflectance. In the process, the algorithm was applied to three pairs of visible spectral bands (i.e. band 1/2, 1/3 and 2/3). A number of 138 pixels that have the same bottom types (sand) but variations in depth (collected from the field work) were selected. For each pair of bands, the reflectance of each selected pixel was transformed to a spreadsheet and converted to natural logarithms. The bi-plots of the transformed data were made and examined. The depth-invariant index was then calculated as explained in Section 2.2.2.3.

4.4.4 Image Classification

The seagrass beds in the Khung Kraben Bay were classified by using a digital image processing approach run on the IDRISI32 program (Eastman, 2001a; 2001b). The supervised classification methods i.e. the minimum distance to means, parallelepiped and maximum likelihood classification techniques were applied. Field data from the previous steps were used as training sites for this process. Two scenarios were established. First, the image was classified based on the seagrass species i.e. *E. acoroides*, *H. pinifolia* and non-vegetated area. The second scenario was the classification based on the presence (or absence) of seagrasses (i.e. seagrass area and non-vegetated area).

4.4.5 Accuracy Assessment

Inaccurate maps can mislead policy planners and decision-makers. An error matrix presenting errors of commission and omission and Kappa index of agreement values was therefore calculated to evaluate accuracy and reliability of the results. This assessment was undertaken by comparing the ground truthing data with the result of classification.

4.5 Output Assessment

Finally, the results of the seagrass bed classification from both scenarios were evaluated. In addition, the classification techniques were assessed.

The steps of the research methods are summarized in Figure 4.1.

