EFFECTS OF LANDSCAPE CHARACTERISTICS ON MIGRATORY SHOREBIRD COMMUNITIES IN THE INNER GULF OF THAILAND

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT
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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science (Natural Resource Management)
School of Bioresources and Technology
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Abstract

Shorebirds are declining worldwide due to loss and degradation of critical breeding and wintering habitats. Human-modified habitats, particularly salt-pans which are used by shorebirds in North America, Europe, Asia, and Australia, may be an adequate substitute for natural habitat during migration at least for some species. However, the importance of salt-pans for shorebirds at a broad landscape scale has largely not been quantified. Influences of landscape characteristics on species richness, abundance, and diversity of shorebirds were studied at 20 sites covering most of the Inner Gulf of Thailand, a landscape with a long history of salt farming. Sites with salt-pans present had significantly higher species richness, abundance and diversity. Areas with larger proportions of aquaculture tended to have lower species richness, abundance and diversity. The proportion of the landscape occupied by larger areas of tidal flats along with salt-pans were the best predictors of sites with higher richness, abundance and diversity. Landscape configurations with higher richness, abundance and diversity of shorebirds also tended to be less fragmented, contain slightly larger patches and more homogeneous patch sizes. In the salt-pans, shorebirds tended to use ponds with exposed moist soil, both as roosting sites and secondary feeding grounds during high tide. Traditional salt-pans appear to contribute significantly to the maintenance of wintering shorebird populations in this landscape and should be investigated elsewhere. Collaboration between researchers and salt farmers to maintain salt-pans as potential shorebird roost sites is urgently needed.

Keywords: Migratory Shorebirds / Landscape Characteristics / Object-based Classification / Traditional Salt-pans / The Inner Gulf of Thailand

หัวข้อวิทยานิพนธ์	อิทธิพลของลักษณะทางภูมิศาสตร์ที่มีต่อชุมชนของนกชายเลน ที่อพยพมาใช้พื้นที่อ่าวไทยตอนใน
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ผู้เขียน	นายศิริยะ ศรีพนมยม
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หลักสูตร	วิทยาศาสตรมหาบัณฑิต
สาขาวิชา	การจัดการทรัพยากรชีวภาพ
สายวิชา	การจัดการทรัพยากรชีวภาพ
คณะ	ทรัพยากรชีวภาพและเทคโนโลยี
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บทคัดย่อ

ประชากรของนกชายเลนทั่วโลกมีการลดลงอย่างต่อเนื่อง เนื่องจากการสูญเสียและการถูกทำลายถิ่นอาศัยสำหรับทำรังวางไข่และถิ่นอาศัยในช่วงฤดูกาลอพยพ นาเกลือเป็นถิ่นอาศัยที่มนุษย์สร้างขึ้นซึ่งพบว่ามีการใช้ประโยชน์โดยนกชายเลนเป็นประจำ ทั้งในอเมริกาเหนือ ยุโรป เอเชียและออสเตรเลีย นาเกลืออาจจะสามารถทดแทนถิ่นอาศัยตามธรรมชาติที่นกต้องการในช่วงฤดูอพยพได้สำหรับนกบางชนิด แต่ความสำคัญของนาเกลือที่มีต่อนกชายเลนในระดับภูมิศาสตร์ ยังไม่มีการศึกษาวิเคราะห์อย่างจริงจัง จึงได้มีการศึกษาอิทธิพลของลักษณะทางภูมิศาสตร์ที่มีต่อความหลากชนิดและจำนวนของนกชายเลนใน 20 พื้นที่ตลอดแนวชายฝั่งอ่าวไทยตอนในซึ่งเป็นบริเวณที่มีการทำนาเกลือมาเป็นเวลานาน จากการศึกษาพบว่าพื้นที่ที่มีการทำนาเกลือจะมีความหลากชนิดและจำนวนของนกชายเลนมากกว่าในพื้นที่ที่ไม่มีการทำนาเกลือ พื้นที่ที่มีสัดส่วนพื้นที่นาเกลือและสัดส่วนพื้นที่หาดเลนอยู่มากจะเป็นตัวทำนายที่ดีที่สุดในการพบความหลากชนิดและจำนวนนกชายเลนที่สูงกว่าพื้นที่อื่น นอกจากนี้ยังพบความหลากชนิดและจำนวนนกชายเลนสูงในพื้นที่ที่มีถิ่น

อาศัยประเภทต่างๆ ที่เรียงตัวค่อนข้างต่อเนื่องกัน ถิ่นอาศัยแต่ละประเภทดังกล่าวนี้จะมีขนาดค่อนข้างใหญ่ ขนาดใกล้เคียงกันและดูกลมกลืนกัน นกชายเลนมักจะใช้บ่อตากน้ำในนาเกลือที่มีดินเลนโผล่ขึ้นมาเป็นหย่อมๆ ในการเป็นที่รวมฝูงพักผ่อนและเป็นทั้งพื้นที่หากินรองในช่วงน้ำขึ้นด้วย นาเกลือแบบโบราณนี้ มีส่วนสำคัญอย่างมากในการช่วยรักษาจำนวนประชากรนกชายเลนที่พบในอ่าวไทยตอนในและน่าจะพบในพื้นที่อื่นๆ เช่นกัน ควรจะมีการสร้างความร่วมมือให้เกิดขึ้นอย่างเร่งด่วนระหว่างนักวิจัยและเจ้าของนาเกลือ ในการจัดการพื้นที่บางส่วนของนาเกลือเพื่อให้นกชายเลนสามารถใช้เป็นที่พักรวมฝูงได้

คำสำคัญ : นกชายเลนชนิดที่อพยพ / ลักษณะทางภูมิศาสตร์ / การวิเคราะห์ภาพถ่ายดาวเทียมโดยใช้ลักษณะกลุ่มวัตถุภาพ / นาเกลือแบบโบราณ / อ่าวไทยตอนใน

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CHAPTER 1 INTRODUCTION

1.1 Background and Problem

Among the 207 populations of shorebirds with known trends among all flyways of the world, almost half (48%) are declining, in contrast to only 16% increasing (International Wader Study Group [IWSG], 2003). The reasons for these declines are diverse and poorly understood, but are likely the result of a reduction and degradation of breeding sites, notably critical stopover and wintering habitats (Goss-Custard and Yates 1992; IWSG, 2003; Piersma et al., 2006; Stroud et al., 2006). Survivorship of shorebirds appears to be significantly affected by ecological factors away from the breeding habitats, so fluctuations in population numbers may be particularly correlated with human disturbance and land use changes, as well as natural cycles occurring on their wintering habitats (Myers et al., 1987; Troy, 1996; Hitchcock and Gratto-Trevor, 1997). On the wintering grounds, feeding habitats can only be exploited by shorebirds if they are associated with suitable roost sites, and roost availability may therefore limit population size (Rogers et al., 2006b). However, natural high-tide roosts are vulnerable to urban development or land reclamation because they tend to be small areas usually located just above the tide line (Mitchell, 1988 in Rogers et al., 2006a).

Salt-pans or coastal salt ponds (saltworks, salt crystallization ponds or salinas) have a long history (Walmsley, 1999) where salt is extracted from sea water through solar evaporation in a series of shallow interconnected evaporation pans varying in size, water depths and separated by dikes (Warnock et al., 2002). Salt-pans have been found to provide important nesting, foraging and roosting habitats for shorebirds during non-breeding seasons throughout the world (Masero and Pérez-Hurtado, 2001; Warnock et al., 2002). For example, salt ponds in San Francisco Bay support large wintering shorebird populations relative to other important wetlands in the US during all seasons (Warnock and Takekawa, 1995; Page et al., 1999; Takekawa et al., 2001; Warnock et al., 2002). In the coastal zones of Mediterranean shorebirds and other waterbirds also use salt ponds as roosting and breeding sites (Walmsley, 1999). In contrast, industrial scale aquaculture which typically occurs along with salt-pans has been identified as a significant threat to coastal ecosystems and shorebird populations because their deep steep-sided ponds and high intensity maintenance are typically unsuitable for shorebirds (Schaeffer-Novelli et al., 2006; Stroud et al., 2006; Wetlands International, 2007).

Although salt-pans and aquaculture ponds appear to be important features in the landscape for the conservation and management of shorebirds, the use of such habitats has not been quantified on a landscape scale. Here we quantified the landscape-level use by overwintering shorebirds in the Inner Gulf of Thailand, focusing in particular on the potential impacts of current land use practices.

1.2 Objectives

1. To classify major land uses along the Inner Gulf of Thailand which are more likely to support overwintering shorebird populations.
2. To determine critical habitats associated with higher richness and abundance of shorebirds.

1.3 Study Scope

There are both of resident and migratory shorebirds using the areas in the Inner Gulf of Thailand, however, this study I focus only on migrants. Several species of migratory shorebirds are regularly overwintering in the Inner Gulf of Thailand. They are breeding in higher latitudes near arctic and migrate to countries near and south of equator during non-breeding seasons. Some species migrate pass through Thailand to south equator countries, but many species are wintering in Thailand.

This study was conducted only in the Inner Gulf of Thailand where the country largest connected intertidal flats occurs, as well as, defined as the country single most important area for shorebirds. The Inner Gulf of Thailand extended approximately 160 km long and cover seven provinces including; Chonburi at the east, Chacheongsoa, Samut Prakarn, Bangkok, Samut Sakorn, Samut Songkram, and reach the west end at Phetchaburi province. I selected 20 focal sites for survey constraint by accessibility of roads.

Data collection was conduct only one migratory seasons which including; southward migration (September - November), mid-winter (December - January), and northward migration (February - April).

1.4 Expected Benefits

This study is one of the first landscape scale scientific researches on migratory shorebirds in the Inner Gulf of Thailand during the time that I started the project (year 2006). I hoped that the results from this research would help to improve the understanding on why there are so many birds at one site but not many birds in the other sites. Knowledge of shorebirds distribution at a large spatial scale would facilitate in better conservation plans initiation. Moreover, the results could be a baseline for establishing the shorebirds special conservation sites which would make sites have been protected by law. The most interesting and challenging application of knowledge from this research is the imitation of shorebirds preference landscape features to restore back critical habitats to help maintain populations of shorebird in Thailand and in the East Asian - Australasian Flyway.

CHAPTER 2 LITERATURE REVIEW

2.1 Shorebirds Classification

Shorebirds or Waders are members of **Class Aves, Order Charadriiformes** which comprises of 215 species in 13 different families, Scolopacidae and Charadriidae are families of the largest and most diverse group (Geeing, 2007). **Order Charadriiformes** contains the "true shorebirds" e.g. sandpipers, plovers, stilts, avocets, oystercatchers, skimmers, turnstones, and phalaropes. Many species of Arctic and temperate regions are strongly migratory, but tropical birds are often resident or move only in response to rainfall patterns. They are specifically adapted to their environment. General characteristic is having long legs (except some smaller species such as Stint) and no web between the toes. Shorebirds are varying in body size as the smallest as 12 cm in length to as largest as 66 cm in length and wide variety bill structures which provide different feeding strategies (Howes and Bakewell, 1989). The major food items for shorebird are small benthic invertebrates picked out of the mud or soil. Different length and shape of bills extract different species of food in the same habitat. Consequently, they are less of direct competition for food. Some larger species which adapted to drier habitats will take larger prey including insects and small reptiles. Beside many of the smaller species are found in coastal habitats and take mostly benthic invertebrate preys.

2.2 Ecology and Behavior of Shorebirds

Shorebirds are a group of birds usually gregarious and inhabit wetland and coastal habitats, where provide a unique combination of food resources and necessary to support a large number of birds (Myers et al., 1987). They occur on nearly every shoreline of the world.

The distinctive characteristic of shorebirds as a group is that many species are long-distance migrants, using a restricted number of widely separated wetlands during their annual journey. Some species are highly migratory, breeding in high northern latitudes and migrating to the tropics and south of the equator. Some species fly as far as 13,000 km from breeding grounds to wintering areas. Then fly again northward back to nesting grounds before breeding season starts, thus they may be fly approximately

26,000 km per year. Some larger species can fly 11,000 km non-stop (Gill et al., 2005). Shorebirds spend 60% or more of the year on the wintering grounds (Barbosa and Moreno, 1999). Therefore, to meet their need of annual life cycle, they are highly dependent on few key sites of good quality wetlands (Myers et al., 1998).

