CHAPTER 1

INTRODUCTION

1.1. General Background

The word "egret" comes from the French word "aigrette" that means both "silver heron" and "brush," referring to the long filamentous feathers that seem to cascade down on the egret's back during the breeding season. Egrets belong to the order Ciconiiformes and the family added along with herons, ibises, and storks. Egrets are wading birds that have long legs, neck, and bills, as well as short tail. It's neck can be bent vertically but not laterally. The sixth cervical vertebrae is long, giving the familiar "S" shape to the neck. Herons and egrets have comb-like serrations on the edges of their middle claws which help them to preen feathers inaccessible by their bills. Many egret species can be identified by wispy, lace-like plumes (called aigrette feathers), which the males display during the breeding season. Most of the egrets are white in color (Robert, 1991).

1.2. Distribution and Habitat Selection of Egrets

Egrets are widely distributed throughout the world including Asia, Australia, Africa, America and Europe (McKenna, 2011; Steele, 2011). The distribution of egrets is scattered and its numbers fluctuate. Some egrets such as Chinese Egret (*Egretta eulophotes*) is critically endangered (BirdLife International, 2012a) while other such as the Snowy Egret (*Egretta thula*) is threatened (BirdLife International, 2012b). Egrets predominantly occur in lowland and tropical water bodies, prefer the shallow water area and water bodies' edges for foraging except Cattle Egret (*Bubulcus cormorandus*) that forages in agricultural fields. Egret selects habitat based on richness of food resources, vegetation structure, composition, and microclimate that provide optimal resources to satisfy their needs (i.e. food, water and shelter) and to perform various activities. They prefer shallow water areas covered with short vegetation or without vegetation due to easier prey detection (Isacch and Martiz, 2003). The availability and quality of suitable habitat are key factors in determining the abundance and distribution of egrets.

Egrets utilize various types of habitats such as wetlands, marshes, swamps, streams, rivers, canals, lakes, ponds, tidal mudflats, agricultural fields, dams, reservoirs and flooded areas (Kazantzidis and Goutner, 1996; McCrimmon *et al.*, 2001; McKenna, 2011; Steele, 2011). Differences in habitat selection could be due to environmental factors such as water depth, prey characteristics (density and biomass) and habitat availability. Previous studies confirmed that microhabitat selection by wading birds is affected by various factors such as social foraging, water level, proximity and height of vegetation, breeding season and prey availability (Safran *et al*., 2000; Bancroft *et al*., 2002; Gawlik, 2002).

1.3. Egrets' Diet

Foraging is a fundamental aspect of bird's biology to ensure survival and reproduction. Egrets employ different foraging behaviours to exploit a wide range of prey items (Fasola, 1994; Kushlan, 2007; Maccarone and Brzorad, 2007). Their diet includes a wide variety of aquatic animals such as small fishes, snakes, amphibians, small mammals and invertebrates such as gastropods, arachnids, bivalves, leeches and worms (Darnell and Smith, 2004; Compton, 2006; McKenna, 2011; Steele, 2011). Food availability for egrets may vary from one area to another depending on the productivity, type and location of a particular habitat. Egrets show extraordinary foraging efforts such as stand and wait, walking slowly or running quickly, wing flick and foot shuffling to catch their prey in a variety of habitats such as streams and river edges, tidal ponds, drainage ditches, and commercial fish pond (Kushlan and Hafner, 2000; McKenna, 2011; Steele, 2011).

Little Egret (*Egretta garzetta*) is an active opportunistic forager. It exhibits wide ranges of hunting strategies in order to catch their prey in shallow waters such as stand on one leg and stir the mud with the other to scare up prey or wave the other bright yellow foot over the water surface to lure aquatic prey into range. They mostly prey on an aquatic and terrestrial insects (beetles, dragonfly larvae, mole crickets, and crickets), crustaceans (*Palaemonetes* sp., amphipods, phylopods, crabs and crayfish), molluscs (snails and bivalves), spiders and worms (Voisin, 1991; del Hoyo *et al.*, 1992; Kushlan and Hancock, 2005; McKenna, 2011).