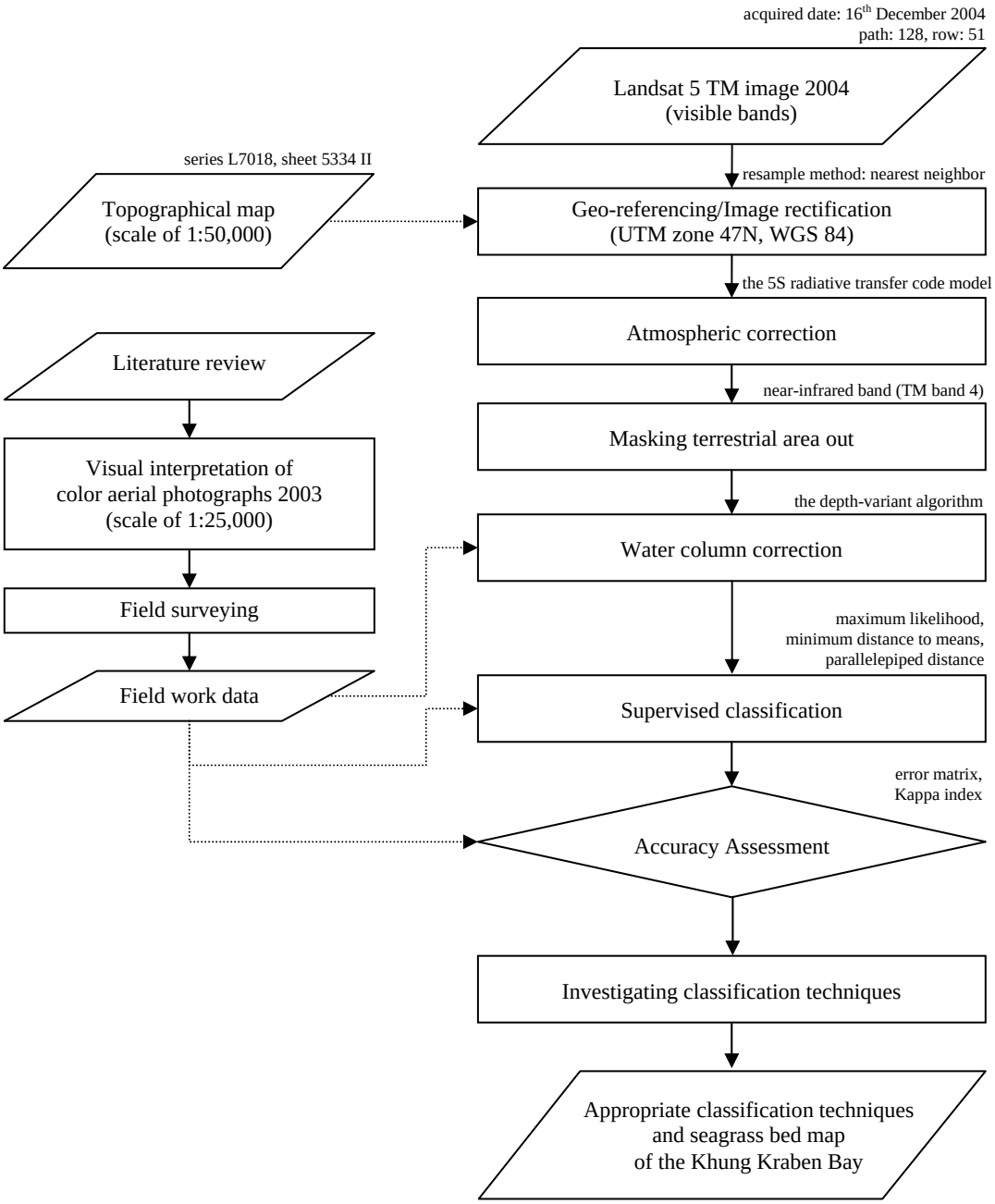


Figure 4.1 Research methods

CHAPTER 5
RESULTS

In this chapter, results of the study are presented. The first section introduces data regarding seagrass species collected from the field survey. Following that, the process of water column correction is presented. The results of satellite image classification undertaken by three different classifiers are then described. In the last section, in order to evaluate the reliability of the results of the classification, accuracy assessment is undertaken.

5.1 Field Survey

The field survey was undertaken on the 10th - 12th December 2004. A total of 296 sampling points were collected along the transect lines (see Chapter 4). At each point, the species of seagrass was identified and noted. Figure 5.1 and 5.2 shows the species of seagrass found.

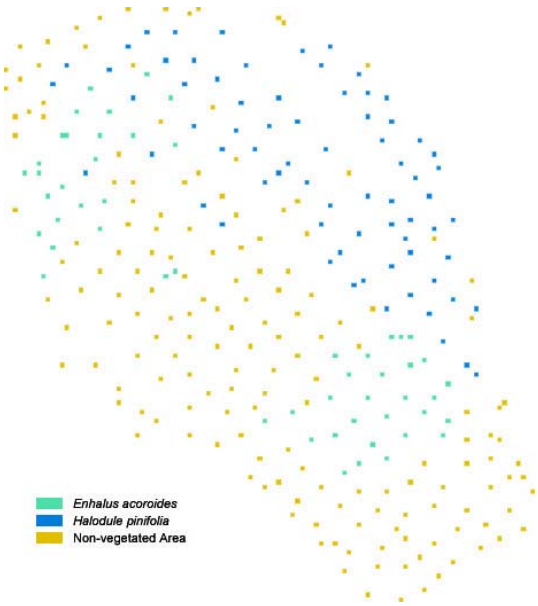


Figure 5.1 Species of seagrass found in the field – *Enhalus acoroides*, *Halodule pinifolia* and non-vegetated areas are presented in green, blue and yellow colors, respectively.

From Figure 5.1 and 5.2 (a), *Halodule pinifolia* is a dominant species found in the study area. This seagrass is found in large homogenous beds lying from the north-western to the south-eastern parts of the bay. The beds are found next to the mangrove forests at approximately from 50-100 m until 750-950 m offshore. With respect to the characteristics of *H. pinifolia*, a dense population is usually found in the middle of the beds while low population is found at the edge. It has to be noted that in summer exposure in daytime especially at the low tide can cause a reduction in the numbers of this healthy seagrass population.

(a) (b)

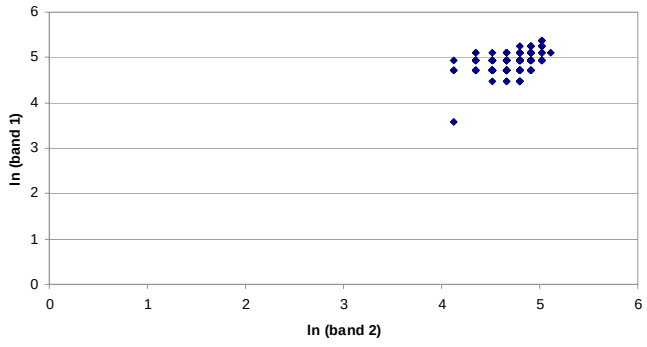
Figure 5.2 The dominant seagrass species found in the Khung Kraben Bay – (a) The beds of *Halodule pinifolia* and (b) patches of *Enhalus acoroides*.

By *H. pinifolia* beds, *Enhalus acoroides* were found in patches pattern at the northern and southern parts of the area (Figure 5.2 (b)). In the north, patches of *E. acoroides* lay in the north-south direction while in the south, they lay in the east-west direction. It should be noted that no seagrass was found in the middle and the southern parts of the bay. In these areas, there could have been deep water that is not suitable for seagrasses.