2.3 Migration Models and Reproductive Consequences

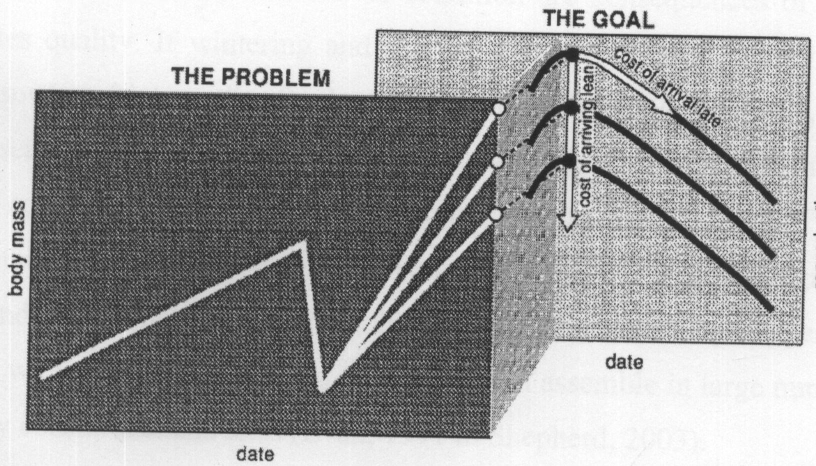

Figure 2.1: The migration models illustration of the way in which staging site quality may influence breeding success through differences in fuel deposition rate (Ens et al., 1994).

An idea of the model describes relationship between arrival date and arrival condition based on fitness measured via reproductive success. The model assumes that reproductive success has an optimum with respect to arrival date, or declines continuously to some final date where reproduction is impossible. Additionally, some minimum condition is required to initiate a clutch. Because shorebirds have relatively low reproductive potential, their populations are particularly sensitive to factors affecting adult survivorship (Hitchcock and Gratto-Trevor, 1997 in Shepherd et al., 2003).

Early arrival may bring several benefits, such as more chance to find the better quality territories with abundant of food supply or safety, provide more options to choose a mate and chance to re-mate, fatten up faster if they have access to better feeding habitats, and have suitable nesting grounds for early egg laying. Late arrival may cause birds lay eggs late, which has many consequences including reduced clutch size, shortage of food availability for chicks as well as adults, and high competition for food availability during autumn migration (Schekkerman et al., 2003).

Arriving in poor condition requires more time to obtain the nutrients to produce a clutch. Moreover, it is possible that there is a direct effect on survival immediately after arrival when food availability is limited and unpredictable due to changes in weather, particularly snow. Thus, some birds may not enough energy to finish incubation or raise their young if they hatch (Schekkerman et al., 2003).

Arrival date and arrival condition are consequences of wintering and staging sites quality. If wintering and staging sites are of good quality (such as rich in food resources, high quality food resources, no or little pollution etc.), thus birds can acquire reserve of fat and nutrient quicker, and can migrate back earlier in good body condition. In contrast of bad quality wintering and staging sites, birds need to spend more time to obtain a reserve of fat and nutrients. This causes birds to migrate late in poor body condition (Schekkerman et al., 2003). Most adult mortality happens during migration or on wintering grounds where shorebird often assemble in large numbers at relatively few key coastal wetland sites (Evan, 1991 in Shepherd, 2003).

2.4 The Flyway Concept

"Flyways" are migration routes or networks of sites connecting breeding and wintering areas, often used by populations of several species simultaneously. Each site is important in itself, but the functioning is also influenced by the quality of the other sites in the chain (Schekkerman et al., 2003). Each individual species and population migrates in a different way and uses a different suite of breeding, migration staging and wintering sites. Hence a single flyway is composed of many overlapping migration systems of individual waterbird populations and species, each of which has different habitat preferences and migration strategies. From knowledge of these various migration systems it is possible to group the migration routes used by waterbirds into broad flyways, each of which is used by many species, often in a similar way, during their annual migration (Boere and Stroud, 2006).

The Concept of a flyways provides a useful means to define a particular populations, thus it can be also a useful tool for research and conservation. Shorebird scientists broadly defined shorebird flyways all over the world into 8 flyways which including; 1) Pacific - Americas Flyway, 2) Mississippi - Americas Flyway, 3) Atlantic

- Americas Flyway, 4) East Atlantic Flyway, 5) Black Sea – Mediterranean Flyway, 6) West Asia – East Africa Flyway, 7) Central Asia Flyway, and 8) East Asian – Australasian Flyway (Fig. 2.2).

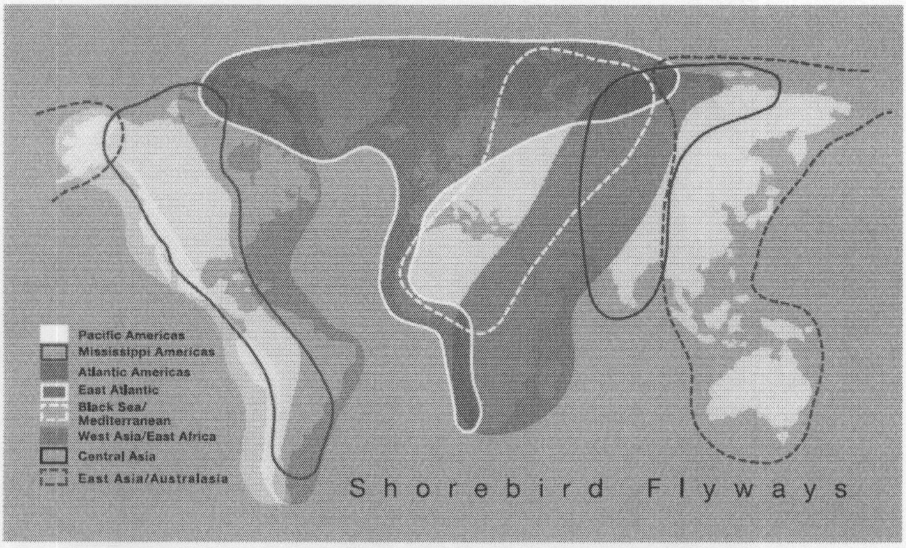

Figure 2.2: Global Shorebird Flyways

2.4.1 The Asian Geographic Region

In the Asian point of view, most of migrant shorebirds breed in the Siberian Tundra, Russian Far-east, Alaska, the Steppes and Deserts of Mongolia, and extreme northern China. Their destinations include East Asia, South-east Asia, Pacific Islands, Australia and New Zealand.

The Asia-Pacific region are recognized based on biological and geopolitical considerations where covering the breeding, staging and non-breeding areas of migratory shorebirds. Just for this region shorebird flyway can be defined into 3 minor flyways (Asia-Pacific Shorebird Network, 2007) (Fig. 2.3) comprise of

1. Central Asian-Indian Flyway
2. East Asian-Australian Flyway
3. West Pacific Flyway

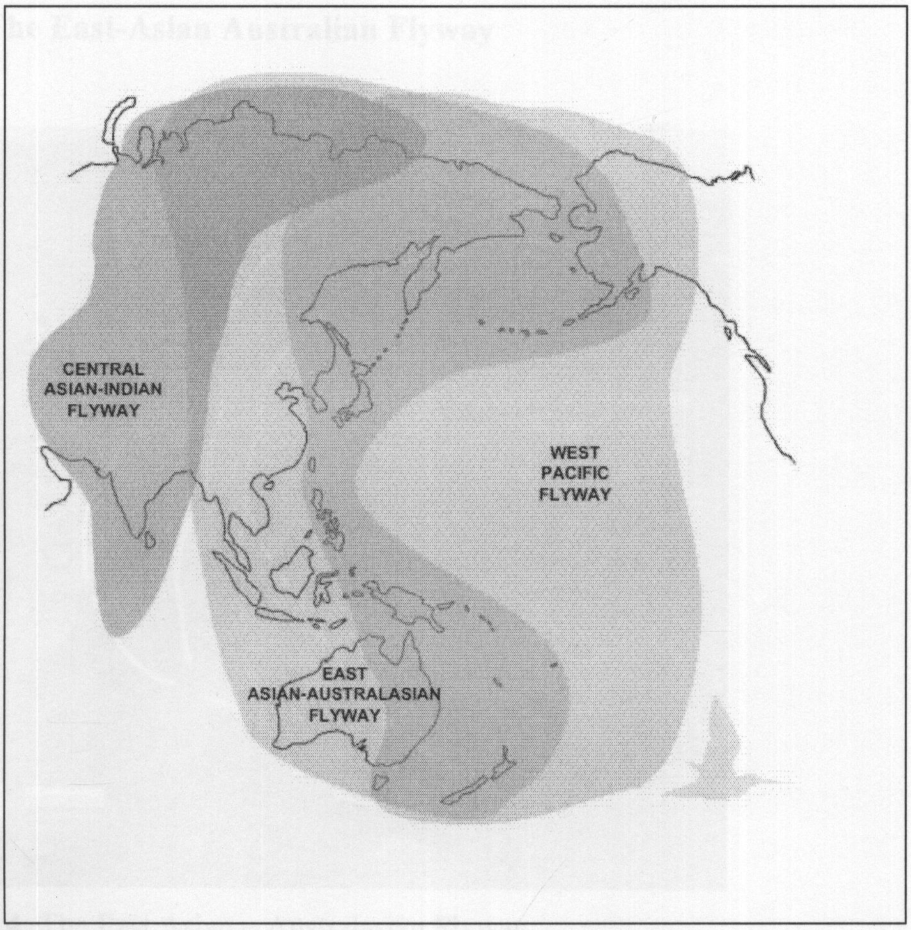

Figure 2.3: Three Minor Flyways in the Asia-Pacific Region

There are at least 243 species of migratory waterbird visited at least 57 countries in the region. "The Threatened Birds of the World", a book published by Birdlife International 2000, identified 50 species of migratory waterbirds are threatened species in Asia-Pacific region. The two main threats to migratory waterbird in the region are loss and degradation of habitats. Because of the region has a rapid and high economic growth which caused unsustainable use of natural resources and degradation of the environment.

Asia is the region that holding the highest number of shorebird populations, and the highest proportion which lack information on numbers and populations trends. Asia and Oceania hold 32 globally threatened species, which is 58% of the entire world's Globally Threatened shorebird species. However, over 80% of wetlands in East Asia and South-east Asia are classified as threatened, with over half under serious threats (International Wader Study Group, 2003).

2.4.2 The East-Asian Australian Flyway

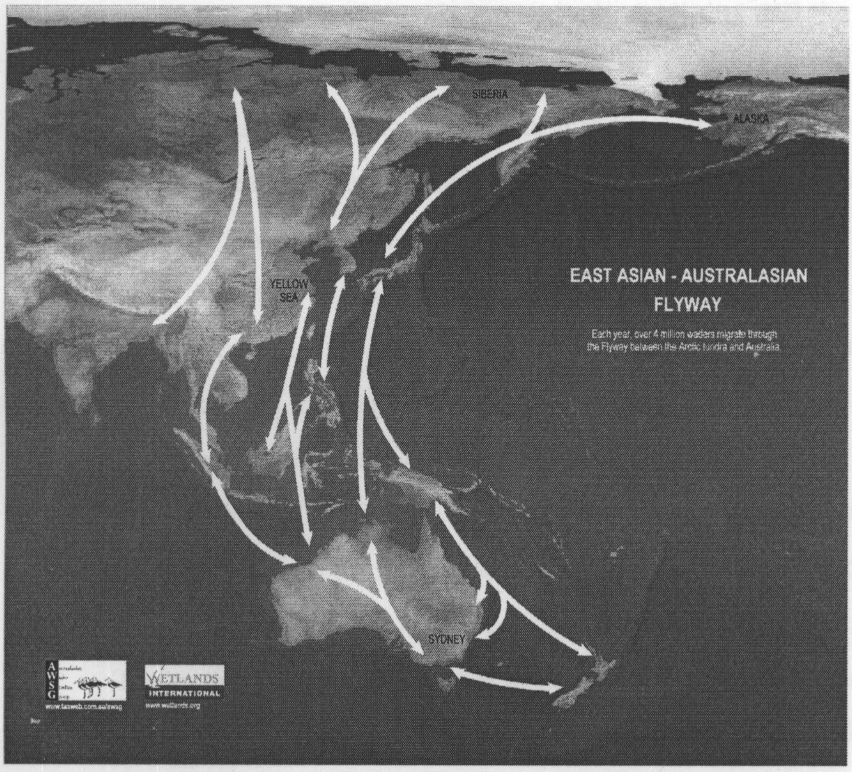

Figure 2.4: The East Asian – Australasian Flyway

There are vast human population pressures in this region which contains over a third of the world's human population and some of the world's fastest growing economies (Wilson, 2003). This has major direct effects to shorebirds: over 80% of wetlands in East and South-east Asia are classified as threatened, with over half under serious threat. Approximately 43% of inter-tidal wetlands in South Korea have been destroyed by land claim (with more ongoing), as also 37% of inter-tidal wetlands on China's coastline (Barter, 2003). All the evidence in this flyway suggests that the greatest current threats to shorebirds come from loss and degradation of habitats in Asia rather than from breeding habitats change in the Northern Hemisphere or non-breeding areas in Australia (Minton et al., 2006).