Cattle Egret (*Bubulcus cormorandus*) exhibits wide range of feeding behaviour but most of the time they walk rapidly in order to keep up with their host such as cattle. They rarely feed without host due to the difficulty in searching for prey. Therefore they prefer to follow along-side grazing livestock to catch any disturbed preys (McKilligian, 2005; Sharah *et al.*, 2008). They foraged by standing still or walking slowly/quickly, waiting for prey to approach, and then stabbing it with a quick thrust of the bill. They primarily foraged on insects such as locusts, grasshoppers, beetles, adult and larva of moth and butterflies, hemiptera, dragonflies, spiders, crustaceans, and molluscs (del Hoyo *et al.*, 1992; Kushlan and Kushlan, 2005).

Intermediate Egret (*Mesophoyx intermedia*) is diurnal feeder, usually stalks their prey methodically in shallow waters (del Hoyo *et al*., 1992; Kushlan and Hancock, 2005). The diet of Intermediate Egret consists predominantly of crustaceans (crayfish), terrestrial insects (grasshoppers, mole crickets, bugs and beetles), aquatic insects (e.g. water bugs and dragonfly larvae) and spiders (Hockey *et al.,* 2005, Kushlan and Hancock, 2005).

Great Egret (*Casmerodius albus*) is a diurnal feeder but most active at dawn and dusk. It usually hunts alone in shallow water, leaning forward called "hunting pose" and waits patiently for its prey to come within the reach of beak. When it spots its prey, it will straighten its neck, draw it back and quickly strike (del Hoyo *et al.* 1992; Kushlan and Hancock, 2005). It wades in shallow water to feed on aquatic organisms such as insects in reeds, bushes, and along the shore line at low tide (Steele, 2011).

Chinese Egret (*Egretta eulophotes*) is an active forager i.e. it hunts on shrimps, crustaceans, worms, insects, small aquatic invertebrates, amphibians, and fishes in shallow water. It either hunting alone or in flocks mixed with other heron species. It walks slowly to watch its prey and sometime it also chase the prey by running with open wing (del Hoyo *et al*., 1992).

The availability of habitat and fluctuation of water level allowed some flexibility in foraging technique used by egrets (Smith, 1995). Generally many species of wading birds require suitable hydrology and water level to allow individuals of various body sizes or leg lengths to access prey. This adaptation is reflected in their diet, foraging strategy, and habitat preferences (Kushlan and Hafner, 2000). Egrets utilize water bodies of different sizes (Chavez–Ramirez and Slack, 1995) and quality (Ramo and Busto, 1993). The Cattle Egret is less tied to watery environments and prefers to forage in agricultural fields. It followed livestock to catch invertebrates flushed by movement.

Egrets employ different foraging behaviours to exploit wide range of prey items (Fasola, 1994; Kushlan, 2007; Maccarone and Brzorad, 2007). Key factors that influence habitat selection by avian include prey density and prey distribution (Arengo and Baldassarre, 1999), and prey detection and competition (Gawlik, 2002). Egrets often form large mixed-species aggregations (flocks) both when foraging and nesting. Large aggregations increased foraging success such as higher capture rates and efficiencies (Cezilly *et al.*, 1990) and reduced energy expenditure (Master *et al.*, 1993). However, it is difficult to associate between the neighbour's presence and the concentration of food resources as the key contributor in increasing foraging efficiency. The probability of capturing prey, the relative sizes of available prey in different habitats, and intensity of competition are all likely to influence foraging decisions (MacCarone and Parsons, 1994). Foraging decisions in egrets are complex, it often involve different considerations that may be influenced by both biological and physical factors. For example, foraging decisions may be reflected by prey dispersion, the likelihood of prey detection and capture, and the energetic and nutritional values of different types of prey (Gawlik, 2002). Competition and threat of predation also affect foraging decisions (Cristol and Switzer, 1999). The most common factor determining foraging site selection in response to predation risk is the distance to cover (Walther and Gosler, 2001; Desrochers *et al*., 2002).