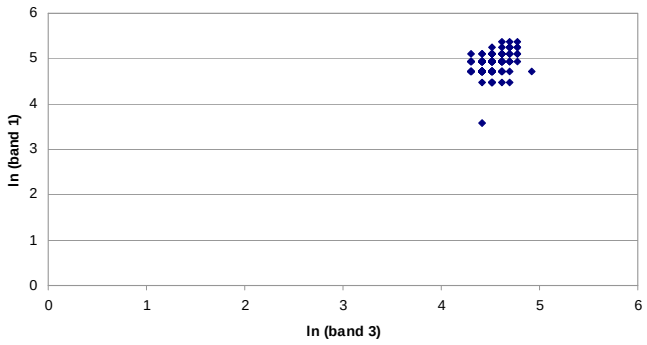
5.2 Water Column Correction

In order to compensate for the effects from the absorption and scattering of the light through the water column, a depth-invariant algorithm was applied (refer to

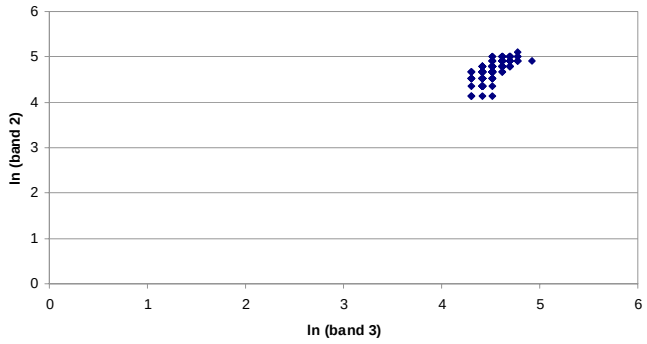
Chapter 2). From the field work data, a number of 138 sampling points representing sands at the depth of 1-4 m were selected. In the calculation processes as explained in Chapter 2, a natural logarithm was applied to the radiance value of those pixels. The bi-plot of log-transformed for the pairs of TM bands 1/2, 1/3 and 2/3 were then created.



(a)



(b)



(c)

Figure 5.3 The bi-plot of natural log-transformed – (a) TM band 1 and 2, (b) TM band 1 and 3 and (c) TM band 2 and 3.

As shown in Figure 5.3, all results of the bi-plots show group pattern of data. The gradient (the ratio of attenuation coefficients; k_i/k_j) of the bi-plots is not very evident. This could have been caused by the fact that the distribution of the depth where the data was collected was not large enough. However, for the most part, the study area is shallow (Chapter 3). Thus, the ratio of attenuation coefficients as well as the depth-invariant index could not be calculated. Consequently, the water column correction was not applied in this research.

5.3 Seagrass Bed Classification

Two scenarios of the classification were established. In the first scenario, the classification was established on a species basis. Three classes were classified. They are *E. acoroides*, *H. pinifolia* and non-vegetated area. For the second scenario, the presence and absence approach was used i.e. there were only two classes of seagrass and non-vegetated area. Data from the field survey was used as training sites for the classification. Three classification classifiers i.e. the minimum distance to means, parallelepiped and maximum likelihood, were applied in both scenarios.

5.3.1 Scenario 1 : Species Basis

Figure 5.4 shows the results of all three classification methods. The classified features of *E. acoroides*, *H. pinifolia* and non-vegetated area are presented in green, blue and red pixels, respectively. For the result of the minimum distance to means classifier (Figure 5.4 (a)), *H. pinifolia* are found along the shoreline and in small patches near the mouth of the bay. *E. acoroides* is found next to *H. pinifolia* toward the mouth of the bay. Large areas of non-vegetation (sand or mud) are found in the southern part of the bay. For the result of the parallelepiped method (Figure 5.4 (b)), the pattern of *H. pinifolia* found is similar to the minimum distance to means technique. However, *E. acoroides* are found in very small numbers from this method. In addition, there are some unidentified pixels (black color) shown. This could have been be caused by a problem of overlapping parallelepiped that is a limitation of this technique. For the maximum likelihood classifier (Figure 5.4 (c)), similar patterns of

H. pinifolia are found, however, larger areas are found extending along the shoreline toward the mouth of the bay. *E. acoroides* are found scattered throughout the bay except in the southern part.