The East Asian-Australasian Flyway is the flyway with the highest number of shorebird populations and also the highest proportion of populations which information on numbers and trends is lacking. For populations of known trend on this flyway, 82% are declining and only 9% increasing. The status of Australasian endemic populations is better known (49% with unknown trend), and equal numbers (38%) are declining and increasing. Asia and Oceania hold 29 globally threatened and near threatened species – 69% of all shorebird species globally. Among 12 globally threatened species on this increasing. Asia and Oceania hold 29 globally threatened and near threatened species – 69% of all shorebird species globally. Among 12 globally threatened species on this flyway, one is possibly extinct, six are actively declining and the status of the remaining five is unknown. None is recovering its status

Shorebirds were considered to utilize the East Asian-Australian Flyway if they migrate through eastern part of Asia as shown in figure 3. The northern boundary begins at northeastern Asia and western Alaska to the southernmost at Australia and New Zealand and including costal and near coastal Asia. The western begins at eastern states of India and expanding to east islands of South Pacific. There are 4 seasons of the life cycle of shorebird in the East Asian-Australian Flyway

1. *The breeding season*; approximately June to August.
2. *Southward migration*; approximately August to November.
3. *The non-breeding season*; approximately December to February.
4. *Northward migration*; approximately March to May.

The extent of these seasons is considered to be approximate because of variation in the migratory patterns of different species (Bamford et al., 2003).

In March 1996, an international program was established to protect migratory shorebirds along the East Asian-Australasian Flyway, known as the East Asian-Australasian Shorebird Site Network. The Network links wetlands throughout the Flyway which are important to shorebirds. The East Asian-Australasian Shorebird Site Network is an international cooperative effort supported by both government and non-government organizations. The Network is supported by Wetlands International with funding from Environment Australia. There are 31 sites from 10 countries are in Network now. The Shorebird Site Network promotes the conservation and sustainable use of wetlands that shorebirds use during annual migration (Australian Department of Environment, 2005). Identifying key migratory stopover locations is fundamental to developing conservation measure to protect shorebirds in this flyway as well as around the globe (Minton et al., 2006).

2.5 Shorebird as Ecological Indicators

Shorebirds are attractive birds of economic and ecological importance, and thus are well studied in some parts of the world. Some of migratory shorebirds, very large numbers occur at low densities over extensive breeding areas, but assemblage at much higher densities in the non-breeding season at a few areas, consequently, their population status can be repeatedly evaluated.

A clear characteristic of their migration systems is that they link terrestrial, limnic (inland freshwater) and marine habitats together. They apparently connect continents and hemispheres with their individual movements. Therefore, within shorebirds life cycles, they accumulate and organize information from geographically widely separated localities and combine environmental information from very different kinds of habitats. Shorebirds embrace the entire globe within their migration routes provide us with information about local environmental change; in the same time they integrate phenomena at larger spatial scales (Piersma et al., 1997 and 2006; Klaassen et al., 2001). Consistent with their range of specialized feeding and migration ecologies, they are sensitive to changing of environment, thus, they can be excellent environmental indicators. Knowledge of the population status can provide important information on more extensive environmental change, including those caused by climate change, habitat loss and degradation of habitat quality. Information on their international population status can thus be used to indicate the wider health of their environments. The task of ensuring the good shorebirds conservation status definitely always come together with ensuring of the conservation and wise use of wetlands and other habitats where they regularly using (Stroud et al., 2006).

Piersma and Lindstörm (2004) proposed the concept of using migratory shorebird as ecological indicators. They indicated that, many shorebirds travel over large sections of the world during their annual cycle and use habitats in many different biomes and climate zones. Increasing knowledge of the factors effecting variations in shorebird numbers, phenotype and behavior may allow shorebirds to serve as 'integrative sentinels' of global environmental change. On the basis of numbers, timing of migration, plumage status and body mass, shorebirds could indicate whether ecological and climate systems are generally intact and stable at hemispheric scales, or parts of these systems might be changing.

The number of waterbirds and shorebirds using a particular habitat is related to types and quality of habitats, abundance and availability of food, and level of disturbance. Monitoring of their populations can provide valuable information on the status of wetlands, and can be a key tool for increasing the awareness of importance of wetlands and conservation value (Asia-Pacific Migratory Waterbird Conservation

Strategy, 2005). The biological integrity and ecological value of wetlands can be judged by the occurrence and the number of waterbird and/or shorebirds species that represent a high nature conservation value (Owen and Black, 1990; Eerden, 1997 in Paillisson et al., 2002). Information on shorebird international population status can accordingly be used to indicate the broader health of their environments. Definitely, the task of ensuring the good conservation status of shorebirds is inseparable from ensuring the conservation and wise use of their wetland and other habitats (Stroud et al., 2006).

2.6 World-wide Declining of Shorebirds

Shorebird population trends are severe declining all over the world. Among 511 total populations of shorebirds in every flyways, there are only 207 populations is known trends. Almost half of populations with known trends (48%) are declining, in contrast of only 16% are increasing. The reasons for these declines are diverse and poorly understood. The situation is a matter of international conservation concern. (International Wader Study Group, 2003; Stroud et al., 2006). With three times as many populations in decline as are increasing shorebirds must be considered as one of the most globally threatened group of the world's long-distance migrants (Piersma et al., 2006). Some species appear to be undergoing rapid population collapse, for example, Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*) which has declined by more than 80% over the last 30 years, estimated population only about 200-300 pairs left. The biggest wintering population of 84 individuals from two coastal wetlands in Myanmar recently discovered in 2008 (BirdLife International, 2007 and 2008). Other migratory shorebirds and waterbirds in the East Asian-Australasian Flyway are undergoing similar declines (e.g. continuing decline of Dunlin *Calidris alpina* wintering in Japan) and maybe affected by the same threats of massive habitat loss especially inter-tidal flats (Zöckler et al., 2006).

Species of long-distant migrant are extremely dependent on the continued existence, in good condition, of a few key staging sites. Loss and degradation of these sites have various consequences to shorebirds including an ecological, reproductive success and genetic nature. However, loss and degradation of wetlands continues happening all around the world. This is cause of the poor conservation status of so many species. Disturbances of wetlands and key staging sites lead to damage of their ecological characters which may cause of declining food availability, reduce suitability and ability to continue support the birds. Coastal areas, where the vast greater parts of these key sites occur are under seriously threatened by habitat alteration and destruction by human development, especially reclamation of inter-tidal flat, e.g. in South Korea and China (Davidson and Pienkowski, 1987 in Dinsmore et al., 1998; Moores, 2006; Moores et al., 2008).

2.7 Landscape Characteristics and Its Influence On Shorebirds

The habitat heterogeneity hypothesis assumes that structurally complex habitats may provide more niches and diverse ways of exploiting the resources and therefore increase species diversity (Bazzaz, 1975 in Tews et al., 2004). However, effects of habitat heterogeneity may vary significantly depending on what is perceived as a habitat by the species group studied.

Waterbirds have special population dynamics including much more frequent among-site movements, especially within particular stages of their life cycle, than occur in most other groups of birds (Haig et al., 1998; Taft and Haig, 2005). Whether the landscape context of wetland sites (i.e., spatial pattern of surrounding habitats) can influence the importance of local food resources to waterbirds is a novel question for wetland ecology, and answers may have significant implications for conservation planning of entire wetland landscapes (Wu and Hobbs, 2002 in Taft and Haig, 2005). Landscape structure possibly influences shorebird foraging dynamics during the winter period. In the temperate zone Evans (1976) and Myers (1983) indicated that, food resources can be scarce and patchily distributed over large distances during the winter season, thus shorebirds need to increase their energy intake by using multiple wetlands within a particular landscape (Dunning et al., 1992). Moreover, the energetic costs of flight, thermoregulation and survival will be high (Kersten and Piersma, 1987). Consequently, it should be energetically favorable for wintering shorebirds to concentrate in high wetland density sites (Farmer and Parent, 1997). As a result, discovery and revisiting of wetland sites with high food abundance is perhaps influenced by their particular location in the landscape: highly productive sites that are isolated may be used less than those located in connected wetland areas, and less productive sites surrounded by much wetland habitat could maintain greater use than

1996). And landscape-level study of wildlife can provide the empirical evidence to convince policy makers of the necessity for a broader-scale perspective for environmental protection and management (Pearson, 1993).

Taft and Haig (2005) suggested that wetland landscape context is greater ecological significant than food abundance. Productive sites those appear to be more adjacent shorebird habitats and closer to a wetland neighbor attracted the most birds. Spatial distribution of habitat across the landscape may be an important factor affecting the distribution of birds at a large scale and therefore shaping patterns observed at a smaller patch scale. In wintering ground feeding habitat is vital for shorebird, however, it will be used only if they are associate with suitable roost sites (Rogers et al., 2006).

2.8 Conservation of Long-distance Migratory Shorebird Populations

2.8.1 Long-term Demographic Monitoring of Shorebird Populations in Non-breeding Areas

For effective conservation, the functional links between sites within each network need to be understood. There are 2 main steps must be taken before we will able to completely understand flyway networks.

1. All sites in network need to be physically mapped. Which site is used by population or part of population must be identified. What purpose is it connected to the other sites and which resources their functioning is base need to be uncovered.
2. In term of population dynamics, we need to understand how the functioning of separate sites is linked to other sites and the whole of flyway.

More and better population monitoring are urgent needed. Monitoring might be most effectively undertakes on particular population, which especially associated with certain geographical regions or habitats. According to the extensive declines of many migratory waders indicated that internationally coordinated research, national and international level of monitoring systems are vital and urgent need to develop to uncover reasons behind the declines (Schekkerman et al., 2003). Beside of population study, stopover habitats conservation strategy should focus the essential factors that maintain prey diversity and abundance, and try to combine mosaic of stopover sites to uncover reasons behind the declines (Schekkerman et al., 2003). Beside of population study, stopover habitats conservation strategy should focus the essential factors that maintain prey diversity and abundance, and try to combine mosaic of stopover sites to total area protection (Elner and Seaman, 2003). Shorebird use difference foraging habitats by day and by night. They move from intertidal area to roost and feed in nearby sites. Therefore, conservation plans for shorebirds of key coastal wetland sites may provide greater benefits by incorporating all important separated terrestrial habitats with coastal and wetland habitats (Shepherd et al., 2003).

Changing in environmental conditions may have an impact on demographic parameters directly, thus demographic monitoring can be an early indicator of future population change (Monaghan et al., 1989 in Robinson et al., 2005), as well as help to understand the causes of population declines and to inform management decisions (Goss-Custard, 1996; Atkinson et al., 2003 in Robinson 2005). Long-term monitoring can help in identifying sites of conservation importance and may establish role of international commitments (Stroud et al., 1990; Robinson et al., 2005).

2.8.2 Information Needs for Shorebird and Wetland Conservation

Asia-Pacific Migratory Waterbird Conservation Committee (2001) suggested that baseline information is a prerequisite to plan and monitor management actions for waterbirds and their habitats. Success or failure of conservation actions cannot be accessed without strong scientific time series information on population status and distributions.