1.4. Species Description

1.4.1. Great Egret (*Casmerodius albus*)

It is the largest birds among egret species. It has white plumage, yellow dagger-like bill, dark olive-grey or sooty black feet and extremely long legs and neck (Figure 1.1). Facial skin is olive–yellow. Its size ranges from 85–102 cm, wingspan is 165–215 cm, and up to 1000 grams of body weight (Jones, 2002; Robson, 2008; Steele, 2011). During breeding season, the bill turns mostly black and the facial skin becomes green. It stalks in shallow waters or mud flats, walking slowly or quickly with their strong neck and when the prey is sighted, it will stretch out its neck to immediately snatch the prey. It feeds on molluscs, amphibians, aquatic invertebrates, small reptiles, crustaceans and occasionally other small animals but fish make up the bulk of its diet (Jones, 2002; Steele, 2011; Birdlife International, 2012c). It usually forages in water, wading through the shallows water or standing motionless before stabbing its prey. It also had been seen taking prey while flying. It prefers marshes, swampy areas, streams, rivers, ponds, lakes, mudflats, canals, and flooded fields (Jones, 2002; Birdlife International, 2012c).

Figure 1.1. Great Egret (*Casmerodius albus*)

1.4.2. Little Egret (*Egretta garzetta*)

Little egret is a small waterbird with pure white colour, plumes on crest, back and chest, bill and legs are black with yellow toes (Figure 1.2). Its size ranges from 55 to 65 cm, wing span from 88–95 cm, wing length vary from 24 to 30 cm and weigh may vary from 280 to 614 gm (Robson, 2008; McKenna, 2011). Male and female look alike. Breeding individuals have long breeding plumes (two droop at nape and a few lacy ones on the back and rump), bluish–green face and reddish lores. Little egret hunts fish, molluscs and invertebrates using a wide variety of techniques. It may patiently stalks their prey in shallow water or stands on one leg and stir the mud with the other to scare up prey, or stand on one leg and wave the other bright yellow foot over the water surface to lure aquatic prey into range.

Figure 1.2. Little Egret (*Egretta garzetta*)

1.4.3. Intermediate Egret (*Mesophoyx intermedia*)

Intermediate Egret is a medium sized bird measured from 65 to 77 cm long and weighs 105 to 115 gm (Wells, 1999). It looks similar to the Great Egret but much smaller. It has a rounded head and the orange bill is shorter and not so acutely angled (Figure 1.3). The neck is about the same length as the body. In breeding plumage it has deep pink to red bill, blue-green facial skin, long breast, and wing plumes extending beyond the tail. Breeding birds may have reddish or black bill, greenish yellow gape skin, with loose filamentous plumes on breast and back, and dull yellow or pink on the upper legs. It prefers shallow water, wet grasslands and pastures for foraging. It stalks its prey in shallow coastal or fresh water, including flooded fields. It eats fish, frogs, crustaceans and invertebrates (Hockey *et al.* 2005; Kushlan and Hancock, 2005).

Figure 1.3. Intermediate Egret (*Mesophoyx intermedia*)

1.4.4. Cattle Egret (*Bubulcus cormorandus*)

Cattle Egret (formerly known as *Bubulcus ibis*) is a small, gregarious bird with medium-size neck and small, sharp, and slightly down-curved yellow to pinkish bill (Figure 1.4). Its size ranges from 46 to 56 cm, wingspan ranges from 88 to 96 cm, wing length from 24 to 26 cm, tail length ranges from 8.3 to 9.6 cm and the weight is 270 to 512 gm (Krebs *et al.,* 2004; Robson, 2008). The legs and feet are light orange in colour. During breeding season, the adult develop buff feathers on head, back, and breast. In addition its legs and bills also become brighter. It can be found in grasslands, woodlands, wetlands, pastures and croplands, especially where the drainage is poor. Cattle Egret prefers grasshoppers, especially during breeding season but also eat various types of invertebrates. It also eats frogs, cane toads, lizards and some small mammals. Its sharp bill is used in a lunging and stabbing manner. It often feeds by following large animals such as cattle, grabbing invertebrates and worms that were disturbed by large animal's feet. It also sits on cattle to look out for invertebrates (Wells, 1999).