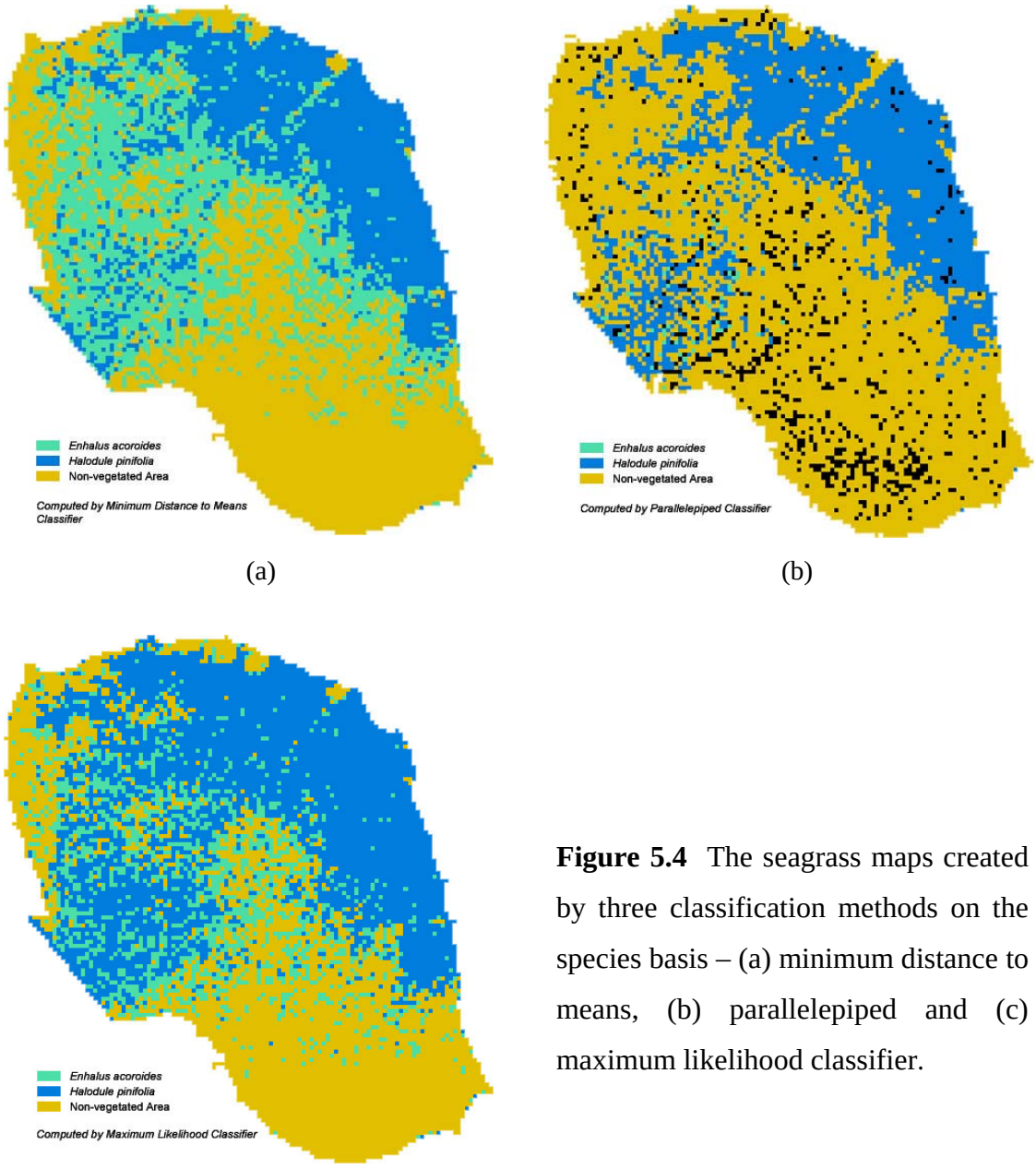


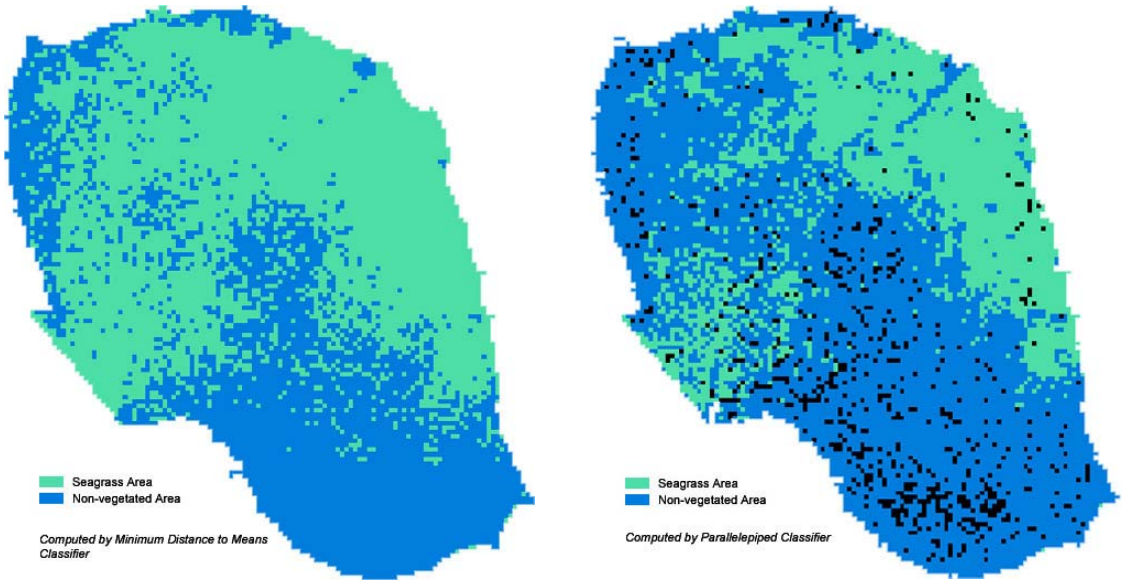
Figure 5.4 The seagrass maps created by three classification methods on the species basis – (a) minimum distance to means, (b) parallelepiped and (c) maximum likelihood classifier.