For many waterbird species, comprehensive information including breeding ranges, migration routes, important staging sites, wintering grounds, feeding requirements, quality of habitat and carrying capacity, seasonal / annual usage of particular habitat, and population changes is not available. Distributions and populations monitoring during the migration cycle is still scarce, accordingly information on population sizes and trends of many species remain unknown.

The exchange of information on waterbirds status and their habitats will make conservation actions possible. Information exchange will benefit greatly by computer-based information storage and retrieval systems, especially as accessibility and skills to operate computer-based systems increase across the region. For example of some quite newly launched and recently updated websites (between 2007 – 2008) in the East Asian – Australasian Flyway, such as

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- The Australian Wader Studies Group - http://www.awsg.org.au/
- Asia – Pacific Shorebird Network - http://www.shorebirdnetwork.org/
- Shorebird Conservation Toolkit - http://www.shorebirds.org.au/
- Birds Korea – http://www.birdskorea.org/

CHAPTER 3 STUDY AREA

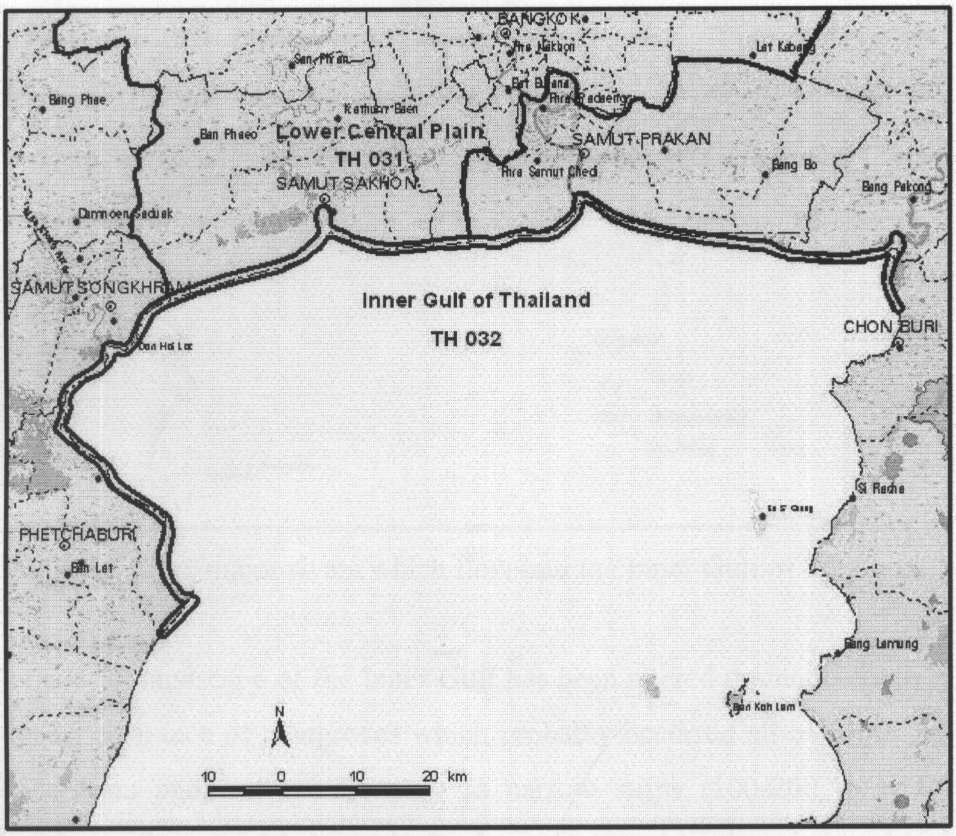

Figure 3.1: The Inner Gulf of Thailand Map from the Important Bird Area Project (Bird Conservation Society of Thailand, 2004).

The Inner Gulf of Thailand is one of an important wintering and staging sites in the East Asian-Australasian Flyway which located between latitude 13°53‘E, longitude 100°40‘E, 0-2 meters from mean sea level and enclosed shallow bays (45-80 m depth) (Fig. 3.1). The Inner Gulf extending along approximately 160 km of shoreline from the east coast at Klong Tam Ru, Chonburi Province to the west coast at Laem Pak Bia, Phetburi Province, encompasses five major rivers including the Bang Pakong river, the Chao Phraya river, the Tha Chine river, the Mae Klong river and the shorter one Phetchaburi river (Fig. 3.2).

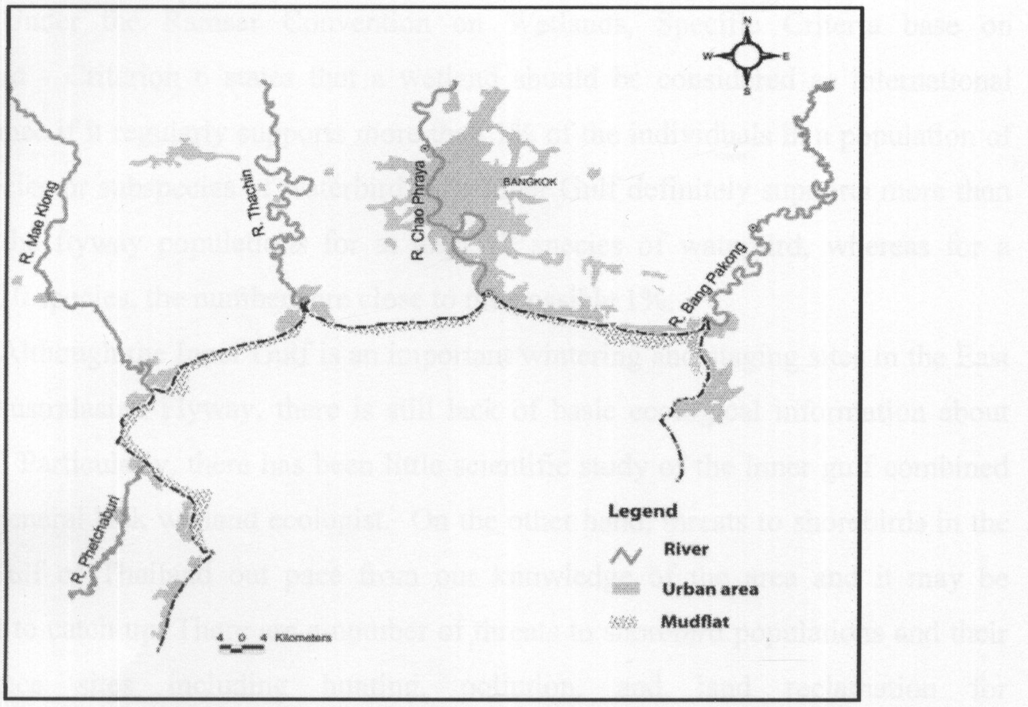

Figure 3.2: Five major rivers which flow into the Inner Gulf of Thailand.

The coastal landscape of the Inner Gulf has been altered dramatically to other land use types; clearance of mangroves which probably occurred all over the gulf as long as 100 years ago and remain only as narrow strips (100-200 m wide) of secondary growth. Supratidal habitats in the Inner Gulf and likely suitable shorebird habitat includes approximately 235 km^2 of mudflats (Erftemeijer & Jugmongkol 1999), 129 km^2 of mangroves, 320 km^2 of salt-pans which appeared in this area dating back perhaps 800 years, 400 km^2 of low intensity prawn-capture ponds and other aquaculture including some of abandoned and unutilized shrimp ponds (Round & Gardner 2008). These habitats are critically important for both migratory and resident waterbirds, especially shorebirds. Over 100 waterbirds have been recorded in the gulf, 65 species are shorebird. Allowing for vagrants and passage migrants, 18 Globally Threatened species and 10 Near-threatened species (Black-tailed Godwit just was up-listed recently by IUCN red list in 2006) visit habitats around the inner gulf and its hinterlands. The estimation of shorebirds alone, the total number is approximately 100,000 – 135,000 birds per year (Erftermeijer and Jugmongkol, 1999). In fact, the accurate number could be significantly higher than this number. Many of Shorebirds spend their non-breeding period in Thailand around six to seven months per year (Round, 2003).

Under the Ramsar Convention on Wetlands, Specific Criteria base on waterbird - Criterion 6 states that a wetland should be considered as international importance if it regularly supports more than 1% of the individuals in a population of one species or subspecies of waterbird. The Inner Gulf definitely supports more than 1% of the flyway populations for at least 17 species of waterbird, whereas for a further 10 species, the numbers are close to the possible 1%.

Although the Inner Gulf is an important wintering and staging sites in the East Asian-Australasian Flyway, there is still lack of basic ecological information about the gulf. Particularly, there has been little scientific study of the inner gulf combined with a general lack wetland ecologist. On the other hand, threats to shorebirds in the Inner Gulf of Thailand out pace from our knowledge of the area and it may be difficult to catch up. There are a number of threats to shorebird populations and their importance sites including hunting, pollution, and land reclamation for industrialization, urbanization, road construction and aquaculture. Some of the development and other mega-projects of the Thai government are planned for the inner gulf also such as oil refineries. Most important wintering sites both offshore and onshore habitats lack any legal protection from the government as well as most of the area lie outside the boundary of protected areas. There is just a small area of mudflats list as Ramsar site in the gulf, "Don Hoi Lot", but it is the single most disturbed and possibly least valuable for shorebird in entire the gulf (Round 2001). In spite of being identified as an Important Bird Area of Thailand and Asia, inner gulf is still under a number of threats. There is an urgent need for comprehensive zoning and environmental protection plans to ensure that this special shorebird habitat can continue support abundance of both wintering and resident waterfowls and especially still play its international important role.

Conservation and Management Priority

Erftemeijer and Jugmongkol (1999) made recommendations of short-term conservation and management of the Inner Gulf which can be concluded following these

1. Nominate the Inner Gulf for inclusion as a list site in the East Asian-Australian Site Network.
2. Established Non-hunting Areas under the Wild Animals Reservations and protection Act (1992) on key sites within the gulf.

3. Designate the intertidal mudflats in the gulf as Environmental Protection Areas as provided under the Enhancement and Conservation of National Environmental Quality Act (1992).
4. Develop an Integrated Coastal Zone Management Plan for the Gulf. The plan should incorporate environmental, social and economic needs into one single plan for long term sustainable development.

Round (2001) recommended that, improve knowledge of shorebird numbers, distributions and patterns of seasonal usage, including locations of breeding colonies and feeding areas, is a prerequisite for develop future conservation plans and management. Programs of routine monitoring should be established such as simple count of birds monthly throughout the year by Bird Conservation Society of Thailand or University Student or volunteers etc. More frequent monitoring at key site and key period such as wintering season should be made. Other recommendation made in Erftemeijer and Jugmongkol 1999 suggested that benthic invertebrates sampling, local community activities such as salt farming and traditional prawn-capture pond regimes etc. should be included in survey and monitoring programs.

CHAPTER 4 METHODS

4.1 Shorebirds Surveys

4.1.1 Focal Sites Selection

Twenty focal sites were selected for migratory shorebird surveys; six sites were well-known to birdwatchers and the other 14 were uniformly spaced approximately 4 km apart (to reduce spatial autocorrelation) constrained by road access (Fig. 4.1). The 20 sites covered a representative gradient of potential shorebird habitats.

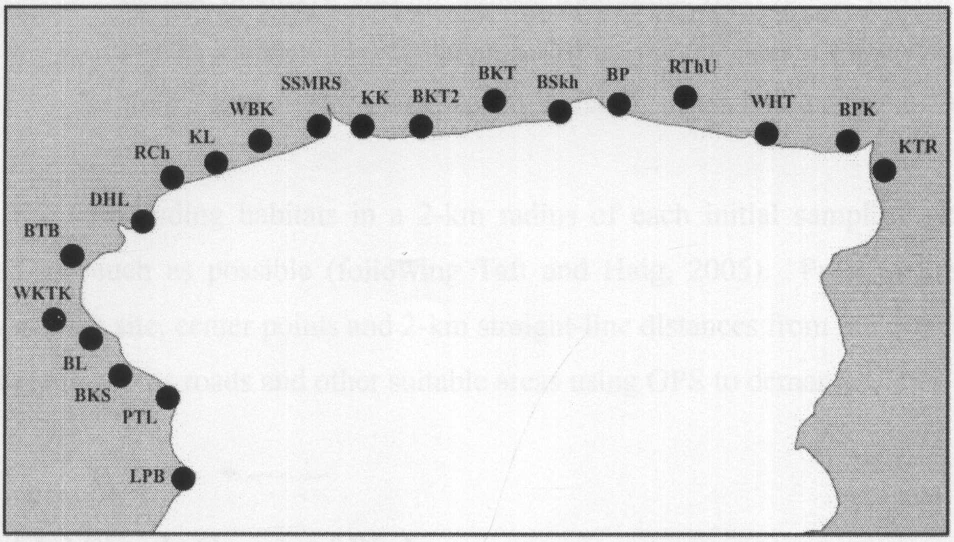

Figure 4.1: Twenty selected focal sites for shorebird surveys.