Figure 1.4. Cattle Egret (*Bubulcus cormorandus*)

1.4.5. Chinese Egret (*Egretta eulophotes*)

The body of this egret is generally white with shaggy crest, blue-green lores, orange-yellow bill, and black legs with yellow feet (Figure 1.5). This egret has 68 cm long crest on the head and yellow bill (Robson, 2008). Breeding adults have blue facial skin, shortest shaggy nape plumes, long back and breast plumes, blackish legs and greenish-yellow feet. It occurs in shallow tidal estuaries, mudflats and bays, occasionally visiting paddy-fields and fishponds. It feeds on mudflats and tidal flats with other herons and egrets. The diet includes small fish, molluscs, crustaceans, reptiles, amphibians, and large invertebrates. It often wades in shallow water when foraging. It roosts on rocky shores, islets or shingle banks. Chinese Egret is more active when foraging and use a variety of foraging techniques such as alternate walking and running through tidal-flat shallows, covering several hundred meters in a circuit. Other techniques include waiting and sometimes foot vibration. It is a threatened species and the greatest threat is habitat loss and degradation through reclamation of tidal flats and estuarine habitats for infrastructure, industry, aquaculture and agriculture, and pollution.

Figure 1.5. Chinese Egret (*Egretta eulophotes*)

1.5. Palm Oil Mill Effluent (POME) Ponds

Oil palm (*Elaeis guineensis*) is vastly cultivated as a source of cooking oil in Malaysia and currently has significantly contributed to the economic growth of the country. The Malaysian palm oil industry had grown rapidly over the years and Malaysia has become the world's second largest producer and exporter of palm oil and its products (41.3%, after Indonesia at 44.5%). By the year 2010, more than 4.8 million hectares of land are planted with oil palm, occupying more than one-third of the total cultivated area in Malaysia and 11% of the total land area (Malaysian Palm Oil Board, 2010a; Belai *et al*., 2011).

Malaysian palm oil industry holds two core advantages over other substitutes such as soybean and vegetable oils. Firstly, oil palm produces four to five tons of oil per hectare which is eight to ten times higher than other oilseeds such as rapeseed and soybean. Secondly, within the palm oil industry, Malaysian palm oil has three major strengths compared to competing global producers. These are; (i) highest average palm oil yields, i.e. about 21 tons per hectare per year, (ii) excellent plant breeding activities, i.e. 20 world-class seed producers and annual production capacity of 87 million seeds and its leading R & D activities such as researches in oil palm genome, tissue culture and biotechnology, and (iii) conducive regulatory environment, i.e. Malaysia's palm oil industry is regulated by Malaysian Palm Oil Board (MPOB), which awards licenses across the value chain from seed producers to export of palm oil as well as developing policies, guidelines and practices to monitor and assist the industry (Dompok, 2009). The palm oil industry is forecast to grow by 7.1 percent over the next ten years, driven by further gains in average productivity of fresh fruit bunch (FFB) yield and of the oil extraction rate (OER), which is currently at 20.5% (Dompok, 2009). The total exports of Malaysian oil palm products (constituting of palm oil, palm oil kernel, palm kernel cake, oleo chemicals and finished products) reached 20.13 million tons (Shian, 2007). Of this, the exports of Malaysian palm oil alone reached a commendable figure of 18.2 million tons (Zainudin, 2010; Gunstane, 2012).