Among three methods (Figure 5.4 a to c), the maximum likelihood technique tends to provide largest *H. pinifolia* beds while the minimum distance to means classifier seems to provide largest areas for *E. acoroides*. The result of the

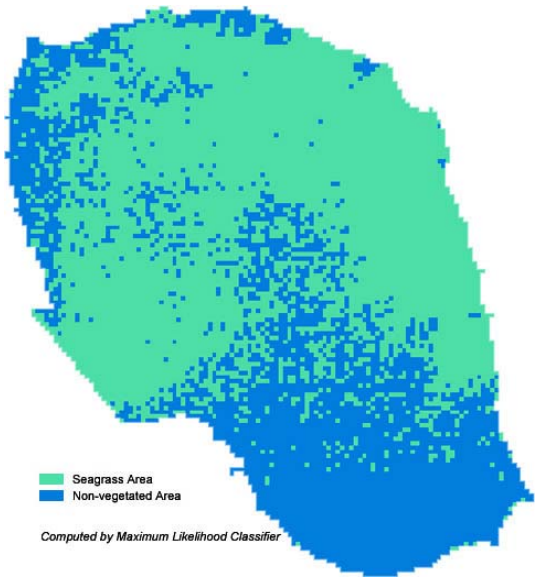
parallelepiped method shows a very small area of *E. acoroides* but a fair number of unidentified pixels.

5.3.2 Scenario 2 : Presence and Absence Basis

In this scenario, the satellite image was classified by the presence of seagrasses. The results of the classification are shown in Figure 5.5



(a) (b)



(c)

Figure 5.5 The seagrass maps created by three classification methods on the presence of seagrasses basis – (a) minimum distance to means, (b) parallelepiped and (c) maximum likelihood classifier.

As shown in Figure 5.5, the classified features of seagrass and non-vegetated areas are presented in green and blue pixels, respectively. Figure 5.5 (a) and (c), the minimum distance to means and maximum likelihood classifiers show similar pattern of seagrass. A large area of seagrass is found from inshore toward the mouth of the bay. For the parallelepiped method, a smaller area of seagrass was found and there are still some unidentified pixels (black color) found (Figure 5.5 (b)).

5.4 Accuracy Assessment

In the processes of accuracy assessment, an error matrix and Kappa index were calculated to evaluate efficiency of the methods in classifying seagrasses. The error matrix shows the accuracy of each classified class by calculating errors of exclusion (omission error) and errors of inclusion (commission error). The omission error can be regarded as the producer's accuracy while the commission error is the user's accuracy (see section 2.2.2.5). The Kappa index represents an overall accuracy of the classification. Ideally, the Kappa index equals 1, indicating no misclassification.

5.4.1 Accuracy Assessment of Scenario 1

The error matrixes and overall Kappa index value of the classification methods are presented in Table 5.1. All three techniques provide very low overall Kappa index value. The highest value is 0.3910 for the minimum distance classifier. From Table 5.1 (a), for the minimum distance to means classification, high accuracy in classifying *H. pinifolia* is shown i.e. a producer's accuracy is 71 per cent and a user's accuracy is 88 per cent. However, there are some pixels that were misclassified as *E. acoroides*. On the other hand, for *E. acoroides*, low accuracy for both producer and user is shown (about 43 and 24 per cent, respectively). The accuracy of classifying non-vegetation class is also low. This is caused by the misclassification between *E. acoroides* and non-vegetated classes.

Table 5.1 Error matrix and overall Kappa index of three classification methods on the species basis

(a) Minimum distance to means classifier

		Reference Data					
		E. acoroides	*H. pinifolia*	Non-vegetation	Total	Commission Error	User's Accuracy
Classified Data	*E. acoroides*	23	19	53	95	0.7579	24.21%
	H. pinifolia	1	51	6	58	0.1207	87.93%
	Non-vegetation	29	2	107	138	0.2246	77.54%
	Total	53	72	166	291		
	Omission Error	0.5660	0.2917	0.3554		0.3780	
	Producer's Accuracy	43.40%	70.83%	64.46%			62.20%