Site name abbreviations listed below:

LPB = Laem Phak Bia, **PTL** = Pak Thalae, **BKS** = Bang Khunsai, **BL** = Ban Laem, **WKTK** = Wat Khaotakrao, **BTB** = Bang Taboon, **DHL** = Don Hoi Lot, **RCh** = Rang Chan, **KL** = Kalong, **WBK** = Wat Bangkhud, **SSMRS** = Samut Sakhon Mangrove Research Station, **KK** = Kok Kham, **BKT2** = Bangkhuntien 2, **BKT** = Bangkhuntien, **BSkh** = Ban Sa-khla, **BP** = Bang Poo, **RThU** = Ratchabhat Thonburi University, **WHT** = Wat Hongthong, **BPK** = Bang Pakong, **KTR** = Klong Tam Ru.

Data was collected during the non-breeding period from October 2006 – mid April 2007, covering southward migration, mid-winter and northward migration. We conducted 2-hour surveys per site visit on randomly chosen days during daylight hours (0700–1830) and visited each site four times in total; two surveys at low tide when shorebirds are more likely to forage offshore and two surveys at high tide when birds roost onshore. Thus, the survey of four visits combined were cover two major types of habitat which shorebirds obviously use during non-breeding seasons including;

- Intertidal flats which are primary feeding habitat for shorebirds, however, the birds can be able to access only at low tide periods and unable to access during high tide periods.
- Supratidal habitats which are both natural and man-made habitats, locate just above tide line. Supratidal habitats along the Inner Gulf including remaining mangroves, traditional salt-pans, traditional prawn-captured ponds, intensive shrimp ponds, traditional fish ponds, intensive fish ponds, clam ponds, abandoned shrimp ponds, stream networks, paddy fields, reed swamps, scrubs and orchards, urban and industrial zones.

The surrounding habitats in a 2-km radius of each initial sampling site were surveyed as much as possible (following Taft and Haig, 2005). Prior to the initial surveys at each site, center points and 2-km straight-line distances from the centers were marked along access roads and other suitable areas using GPS to demarcate sites.

4.1.2 Simple Counts of Birds

Shorebirds counting were carried out during the non-breeding or wintering seasons including; southward migration season from September – November 2006, mid-winter from December 2006 – February 2007, and northward migration season from March – mid-May 2007. Time period to count shorebirds for each site was chosen as similar as possible of tide cycle period using 50%-50% counting efforts, for example, 2 times counting at high tide period and also 2 times counting at low tide period. Every site was visited 4 trips during non-breeding season base on logistical constraints of time and expense.

There were 3 techniques for counting shorebirds applied to this study which widely used in other studies of shorebird survey including

- Direct Counts

Direct counts of birds conducted when relatively small numbers of birds are present (less than 3,000), and there is limited movement, little disturbance, the birds

- Estimation Counts

Estimated counts conducted when there are large numbers of birds present (more than 3,000), the birds are very tightly packed together, and/or cannot be easily identified due to poor light (e.g. viewing into the sun), or the distance between the birds is large. This method estimates a "block" of birds within a flock, e.g. 5, 10, 20, 50, 100, or 500 birds depending on the total number of birds in the flock and the size of the birds. The block is then used as a model to estimate the size of remaining flock (Bibby et al., 2000; Howes and Bakewell, 1989).

- Roost Counts

Counting roosts conducted when birds are present at roosting sites or while they are roosting at high tide, and not too tightly packed. In this case birds will be directly counted. Counts will start at least 2 hours before high tide (Bibby et al., 2000, Howes and Bakewell, 1989).

Birds were spotted with a high quality spotting-scope Pentax PF-80ED with 80mm X 20-60 times magnification to provide correctly species identification at distance and in poor light conditions. Number of species and number of individuals for each species present at each site were recorded.

All species were counted separately except for Lesser Sand Plover (*Charadrius leschenaultii*) and Greater Sand Plover (*Charadrius mongolus*) which were pooled because they typically occur in large, tightly packed flocks, and are difficult to differentiate at a distance.

4.2 Habitat and Landscape Measurements

High-resolution satellite images from SPOT-5 (5 m resolution, captured on January 2006) were used to characterize fine scale habitat maps along the coast of the inner gulf of Thailand. SPOT-5 large scene images were subset into a small scene approximately 5x5 km (Fig. 4.2) for each focal site using ERDAS Imagine 9.1.

Figure 4.2: Example of SPOT-5 image 5X5 km sub-scene.

Then, using an object-based classification method in Definiens Developer V.7 created categorical map of each focal site. With Definiens, similar objects were able to classify, such as salt farms in slightly different stages all as "salt-pans", a task that found particularly difficult with standard supervised or unsupervised classifications in other software.

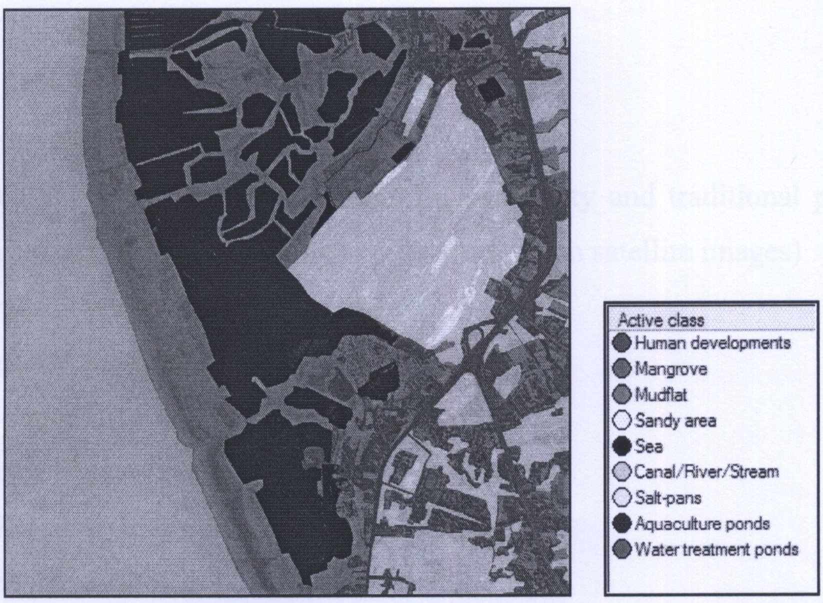

Figure 4.3: Example map of object-based classification method in Definiens Developer V.7.

Habitat composition and landscape metrics of each site in 2-km radius from center point that has been marked on a preliminary survey were assessed using the Patch Analyst extension in ArcView GIS 3.2.

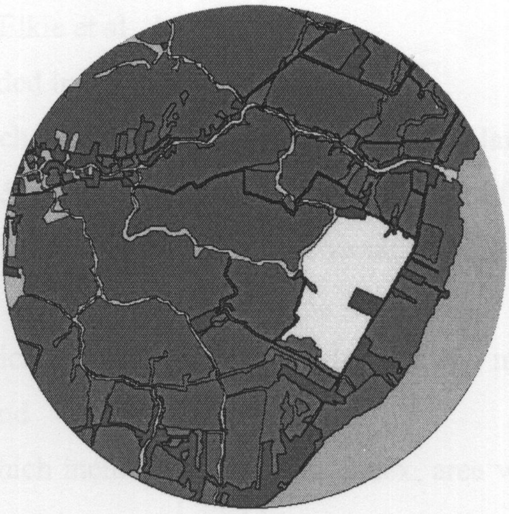

Figure 4.4: A 2-km radius map extracted from ArcView GIS 3.2 before analyze habitat composition and landscape metrics in Patch Analyst.

A 2-km radius was chosen because it captured variation among sites, as found in previous landscape studies of shorebirds which also used this scale (Sanzenbacher and Haig, 2002; Taft and Haig, 2005).

Habitat composition was classified following major types of land uses present along the Inner Gulf of Thailand including;

- tidal flats
- mangroves
- aquaculture ponds (combining both high-intensity and traditional practices because they were not possible to distinguish from satellite images)
- natural salt ponds
- traditional salt-pans
- sand-spits
- water-treatment ponds
- development (roads, buildings, factories etc.)
- stream networks
- reed swamps
- paddy fields
- non-mangrove vegetation (orchard, plantation and scrub)

Landscape configurations of each site were quantified using 16 landscape metrics available in Patch Analyst (Elkie et al., 1999).

The metrics are divided into 4 categories below;

1. ***Area Metrics*** which includes patch class area and total landscape area,

2. ***Patch Density & Size Metrics*** which includes number of patches, mean patch size, median patch size, patch size coefficient of variance, and patch size standard deviation,

3. ***Edge Metrics*** which includes total edge, edge density, mean patch edge, and contrasted weighted edge, and

4. ***Shape Metrics*** which includes mean shape index, area weighted mean shape index, mean perimeter-area ratio, mean patch fractal dimension, and area weighted mean patch fractal dimension. Relative patch diversity between sites were measured using a landscape diversity index (Shannon's Diversity Index); the index increases as the number of patch types increases.

4.3 Statistical analyses

Three index included species richness, abundance and diversity of each site were assessed.

Species richness was defined as the number of shorebird species observed at a site.

Abundance was based on the absolute count of individuals at a site summed over the four surveys.

Diversity was estimated using Fisher's alpha diversity index.

To examine the relationships among the 20 sites, we used the Bray-Curtis dissimilarity index scores as inputs into a cluster analysis using average linkage clustering to group sites by habitat composition following Oksanen (2006). Subsequently, the relationship between the sites and the habitat composition were examined by overlaying the above classification linkage into an ordination diagram using canonical correspondence analysis (CCA) using the original dissimilarities scores as input. To indicate which particular habitat type influenced the grouping, we performed permutation tests based on 1 000 permutations to select significantly different habitats between groups at a significance level of $p < 0.05$ and fit the significant habitats as vectors on the CCA ordination diagram. Then, differences between groups of sites organized via the CCA analysis in terms of species richness, abundance and diversity were compared using Wilcoxon rank-sum tests.

Multiple linear regression models were constructed using land cover types and landscape metrics as independent variables to predict richness, abundance and diversity of shorebirds. The best performing models were picked from the resulting set of significant ($p < 0.05$) candidate models based on the lowest AIC. With the exception of the GIS spatial analyses, all statistical analyses were performed in program R (http://www.r-project.org).

CHAPTER 5 RESULTS

5.1 Shorebird Surveys

A total of 35 shorebird species were observed during the four surveys of the 20 focal sites. Total counts of individual species abundances for all sites and surveys ranged from one individual for Spotted Greenshank (*Tringa guttifer*) to 35 334 individuals for sand plovers (Table 5.1). Of the 35 species, two are of conservation concern, the endangered Spotted Greenshank and the critically endangered Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*) (Birdlife International, 2009a, 2009b).

The total abundance of shorebirds per site (based on total counts from the four surveys) ranged from 24 to 23 122 individuals (Fig. 5.1), while species richness ranged from six to 27 species and Fisher's alpha from 1.13 to 4.02. Samut Sakhorn Mangrove Research Station (SSMRS) had the highest species richness (27 species: min 7 – max 17 per survey) and abundance (23 122 total: min 1 780 – max 10 731 individuals per survey) (Fig. 1B). However, Laem Pak Bia was the site of highest diversity also based on the four surveys combined (Fisher's alpha = 4.02 while SSMRS was 3.02), it contained an equal number of species (27 species: min 8 – max 16) compared to SSMRS but with a lower total abundance with only 3,315: (min 387 – max 1 092 individuals per survey).