The fresh fruit bunches (FFB) from the oil palm plantation have been harvested and sent to the palm oil mill for processing. It has been estimated that about 75.5 million tons of FFB have been processed in the Malaysia (Lau *et al.*, 2008). During this process, liquid effluent is generated from sterilization and classification processes in which large amounts of steam and hot water were used. Later, a significant amount of wastewater is produced, with high content of organic waste materials known as Palm Oil Mill Effluent (POME). POME is a thick liquid, yellowish to brownish colloidal suspension containing 95–96% of water, 0.6–0.7% of oil and 4–5% of total solids (Khalid and Wan Mustafa, 1992; Borja and Banks, 1994; Ma, 2000; Poh, 2008). It is an acidic wastewater with fairly high polluting properties, with an average of 25,000 mg/l biochemical oxygen demand (BOD), 55,250 mg/l chemical oxygen demand (COD) and 19,610 mg/l suspended solid (Shian, 2007). It is estimated that to process one ton of crude palm oil, approximately between 5 to7.5 tons of water is required and more than 50% of water end up as palm oil mill effluent (Ahmad *et al*., 2003).

The rapid development of palm oil industries in Malaysia after few years produced high amount of palm oil mill effluent (POME). It is estimated that 434 palm oil mills, 43 crushers, 52 refineries, 18 oleo–chemical plants and 25 biodiesel plants throughout the nation are generating 30 million tons of POME annually (Dompok, 2009; Malaysian Palm Oil Board, 2010a). Thus, the palm oil industry in Malaysia has been identified as a the largest polluter of rivers (Vairappan and Yen, 2008). For instance, 44 million tons of POME were produced and discharged into the rivers in 2008 (Wu *et al*., 2010).

POME ponds are a type of wetland and generally defined as a small and shallow water bodies that were constructed to trap the chemicals and sediment from palm oil mill effluent. The basic functions of these ponds are to speed up the natural processes by which water purifies itself through pond chain systems. The pond system has been applied in Malaysia for POME treatment since 1982 (Ma *et al.*, 1993). POME ponds provide a favourable foraging habitat for waterbirds especially egrets, herons, bitterns, ducks, plovers and also for some terrestrial birds such as mynas and crows (Lai *et al.*, 2007). The exposed compact waste materials in POME pond provide suitable foraging site while fallen dead trees offer loafing sites for birds. Although biological communities of POME ponds have been characterized and a number of biotic indices have been developed (Bella, 2005; Boix *et al*., 2005), little is known about how POME ponds are affecting waterbirds especially egrets diversity. Therefore, a detailed research on the roles of POME ponds in providing resources for birds is needed. This research will also provide information on the function of this wetland area in maintaining biodiversity.

1.6. Problem Statement

Egrets are an important component of wetland ecosystems and often exhibit distinct correlationship with their habitats (Kushlan and Hafner, 2000; McKenna, 2011; Steele, 2011). Apparently, information on egret foraging ecology (i.e. probing, walking slowly, walking quickly, lean and wait, stand and wait, stand and feed, wing flick, foot shuffle, gleaning, and aggressive behaviour), habitat characteristics and correlationship between the food resources and water quality parameters is scare. The habitat loss and degradation have caused the decline of many egret species around the world (Taylor & Pollard, 2008).

Malaysian wetland habitats are facing an overwhelming pressure from rapid development and urbanization (Asmawi *et al*., 2007). Anthropogenic activities have altered the wetland habitats in a variety of ways that consequently cause great threats to wetland birds (Gillespie, 2007). Following this, the future challenges for wetland conservation and management is estimating the wetland resources and monitoring the trends in egret populations where further decline may cause the extinction of egret species.

In general, information on the egret foraging ecology in POME ponds in Malaysia is lacking. No detailed study has been carried out in POME ponds of Malaysia to examine the egret foraging ecology and their importance for waterbird species. In fact, very little is known on the egret foraging ecology egrets in relation to habitat and food resource, i.e. what would happen to the egret species when their habitat is altered? Would the egret population be increased or decreased? Or would they move to other areas less suitable for foraging and breeding? Hence, it is crucially important to determine the egret foraging ecology in POME ponds within the context of ecological and spatial parameters to understand the egret foraging ecology and the effects of food resources on egrets distribution for effective conservation and better management.