Overall Kappa index of agreement = 0.3910

(b) Parallelepiped classifier

		Reference Data					
		E. acoroides	*H. pinifolia*	Non-vegetation	Total	Commission Error	User's Accuracy
Classified Data	Unassigned	1	1	20	22	1.0000	
	E. acoroides	1	0	5	6	0.8333	0.17%
	H. pinifolia	3	51	11	65	0.2154	78.46%
	Non-vegetation	48	20	130	198	0.3434	65.66%
	Total	53	72	166	291		
	Omission Error	0.9811	0.2917	0.2169		0.3746	
	Producer's Accuracy	0.02%	70.83%	78.31%			62.54%

Overall Kappa index of agreement = 0.3225

(c) Maximum likelihood classifier

		Reference Data					
		E. acoroides	*H. pinifolia*	Non-vegetation	Total	Commission Error	User's Accuracy
Classified Data	*E. acoroides*	18	6	33	57	0.6842	31.58%
	H. pinifolia	10	62	42	114	0.4561	54.39%
	Non-vegetation	25	4	91	120	0.2417	75.83%
	Total	53	72	166	291		
	Omission Error	0.6604	0.1389	0.4518		0.4124	
	Producer's Accuracy	33.96%	86.11%	54.82%			58.76%

Overall Kappa index of agreement = 0.3477

The result of the parallelepiped method (Table 5.1 (b)) provides a high percentage of accuracy for classifying *H. pinifolia* i.e. 71 per cent of the producer's accuracy (equal to the result of the minimum distance to means method) and 78 per cent of the user's accuracy. For *E. acoroides* class, however, most areas were misclassified as non-vegetation. The accuracy shown is then only 0.02 and 0.17 per cent for the producer and the user, respectively. This indicates the low efficiency of such a technique in classifying *E. acoroides*.

With respect to the maximum likelihood classifier (Table 5.1 (c)), for *H. pinifolia*, the highest producer's accuracy of 86 per cent is shown. However, only about 54 per cent of user's accuracy is achieved. Similar to the minimum distance to means technique, the producer's and user's accuracies of *E. acoroides* classification are low (about 34 and 32 per cent). The error matrix also indicates that some pixels of *E. acoroides* were misclassified as non-vegetated area and *H. pinifolia*. For non-vegetation class, the producer's accuracy of class is also low (about 55 per cent) i.e. some pixels of non-vegetated area were misclassified as *E. acoroides* and *H. pinifolia*.

5.4.2 Accuracy Assessment of Scenario 2

As can be seen in Table 5.2, all three classification methods provide fairly high overall accuracy. However, the minimum distance to means method provides the highest overall accuracy (69.07 per cent) and Kappa index of agreement (0.3859) among the three classification techniques. The parallelepiped technique on the other hand provides the lowest overall accuracy (63.57) and Kappa index (0.2816).

From Table 5.2 (a) and (c), the results of the minimum distance to means and maximum likelihood classifiers show high value of the producer's accuracy (about 75 and 77 per cent respectively). This means the majority of the seagrass areas were correctly classified. However, the producer's accuracy for classifying non-vegetation is low (about 64 and 55 per cent) i.e. there are a number of misclassifications between seagrass and non-vegetated areas.

Table 5.2 Error matrix and overall Kappa index of three classification methods on the presence of seagrasses basis

(a) Minimum distance to means classifier

		Reference Data				
		Seagrass	Non-vegetation	Total	Commission Error	User's Accuracy
Classified Data	Seagrass	94	59	153	0.3856	61.44%
	Non-vegetation	31	107	138	0.2246	77.54%
	Total	125	166	291		
	Omission Error	0.2480	0.3554		0.3093	
	Producer's Accuracy	75.20%	64.46%			69.07%

Overall Kappa index of agreement = 0.3859

(b) Parallelepiped classifier

		Reference Data				
		Seagrass	Non-vegetation	Total	Commission Error	User's Accuracy
Classified Data	Unassigned	2	20	22	1.0000	
	Seagrass	55	16	71	0.2254	77.46%
	Non-vegetation	68	130	198	0.3434	65.66%
	Total	125	166	291		
	Omission Error	0.5600	0.2169		0.3643	
	Producer's Accuracy	44.00%	78.31%			63.57%

Overall Kappa index of agreement = 0.2816

(c) Maximum likelihood classifier

		Reference Data				
		Seagrass	Non-vegetation	Total	Commission Error	User's Accuracy
Classified Data	Seagrass	96	75	171	0.4386	56.14%
	Non-vegetation	29	91	120	0.2417	75.83%
	Total	125	166	291		
	Omission Error	0.2320	0.4518		0.3574	
	Producer's Accuracy	76.80%	54.82%			64.26%

Overall Kappa index of agreement = 0.3024

For the parallelepiped classifier, an error matrix (Table 5.2 (b)) shows 44 per cent producer's accuracy for seagrass class. This means many pixels of seagrass areas were misclassified as non-vegetated areas. For the non-vegetated class, the producer's accuracy is high at about 78 per cent, but the user's accuracy is only 65 per cent.