Table 5.1: Common names, scientific names and abundance of 35 species from 20 focal sites in the Inner Gulf of Thailand based on four surveys conducted at each site between October 2006 and April 2007.

No.	Common Name	Scientific Name	Counts (total: min. – max.)
1	sand plover	*Charadrius mongolus + C. leschenaultii*	35 334: 10 – 9 911
2	Black-tailed Godwit	*Limosa limosa*	20 922: 1 – 8 439
3	Red-necked Stint	*Calidris ruficollis*	4 867: 10 – 1 593
4	Marsh Sandpiper	*Tringa stagnatilis*	4 331: 4 – 812
5	Common Redshank	*Tringa totanus*	3 373: 2 – 1 208
6	Curlew Sandpiper	*Calidris ferruginea*	2 283: 1 – 917
7	Pacific Golden Plover	*Pluvialis fulva*	1 725: 2 – 586
8	Broad-billed Sandpiper	*Limicola falcinellus*	1 665: 1 – 551
9	Kentish Plover	*Charadrius alexandrinus*	1 196: 2 – 423
10	Common Greenshank	*Tringa nebularia*	673: 2 – 80
11	Long-toed Stint	*Calidris subminuta*	591: 2 – 186
12	Spotted Redshank	*Tringa erythropus*	543: 2 – 340
13	Whimbrel	*Numenius phaeopus*	291: 1 – 175
14	Temminck's Stint	*Calidris temminckii*	278: 2 – 101
15	Great Knot	*Calidris tenuirostris*	249: 8 – 156
16	Little Ringed Plover	*Charadrius dubius*	236: 3 – 48
17	Red Knot	*Calidris canutus*	229: 12 – 168
18	Small Pratincole	*Glareola lactea*	220: 0 – 220
19	Eurasian Curlew	*Numenius arquata*	217: 48 – 118
20	Wood Sandpiper	*Tringa glareola*	212: 1 – 62
21	Ruff	*Philomachus pugnax*	205:1 – 95
22	Common Sandpiper	*Actitis hypoleucos*	92: 1 – 20
23	Asian Dowitcher	*Limnodromus semipalmatus*	77: 6 – 43

Note: Bird names are sorted from largest to smallest counts. Counts represent the total for all sites and all surveys combined, min & max represent minimum and maximum totals at any given site for all surveys combined (species found in only one site min. = 0).

Table 5.1 (continue).

No.	Common Name	Scientific Name	Counts (total: min. – max.)
24	Grey Plover	*Pluvialis squatarola*	48: 1 – 22
25	Red-necked Phalarlope	*Phalaropus lobatus*	45: 0 – 45
26	Pied Avocet	*Recurvirostra avosetta*	31: 9 – 22
27	Sanderling	*Calidris alba*	27: 11 – 16
28	Ruddy Turnstone	*Arenaria interpres*	19: 2 – 12
29	Common Snipe	*Gallinago gallinago*	18: 1 – 8
30	Grey-tailed Tattler	*Heteroscelus brevipes*	17: 0 – 17
31	Bar-tailed Godwit	*Limosa laponica*	15: 1 – 14
32	Terek Sandpiper	*Xenus cinereus*	14: 2 – 9
33	Spoon-billed Sandpiper	*Eurynorhynchus pygmeus*	5: 1 – 3
34	Far Eastern Curlew	*Numenius madagascariensis*	3: 1 – 2
35	Spotted Greenshank	*Tringa guttifer*	1: 0 – 1

Note: Bird names are sorted from largest to smallest counts. Counts represent the total for all sites and all surveys combined, min & max represent minimum and maximum totals at any given site for all surveys combined (species found in only one site min. = 0).

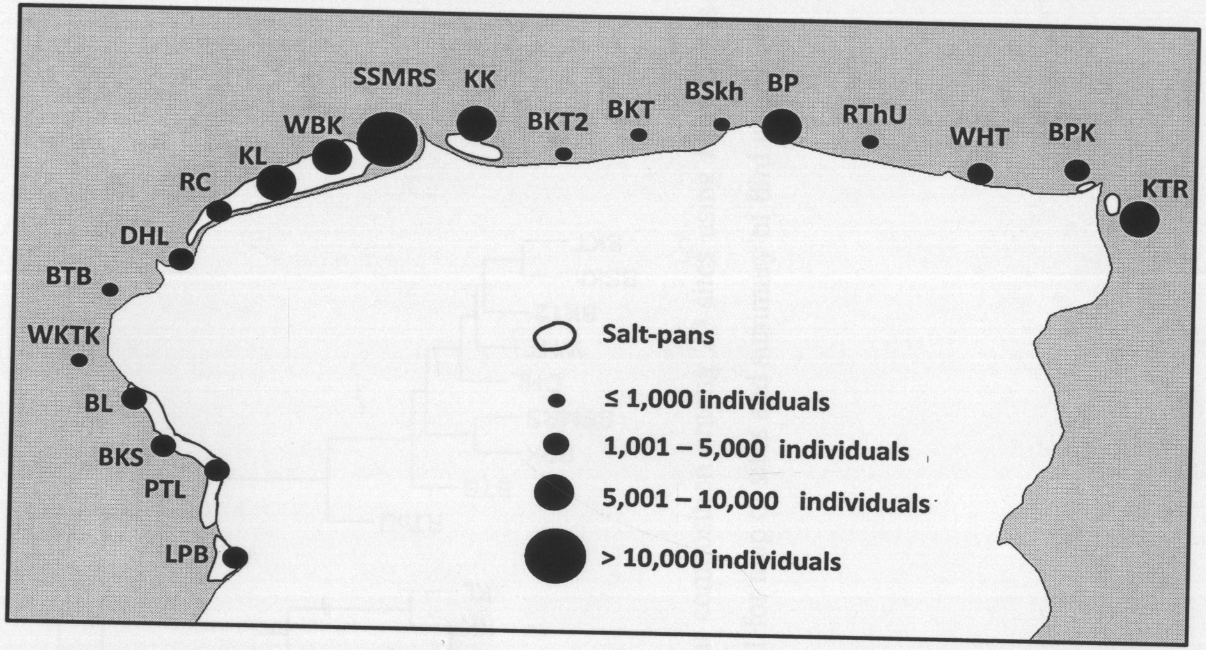

Figure 5.1: The locations of the 20 focal sites with their estimated total shorebird abundance and location of salt-pans.

Site name abbreviations were listed below;

LPB = Laem Phak Bia, **PTL** = Pak Thalae, **BKS** = Bang Khunsai, **BL** = Ban Laem, **WKTK** = Wat Khaotakrao, **BTB** = Bang Taboon, **DHL** = Don Hoi Lot, **RCh** = Rang Chan, **KL** = Kalong, **WBK** = Wat Bangkhud, **SSMRS** = Samut Sakhon Mangrove Research Station, **KK** = Kok Kham, **BKT2** = Bangkhuntien 2, **BKT** = Bangkhuntien, **BSkh** = Ban Sa-khla, **BP** = Bang Poo, **RThU** = Ratchabhat Thonburi University, **WHT** = Wat Hongthong, **BPK** = Bang Pakong, **KTR** = Klong Tam Ru.

5.2 Habitat Grouping

Nineteen out of 20 sites clustered primarily into two major groups based on dissimilarities of habitat composition. While only one highly urbanized site in close proximity to Bangkok, Bang Poo (BP), did not clearly fit these two clusters (Fig. 5.2).

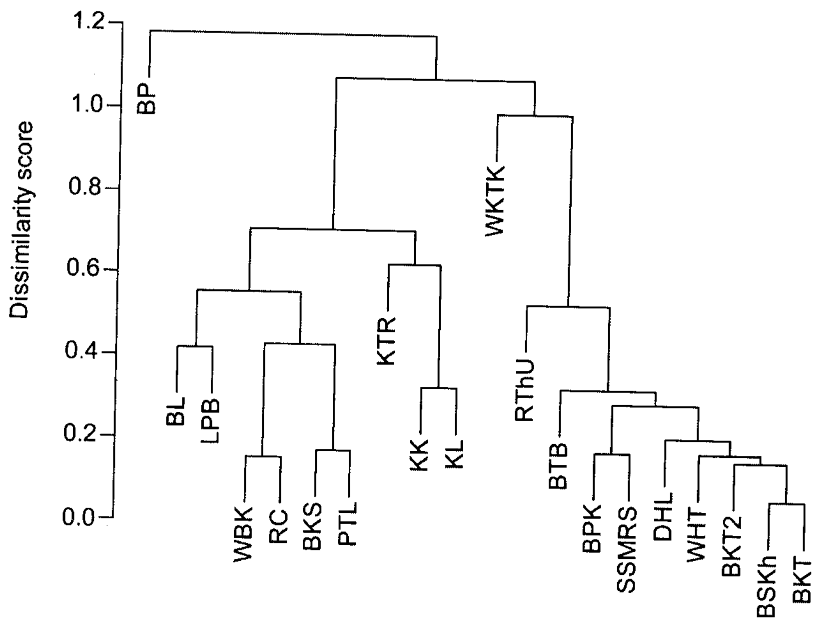

Figure 5.2: Cluster analysis of habitat composition among 20 sites using Bray-Curtis dissimilarity index as input (see Fig 5.1 for map of sites and summary of bird numbers).

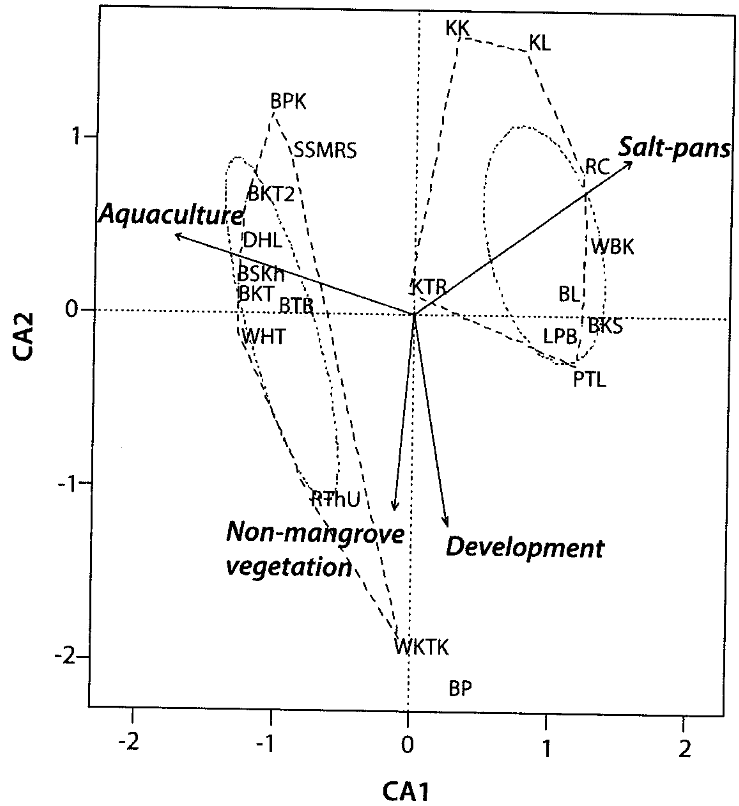

Figure 5.3: CCA ordination diagram fitted with vectors of significant (p<0.05) habitat variables; the diagram used dissimilarity scores from the cluster analysis as input.

Note: Dashed line hulls show members of each group. Dotted ellipses show standard deviations within each group.

CCA ordination indicated that these two groups were well separated because there was no overlap of hull areas (Oksanen et al., 2006) (Fig. 5.3). Four habitat variables, aquaculture, salt-pans, non-mangrove vegetation, and development were significantly different (Permutation test, $p < 0.05$) between the two groups (Fig. 5.3). One group was strongly dominated by salt-pans ($r^2 = 0.91$, $p = 0.001$) as indicated by the length of the vector and the other strongly dominated by aquaculture ($r^2 = 0.92$, $p = 0.001$). Aquaculture occurs throughout the Inner Gulf, but is more prevalent in the eastern side, while only two of the eastern sites, Bang Pakong (BPK) and Klong Tam Ru (KTR) still contain modest areas of salt-pans. The western side of Gulf contains more extensive open areas (land use with no mangroves and other vegetations cover), salt-pans occur in large connected patches and is often the predominant land use; there are also relatively larger patches of secondary mangrove forest (Round et al., 2007).