1.7. Objectives

This study was conducted to document various ecological aspects of egrets that frequent POME ponds in Carey Island, Selangor, Peninsular Malaysia. The ponds are located within oil palm plantations and adjacent to mangrove area. The objectives of this study are:

(i) To determine relative abundance, diversity, richness and evenness of five egret species, i.e. Great Egret (*C. albus*), Little Egret (*E. garzetta*), Cattle Egret (*B.

cormorandus), Intermediate Egret (*M. intermedia*) and Chinese Egret (*E. eulophotes*) at four POME ponds.

(ii) To record and compare various foraging behaviours (such as probing, strike rates, and the efficiency of capturing prey items) displayed by five egret species that utilize POME ponds.

(iii) To examine the availability of food resources in four POME ponds to egrets (such as invertebrates, amphibians and small fishes) in order to understand the importance of POME ponds for egrets survival.

(iv) To measure water quality parameters (i.e. Dissolve Oxygen, pH, turbidity, electric conductivity, ammonium concentration, and temperature) in POME ponds and postulate the relationships between these parameters and availability of food resources for egrets.

1.8. Null Hypothesis

There is no detailed information on egret foraging ecology in the study area. Therefore, the null hypothesis were set to check whether there is a significant difference in egret foraging ecology among five different egret species utilizing POME ponds at Carey Island, Peninsular Malaysia. The null hypotheses in this study were:

H_0 = There is no difference in relative abundance and foraging ecology among five egret species, namely Little Egret (*Egretta garzetta*), Great Egret (*C. albus*), Intermediate Egret (*M. intermedia*), Cattle Egret (*B. cormorandus*) and Chinese Egret (*E. eulophotes*) based on food selection and foraging behaviour.

H_1 = There is no difference in food resources and water quality parameters among four POME ponds.

1.9. Why Egrets was Chosen?

Egrets are particularly a good subject for studying the foraging ecology because they are conspicuous, large and abundantly present in a wide variety of habitats. The information on egret foraging ecology (such as probing behaviour, striking rate, and food selection process), species distribution, and habitat requirements are highly important to understand the threats on egrets' survival and existence (Wilson, 2000; Steele, 2011). Egrets show a variety of tactics in exploiting available resources in different wetland areas in order to feed, stir, loaf and roost (Barbosa, 1995). In addition , foraging behavior, food selection and population dynamics of egrets can be compared between different sites and among different species.

Unfortunately, very little information on egret's ecology is available in Malaysia. Few studies on egret's ecology have been carried out. This includes population study of Cattle Egret (*Bubulcus ibis*) at the grassland area of the University Putra Malaysia (Maling, 1999), the effects of fishing activity of Pacific Reef Egrets (*E. sacra*) along Pulau Tioman coast (Ming and Rajathurai, 2011), and population dynamics of colonial waterbirds (including egrets) in Putrajaya Wetlands (Ismail and Rehman, 2012). It has been noted in many studies that insufficient knowledge posed major problem in avian conservation activities in tropical regions which lead to poor management (Brawn *et al*., 1998; Derrickson *et al*., 1998; Grajal and Stenquist, 1998). Therefore, there is an urgent need for investigating the foraging ecology of different egret species in order to understand their foraging behaviour and habitat preferences. In this study, the information related to foraging ecology of egrets such as probing intensities, strike rates, prey capturing tactics, aggressive behaviour, habitat selection, and the availability of food resources of egrets were documented. The information on foraging behavior, food selection and habitat preference contribute to the knowledge towards the conservation and protection of various sites that are potentially attractive to egrets or other waterbirds.

1.10. Research Framework

Chapter one provides detailed information on egrets background, distribution, habitat selection, diet and morphology. This chapter also describes the POME pond's, Problem Statement, Objective, Null Hypothesis, and why egrets were chosen to study the foraging ecology.

Chapter two described the egret species composition, relative abundance, diversity and habitat preferences in four POME ponds and how sampling of egret relative abundance was done. Results and discussion of egret distribution and diversity and their habitat preference in POME ponds at Carey Island were also presented.

Chapter three focuses on food resources on POME ponds and how food resources were sampled. How data of food resources was analyzed? Results (species composition, relative abundance, diversity and description of insect species) and discussion of results were also presented.