5.5 Summary

In this research, the water column correction was not undertaken because the depth-invariant index could not be calculated. Data regarding seagrass assemblages and bottom substrates along the transect lines collected in the field work was used in the supervised classification. Two scenarios i.e. the classification on species basis and presence and absence basis were implemented. Three classification methods were applied i.e. the minimum distance to means, parallelepiped and maximum likelihood methods. The results showed that the minimum distance to means method provided the highest accuracy in classifying seagrasses. In addition, it provided fairly good results in classifying *H. pinifolia*. However all three classification techniques provided low accuracy in classifying *E. acoroides* i.e. there were a number of misclassifications between *E. acoroides* and non-vegetated areas.

CHAPTER 6
DISCUSSION AND CONCLUSIONS

This final chapter discusses the results of the seagrass bed classification undertaken in the previous chapter. Issues regarding appropriate remote sensing techniques for classifying seagrass beds are also investigated. In addition, the contribution of the thesis and recommendations for further researches are stated.

6.1 Result Discussion

In accordance with the aim of the research i.e. to investigate appropriate remote sensing techniques for seagrass beds classification, supervised classification (including the minimum distance to means, parallelepiped and maximum likelihood classification techniques) were applied to classifying seagrasses of the Khung Kraben Bay. The Landsat TM image was used as data input. A set of error matrixes and Kappa indexes of agreement were calculated for assessing the accuracy of the results. The results of the studies are discussed in the following sub-sections.

6.1.1 Visual Interpretation of the Aerial Photographs

The scale of the aerial photographs is 1:25,000 (greater than Landsat TM image) therefore some features of the seagrasses can be identified. This preliminary study can be very useful in the filed survey planning. However, it should be noted that such interpretation is based on the experience and local knowledge of the analysts about the area. Thus, there is a possibility that bias and/or errors can occur. In addition, Chauvaud *et al*. (1998) mentioned that it was time-consuming to draw very large maps from a large number of photographs. It is also difficult to use such maps for further

analysis (e.g. map comparison and change monitoring) when such results are not transformed into digital format (McKenzie *et al*., 2001).

6.1.2 Digital Image Classification

Because the seagrass ecosystems are submerged habitats and the Landsat TM image used in this research was acquired in the high tide period, there was an attempt to apply the depth-invariant algorithm to compensate for the effects of water attenuation. However, in this study, the ratio of attenuation coefficients could not be calculated. This was because the data collected in the field showed insufficient variation of depths. To solve the problem, it could be possible to increase the number of sampling points. However, in cases where the study area only contains shallow water, it might not be appropriate to apply the depth-invariant algorithm. In addition, the tidal period should be taken into account in selecting the satellite image.

With respect to the classification on the species basis, the minimum distance to means classifier provided the best result among three methods. This also supports the results of the research of Jensiripikul (2002) who studied the shallow underwater features (coral reefs) at Kradat Island. In this research, the minimum distance to means method provided good results in classifying *H. pinifolia* (with 71 and 88 per cent of producer's and user's accuracies). The parallelepiped technique is also good in classifying *H. pinifolia*. However for the overall result there were some unidentified pixels found. This could have been caused by the overlapping parallelepiped. For *E. acoroides,* on the other hand, all classification results had a low percentage of accuracy. The misclassification was frequently found in cases of *E. acoroides* and non-vegetated areas.

An observation made from the results is that all three supervised classification methods seem to provide good results in classifying the dense canopy of seagrasses. There is a limitation in identifying low density seagrasses. The misclassification mostly occurs in the areas of *E. acoroides*, low density *H. pinifolia* and non-vegetated areas (Figure 6.1). Because one of the characteristics of *E. acoroides* is that it is

usually found in separated small patches, it is difficult to identify this species in the 30 m resolution Landsat image. In 30 x 30 m pixel, the radiance of the surrounding substrates i.e. sand or mud can be very much stronger that of this seagrass. The satellite sensor then mainly acquires the radiance from the surrounding substrates. This also happened in the cases of the areas containing low density of *H. pinifolia* (at the edge of the beds). These cases are illustrated in Figure 6.1. This supports the suggestion by McKenzie *et al*. (2001) that the large pixel sizes (30 m spatial resolution) of the Landsat TM data could limit the usefulness of the data in revealing small patches or low densities of seagrass.