The lower-left quarter of CCA diagram, roughly representing three sites, appeared to be influenced by non-mangrove vegetation ($r^2 = 0.37$, $p = 0.014$) and urban development ($r^2 = 0.40$, $p = 0.01$), but suggested weaker correlations. Non-mangrove vegetation including scrub, orchards and plantations were associated with sites Wat Khaotokrao (WKTK) and Ratchabhat Thonburi University (RThu) based on their vector direction; these sites were classified as being farther from other members of their group due to the relatively high dissimilarity scores. Development including urban areas, industrial zones and roads had the highest association with BP, the only site which did not cluster with the other 19 sites.

Species richness and log abundance was significantly higher in sites dominated by salt-pans versus aquaculture (Wilcoxon rank-sum test, $W = 20.5$, $p = 0.049$ and $W = 43$, $p = 0.006$ respectively Fig. 3). However, diversity (Fisher's alpha) was not different ($W = 12$, $p = 0.90$). Significantly higher species richness ($W = 78.5$, $p = 0.009$), log abundance ($W = 72$, $p = 0.037$) and diversity ($W = 75$, $p = 0.019$) were found at sites with salt-pans than those without (Fig. 5.4).

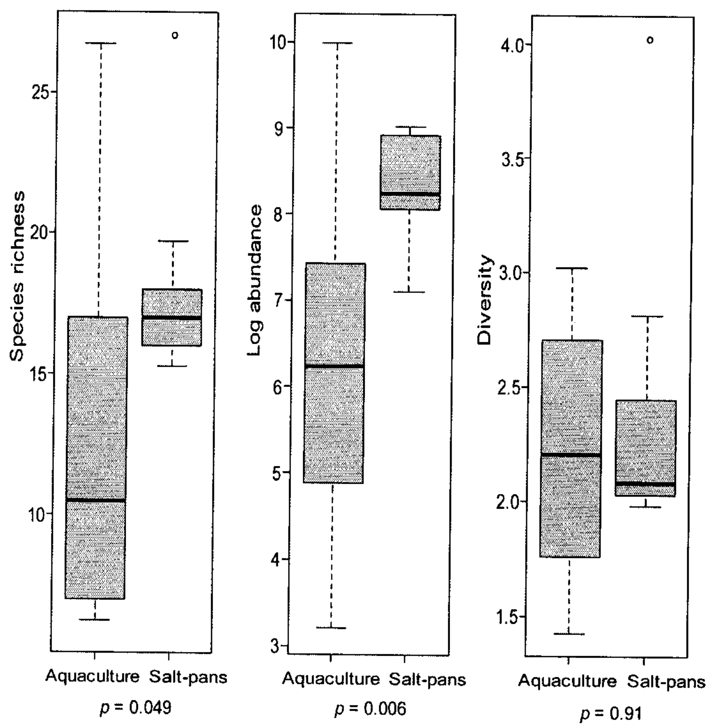

Figure 5.4: Box and whisker plots comparing species richness, log abundance, and diversity between sites associated with aquaculture and sites associated with salt-pans (Aquaculture; N = 10, Salt-pans; N = 9)

5.3 Habitat Composition and Landscape Metric Models

Table 5.2: Multiple regression models of habitat composition and landscape metrics for species richness, log abundance and diversity (Fisher's alpha). Model critical values set to $p < 0.0.5$.

Model	Response index	Parameters in model	Coefficient	*t*-value	*p*	Model adj. R^2
Habitat composition	Species richness	Tidal flats	0.07 ± 0.017	3.38	0.001	0.52
		Salt-pans	0.01 ± 0.003	3.36	0.004	
	Log abundance	Tidal flats	0.006 ± 0.003	2.29	0.035	0.35
		Salt-pans	0.001 ± 0.0005	2.94	0.009	
	Diversity	Tidal flats : Salt-pans	$1.96e^{-05} \pm 4.79e^{-06}$	4.09	0.0007	0.45
Landscape metrics	Species richness	Mean patch size	0.076 ± 0.277	2.54	0.02	0.24
		Total edge	$-4.359e^{-06} \pm 2.390e^{-05}$	-0.18	0.857	
	Log abundance	Mean patch size	-2.648 ± 1.108	-2.39	0.0304	0.49
		Total edge	$-2.11e^{-05} \pm 7.33e^{-06}$	-2.88	0.0125	
		Mean shape index	2.318 ± 0.724	3.20	0.0059	
		Area weight mean shape index	1.01 ± 0.3192	3.16	0.0064	
	Diversity	Mean patch size	0.1025 ± 0.0346	2.96	0.0091	0.41
		Total edge	$-8.212e^{-06} \pm 2.787e^{-06}$	-2.95	0.0095	
		Patch size standard deviation	-0.045 ± 0.0169	-2.67	0.0168	

All three habitat composition models indicated that tidal flats and salt-pans, and the interaction between them appeared to be the best explanatory variables for species richness, log abundance and diversity of shorebirds (Table 5.2). Sites with higher species richness and sites with higher abundance were both most strongly associated with the cover of salt-pans and tidal flats. However, higher diversity sites appeared to be most related to the interaction between area of salt-pans and tidal flats. We also assessed differences among sites based on salt-pans or tidal flats alone. Salt-pans alone were significantly related to species richness (simple linear regression, $r^2 = 0.21$, $p = 0.04$) and log abundance ($r^2 = 0.24$, $p = 0.03$), but was not related to diversity ($r^2 = 0.04$, $p = 0.43$) (Fig. 5.5). Area of tidal flats was significantly related to species richness ($r^2 = 0.29$, $p = 0.01$) and diversity ($r^2 = 0.25$, $p = 0.02$), but not log abundance ($r^2 = 0.13$, $p = 0.12$) (Fig. 5.6). Salt-pans occur in 13 out of 20 sites and 12 of them occur in close proximity to tidal flats. However, area of tidal flats was not correlated with area of salt-pans ($r^2 = 0.02$, $p = 0.58$), and area of tidal flats was not significantly different between sites from the salt-pan group and sites from the aquaculture group ($t = 0.0584$, $p = 0.9543$). Landscape diversity was not significantly correlated with species richness ($r^2 = 0.06$, $p = 0.31$), log abundance ($r^2 = 0.05$, $p = 0.33$), or shorebird diversity ($r^2 = 0.12$, $p = 0.13$).

Multiple regression models of the relationship between shorebird communities and general landscape metrics resulted in additional associations. Sites with higher species richness tended to contain larger *patch sizes* (0.706(Mean patch size)) and lower *fragmentation levels* (– $4.359e^{-06}$ (Total edge)) (Multiple regression, $r^2 = 0.32$, $p = 0.0392$). Higher abundance sites contained *smaller patches* (– 2.684 (Mean patch size)), lower *fragmentation levels* (– $2.11e^{-05}$ (Total edge)), and more *irregular patch shapes* (2.318(Mean shape index) + 1.01(Area weight mean shape index)) ($r^2 = 0.54$, $p = 0.0149$). Higher diversity sites contained slightly larger *patch sizes* (0.1025(Mean patch size)), also lower *fragmentation levels* (– $8.212e^{-06}$ (Total edge)), and lower *variability of patch* sizes (– 0.045(PSSD)) ($r^2 = 0.50$, $p = 0.009$).

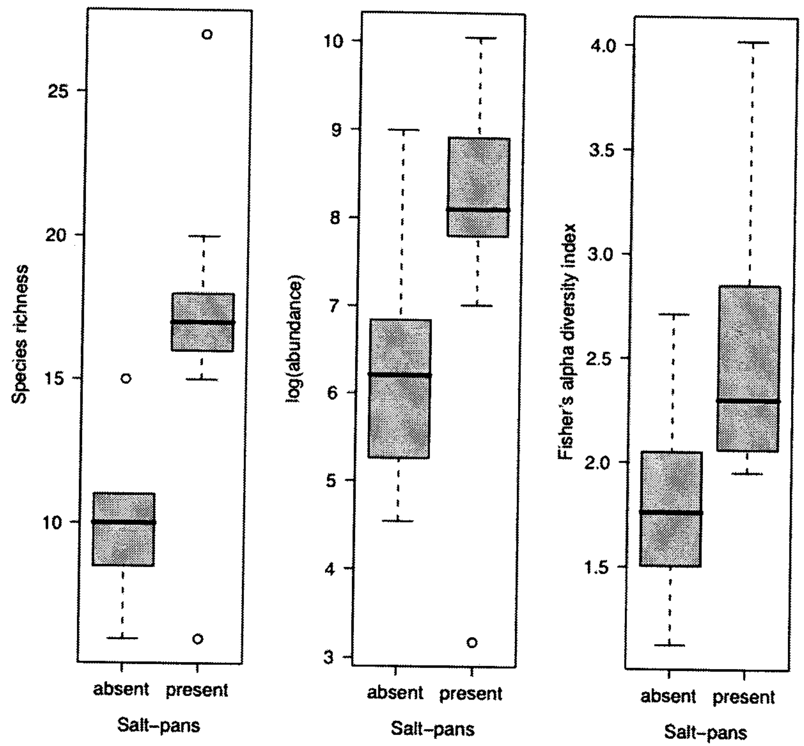

Figure 5.5: Box-and-whiskered plot compare species richness, abundance and diversity between sites which ***salt-pans*** present and absent.

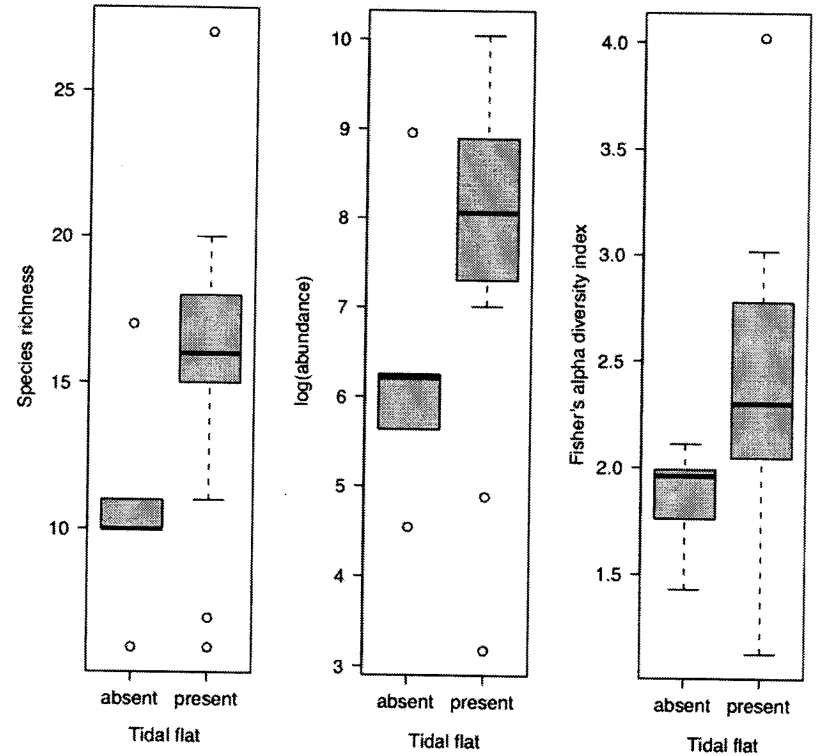

Figure 5.6: Box-and-whiskered plot compare species richness, abundance and diversity between sites which ***tidal flats*** present and absent.

CHAPTER 6 DISCUSSION AND CONCLUSIONS

6.1 Landscape Metrics

Overall, mean patch size, total edge, mean shape index, area weighted mean shape index and patch size standard deviation appeared to be positively related with shorebird abundance, species richness, and diversity based our multiple regression models. The significant metrics reflected area and edge effects, particularly mean patch size and total edge. Habitat area (patch size) and edge are key components of the habitat structure, and are likely to co-vary within landscapes and also have potential to interact; however, they express different features of landscape structure and ecological process in distinct ways (Fletcher et al., 2007). Edge effects influence movement of organisms and provide access to spatially separated resources (Ries et al., 2004). All models indicated that edge effects, reflecting sites with lower fragmentation levels are more suitable for shorebirds, as they may perceive multiple patches of narrowly separated wetlands as a single large connected wetland (Farmer and Parent, 1997). The species richness model suggested that as patch size increases, species richness should increase. This seems to be a general pattern in other types of habitats in which larger patches are correlated with increased bird abundance and species richness (Bender et al., 1998).