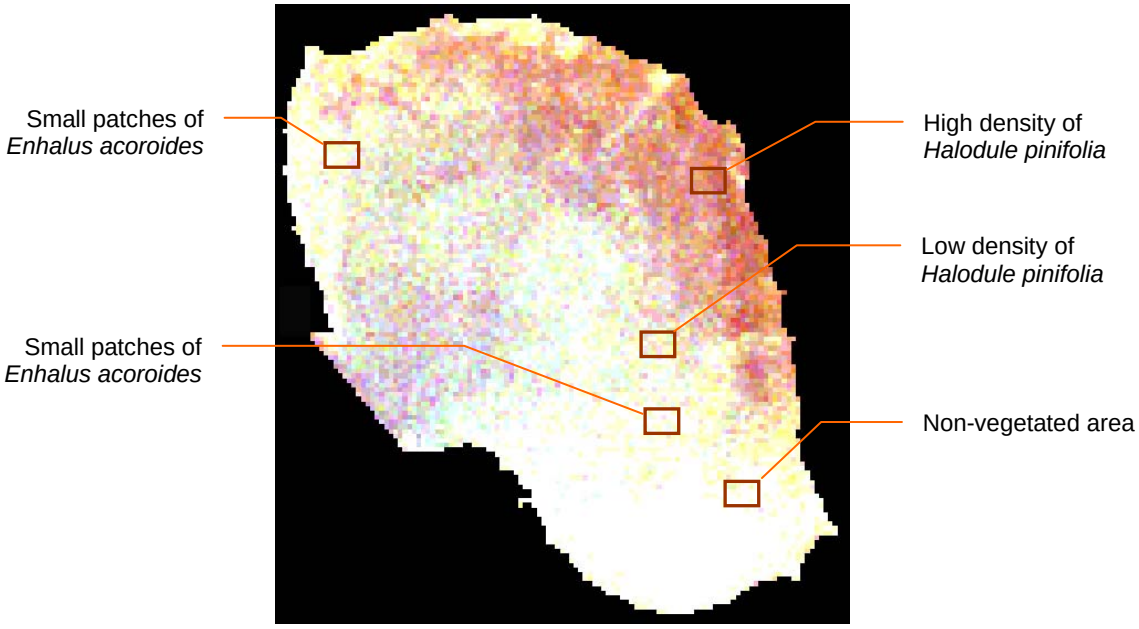


Figure 6.1 Pixels (of the true color composition of Landsat TM image) representing *Enhalus acoroides*, *Halodule pinifolia* and non-vegetated areas.

For the classification on the presence of seagrass, all three classification methods provide fairly high overall accuracy. The result of the minimum distance to means method shows the highest overall accuracy (69.07 per cent) and Kappa index of agreement (0.3859). However, there were still a considerable number of misclassification between seagrass and non-vegetated areas.

From two scenarios, the minimum distance to means method seems to provide the highest accuracy in classifying seagrasses. However, a number of misclassifications are still evident.

6.2 Contribution of the Thesis

This research originated from an intention to fill the gap of remote sensing technology development for seagrass beds classification. The research also aims to satisfy the need for a decision support tool for seagrass management in Thailand. The objective of the study was to investigate appropriate remote sensing techniques for seagrass bed classification. This is also the first time that satellite imagery, Landsat TM data, was used in classifying seagrass habitats in the Khung Kraben Bay.

Although the results of the research did not categorically show what is the best method for classifying seagrass beds, it seemed to succeed in demonstrating how remote sensing techniques with the Landsat TM image can be used as a tool for the seagrass beds inventory in shallow water environments. It is highly recommended that this study should be further developed (see the following section) because of the advantages of the remote sensing technology in terms of reducing cost, time and efforts in the fieldwork.

The advances in knowledge of implementing remote sensing techniques for seagrass bed inventory could contribute to various applications. For example, ecological data such as abundance of seagrasses, biomass and productivity could be integrated with remote sensing data to investigate the relationships between such ecological characteristics and the reflectance values. For more sophisticated studies, it would be possible to integrate remote sensing data with ecological and socio-economic data to examine the relationships between seagrass ecosystems and human uses.

Despite the fulfillment of this research in terms of its academic aims, an issue regarding the usefulness of the knowledge should also be focused on. It is important to

encourage good cooperation (and communication) between the remote sensing specialists (as information providers) and users (e.g. resource managers) (Hoffer, 1994). For example, a training program about remote sensing and GIS for the users might be useful.

6.3 Recommendations for Further Researches

To improve the accuracy in classifying seagrasses at the Khung Kraben Bay and also other areas, quality of the data input has to be taken into account. Higher resolution remote sensing data such as IKONOS (Mumby and Edwards, 2002), SPOT 5 (Pasqualini *et al*., 2005) as well as digitized (color) aerial photographs (Chauvaud, 1998; Pasqualini *et al*., 1998; Agostini *et al*., 2003a) are recommended.

In addition, the tidal period should also be taken into account in selecting the image. It would also be interesting to try increasing the number of sampling points for the depth-invariant algorithm implementation.

In terms of technical approach, it would be interesting to investigate the efficiency of other methods such as the band ratio application, principal component analysis (PCA), and other supervised classification such as Mahalanobis classifier in classifying the seagrasses. It would also be interesting to investigate the applications of such techniques to all bands.

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