However, the abundance model indicated that smaller patches contained higher abundances, the opposite of what is typically found (Fletcher et al., 2007). During the non-breeding season shorebirds feed mainly on highly productive tidal flats accessible only at low tide and are forced to leave these feeding grounds to roost site during high tide (Goss-Custard and Yates, 2006). Highly productive feeding sites are only of use if they are associated with suitable roost sites, which are characterized by low risk of predation and low commuting costs between roost site and foraging areas (Dias et al., 2006; Rogers et al., 2006a, 2006b). Availability of suitable roost sites can therefore limit population sizes, thus a single small suitable roost site may hold thousands of shorebirds (Dias et al., 2006; Rogers et al., 2006b). Therefore, abundance may not necessarily increase with increasing patch size. Some of our study sites, for example BP, a few thousand black-tailed godwit (*Limosa limosa*) roosted in only one small pond (approximately 0.05 km^2) in an otherwise highly urbanized landscape. The roosting pond is only 140 m away from nearby mudflats and encircled by mangroves and one of the last remaining natural high tide roost site in the Inner Gulf. Patch sizes can hold higher abundances also depending on variations in patch quality, which depend on water depth, salinity, availability of exposed moist soil and invertebrate prey (Fletcher et al., 2007). There are seven sites out of 20 where no obvious roost sites were found, however, we did not quantify roost site availability. At sites where birds were found roosting in salt-pans, only one third of the total salt-pan area appeared to be available for roosting, roughly estimated from satellite images, and only a small percentage (probably less than 10%) of this available habitat was used by birds.

6.2 Effects of Particular Land Use Patterns on Richness, Abundance and Diversity

Cluster analysis and ordinations indicated that 19 of the sites along the Inner Gulf of Thailand could be divided into 2 groups; 1) sites characterized by large expanses of aquaculture and 2) and those with large amounts of salt-pans, with the 20^{th} site associated with higher levels of urban and industrial development. As expected, sites in which the surrounding landscape hold higher proportions of salt-pans and lower proportions of aquaculture had significantly higher levels of shorebird richness and abundance than sites which hold higher proportions of aquaculture, but there was no difference in diversity. This might be an effect of roost availability, because the proportion of tidal flats in these two groups was not different.

6.2.1 Aquaculture

Industrial-scale aquaculture has been noted as a significant threat to shorebird populations in both Atlantic and Pacific flyways (Schaeffer-Novelli et al., 2006), primarily through water pollution and hydrological alteration (Redstone Strategy Group, 2008). For example, clam farms in France have strong negative effects on shorebirds because such farms are sometimes set up on tidal flats and force shorebirds to abandon highly productive feeding sites for less productive sites (Godet et al., 2009). Along the East Asian – Australasian flyway aquaculture has also been blamed for the decreasing and Australia (Gosbell and Clemens, 2006; Melville and Battley, 2006; Minton et al., 2006; Round, 2006). In vast areas of the Southeast Asian coast, aquaculture has replaced supratidal habitats and reshaped coastal landscape along with urbanization and industrialization, particularly in Malaysia, Myanmar and Thailand (Wetlands International, 2007).

In the Inner Gulf of Thailand most industrial-scale shrimp ponds last only 3-7 years, and in approximately 1990 this industry nearly collapsed due to inappropriate management, proliferation of fungal disease and accumulation of chemical residues (Stevenson, 1997; Round, 2006). As a result, an estimated 40 000 ha of ponds were abandoned (Kaosaard and Wijukprasert, 2000) and these habitats are sometimes used by shorebirds (Round, 2006). However, many of these abandoned ponds have been converted to deep, permanent and steep-sided ponds for clam and crab cultivation or commercial fishponds which are largely unusable or limit access for shorebirds and other waterfowl except perhaps opportunistically when water is drained during harvesting or maintenance. In addition, some of these ponds are completely destroyed by soil excavation for fill for development elsewhere (Round, 2006; Round and Gardner, 2008; Yasué and Dearden, 2009). However, subsistence-level aquaculture such as traditional prawn-captured ponds is probably more usable by shorebirds because these systems also contain shallow water storage ponds (Yasué and Dearden, 2009).

6.2.2 Tidal flats & Salt-pans

Tidal flat area and salt-pans together were the best predictors of species richness, abundance, and diversity. Tidal flats or salt-pans by themselves appeared to explain less of the variation in these indices, perhaps representing the need of shorebirds for adequate areas for both feeding and roosting. Our results suggest salt-pans are important for supporting migratory shorebird populations in this area, primarily as roosting sites. Some smaller shorebirds such as stints (*Calidris spp.*) and broad-billed sandpiper (*Limicola falcinellus*), may exploit salt-pans at all stages of the tide cycle (Round, 2006; Round and Gardner, 2008), suggesting they use the sites for foraging as well as sites for resting during high tide.

Traditional salt-pans in Thailand consist of shallow interconnected pans varying in size, water depths, separated by dikes. Most are operated by small teams of local

Traditional salt-pans in Thailand consist of shallow interconnected pans varying in size, water depths, separated by dikes. Most are operated by small teams of local people who rarely use large machines, in contrast to the Mediterranean and US where extensive areas of salt-pans are managed by a single or few large companies (Walmsley, 1999; Warnock et al., 2002). The traditional salt farming system is comprised of 4 major parts; 1) main water storage ponds with relatively deep standing water (30 cm up to 1 m or more), 2) low salinity evaporation ponds which are shallow (5-20 cm) and typically contain dense growths of algae and/or exposed moist soil, 3) high salinity (approximately 200 ppt) evaporation ponds, and 4) bittern storage ponds and crystallizers containing solid, crystallized salt. The low salinity evaporation ponds are mostly used by birds because of a combination of salinity and water depth, typically less than 10-15 cm. Smaller shorebirds prefer depths of roughly 4 cm except for those that can swim such as phalaropes (Isola et al., 2000). These ponds often contain features structurally similar to natural mudflats or shallow salt marsh. The endangered spotted greenshank (*Tringa guttifer*) and the critically endangered spoon-billed sandpiper (*Eurynorhynchus pygmeus*), both with remaining populations of less than 1 000 individuals (Birdlife International 2009a, 2009b), often use such ponds in the Inner Gulf. For the latter species, at least 12 individuals per year use the Inner Gulf and traditional salt-pans appear to be a significant component of its wintering habitat (Bunting and Zöckler, 2006; Nimnuan and Daengpayon, 2008). Other studies that have pointed to the importance of salt-pans for shorebirds include an investigation of common redshank (*Tringa totanus*) in southwest Spain which showed they use salt ponds were important as supplementary foraging grounds, especially during the pre-migratory mass-gain period (Masero and Pérez-Hurtado, 2001). Banded stilt (*Cladorhynchus leucocephalus*), a seasonal migrant within Australia use salt-pans during the spring of dry years when natural salt lakes dry up (Alcorn and Alcorn, 2000). In the northern regions of the East Asian – Australasian flyway, shorebirds use salt-pans along the coast of the Yellow Sea region of South Korea and China (Moores, 2006; Yang and Zhang, 2006) and at specific sites in this region of China, salt-pans are thought to support approximately 100 000 shorebirds per year (Barter et al., 2003).

6.3 Conservation Implications

In addition to tidal flats as primary feeding grounds, salt-pans appear to be critical habitat for shorebirds overwintering in the Inner Gulf of Thailand and are likely to be so elsewhere. This man-made habitat appears to be at least a partial substitute for natural supratidal and tidal habitats particularly during non-breeding seasons by providing suitable roost sites and supplementary feeding sites during high tide. Abandoned intensive shrimp ponds which are found widely in the western portion of the Inner Gulf for example, are typically little used by birds could be potential targets for restoration. Restoration of these abandoned ponds by imitating characteristics of natural salt ponds or salt marsh may increase roost site availability for the birds (Warnock, 1994; Warnock et al., 2002). This includes adjusting the water depth from 0 up to 10 cm and maintaining several ranges of the salinity (Isola et al., 2000; Warnock et al., 2002). The selected restoration ponds would be established in close proximity to tidal flats as similar to the characteristics natural roost sites as possible. Collaboration between researchers, as well as government agencies and NGOs, with local salt farmers to demarcate significant sites, restore supratidal and tidal habitats and maintain salt-pans as potential shorebird roost sites is urgently needed if areas like the Inner Gulf of Thailand are to continue to support significant numbers of shorebirds.

6.4 Limitation of This Study and Suggestion for Future Research

6.4.1 Limitation of This Study

- According to a very large extensive area of the Inner Gulf of Thailand and limitation of accessibility of roads, surveys are quite difficult to cover as many sites as expected. Even in only one site, to cover as much as surrounding habitat is takes time for each survey, especially with only one researcher conducted the research made the task more difficult.

- Budget also became one of the most limitations for the project. Because of small amount budget funded for conducting a research in very large extensive area and need a lot of traveling by car which very costly by car rental each day and petrol. Thus, numbers of survey for each site and time spent during each survey have to adjust follow a limitation of budget.

6.4.2 Suggestion for Future Research

- At least 2 consecutive years or migration seasons would provide better data on number of birds, as well as, allow investigating of population turn-over rate and year-to-year variation.

- Increasing numbers of observer should make higher detection rate of birds count, especially when birds flying to feed or roost in a big flock of multiple species. Then, at least 2 observers can help check the species that one another missed, and also help check the birds which just flying in the other observer start counting.

- Surveys of roost sites all over the Inner Gulf, investigate features of particular roost site at fine scale and landscape scale, as well as, conduct GIS analysis of those roost sites would be highly valuable for develop a robust conservation plans for shorebirds in the Inner Gulf of Thailand.

- Investigation of food availability for shorebirds by comparing benthic invertebrates mass between evaporation ponds of salt-pans and tidal flats may help to construct better models to describe appearances of higher numbers of birds at a particular site, and also present of particular species in some sites. Intensive benthic invertebrates survey along the Inner Gulf both in tidal flats and supratidal habitats are needed.

- Long-term monitoring of conservation concern species is urgently needed, such as Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*), Spotted Greenshank (*Tringa guttifer*), and Asian Dowitcher (*Limnodromus semipalmatus*). As well as, the species that global population trends are decreasing such as Black-tailed Godwit (*Limosa limosa*), Common Redshank (*Tringa totanus*) and Spotted Redshank (*Tringa erythropus*).

- Habitat restoration is a challenging approach to proceed as soon as possible. By collaboration between government, NGOs, local communities, landowners and researchers, this effort would be possible and worth to try. Because of sea level rising due to global warming and high rate of coastal erosion every year, consequently, primary feeding habitat on tidal flat continues decreasing. Thus, restore unused land or abandoned ponds back to usable ponds for shorebirds will substitute them at least more secondary feeding habitats and secure roosting sites.

- Declaration of sites that contain high abundance of shorebirds and also regularly present of conservation concern species as the special shorebirds conservation sites. This will legally help projecting both of resident and migratory shorebirds in the Inner Gulf of Thailand, and also help sustain viable populations of shorebirds in the East Asian-Australasian Flyway.

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Publications

1. Sankamethawee, W., Nimnuan, S., Sripanomyom, S., Pobprasert, K., Pierce, A. J. and Round, P. D., 2008, Diet and Breeding Biology of Asian Golden Weaver (*Ploceus hypoxanthus*), **Bird Conservation International,** Vol. 18, pp. 267-274.

2. Sripanomyom, S., 2008, "Landscape characteristics and necessary habitats for migratory shorebird communities in the Inner Gulf of Thailand", **The 12th BRT Annual Conference**, October 10-13, Surat Thani, Thailand, pp. 172-178.

3. Sripanomyom, S., Round, P.D., Savini, T., Trisurat, Y. and Gale, G.A., 2010, The importance of traditional salt-pans for

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