Chapter four focuses on foraging strategies of egrets employed in four POME ponds, the objectives and methodology (how foraging techniques were sampled and analyzed of this study). Results (type of foraging strategies employed by egrets while foraging) and discussion on foraging behavior of five egret species.

Chapter five contained information on POME pollution in Malaysia, current status of the palm oil mill industry, sampling of water quality of POME ponds, results and discussion of different water quality parameters of POME ponds and their effects on insects and egrets.

Chapter six provides general information on various aspects of foraging ecology of egrets, distribution, diversity and their association with food resources and water quality parameters in different wetland habitats particularly POME ponds of Malaysia.

CHAPTER 2

DIVERSITY AND ABUNDANCE OF EGRETS IN POME PONDS AREA

2.1. Introduction

Despite the richness in avifauna, POME pond habitats are rarely researched even for basic avian information such as species composition, relative abundance, and species diversity. Monitoring species abundance and diversity is highly important to understand avian community structure. This understanding will allow comparison of different habitats in determining the most preferable habitat for waterbirds such as egrets. Relative abundance is the percentage of individual numbers of particular species to total number in a particular area (Zakaria *et al*., 2009). Species diversity is a measure of the variation of species within an ecological community that incorporates both species richness (the number of species in a community) and the evenness of species' abundances (McGinley and Duffy, 2010). Species abundance and species diversity are key aspects in avian community structure because it indicates the number of different species and their richness in the dwelling area. For waterbirds such as egrets, species relative abundance and diversity are depending on water level, richness of food resources and suitability of foraging and rearing sites (Robertson and Liley, 1998).

Egrets are important components of wetlands and their abundance may indicate ecological conditions of particular habitat. They are predominantly associated with water and prefer a variety of habitats with shallow water such as wetlands, ponds, lakes, wastewater ponds, intertidal mudflats, estuaries, aquacultural ponds, agricultural fields and reservoirs. In these areas they mainly feed on diverse food sources that are available (Kushlan, 1993; Ogden, 1994; Frederick and Ogden, 2003). They wade in shallow water to catch a variety of aquatic animals with their bills (Yu-Seong *et al.*, 2008).

Regular population monitoring is a way to determine the changes in avian community parameters (Kirby *et al.*, 1995). Monitoring relative abundance and demographic rates (productivity, recruitment, survival) of egrets provide information on population changes and help in conservation and management actions. Information on egret's species abundance, distribution and habitat requirements is highly important to understand the threats to their survival and existence (Caughley, 1994; Green, 1995).

Carey island is rich in avian diversity with 65 species of bird have been recorded (Ramli *et al.*, 2006). From this, 31 species have been recorded in POME ponds area alone (Hassan-Aboushiba *et al*., 2011). Carey Island comprises of different habitats such as mangrove forests, mud flats, oil palm plantation, agricultural fields and rivers. Differences in habitat caused variation in microclimate (such as temperature, light intensity and relative humidity) and microhabitat characteristics (such as trees, shrubs and grasses) that potentially affects the distribution of egret species. Heterogeneous habitats seemed to provide wide ranges of resources for egrets such as refuge from predators, safe and suitable foraging, nesting and roosting sites.

The information on egret abundance and diversity in Malaysia is scarcely recorded. Few studies were conducted on population of Cattle Egret (Sat, 1999; Sheldon *et al.,* 2001) and Pacific Reef Egret (Ming and Rajathuari, 2011), the effects of water level fluctuations on waterbirds distribution and aquatic vegetation composition (Rajpar and Zakaria, 2011), and population dynamics of colonial waterbirds in Putrajaya Wetlands, Malaysia (Ismail and Rehman, 2012). Although there are about 434 palm oil mills throughout Malaysia that generate 30 million tons of POME (Malaysian Palm Oil Board, 2010), there is no information on egrets relative abundance and diversity in POME ponds area. Insufficient knowledge always resulted in inefficient conservation management and activities (Brawn *et al.*, 1998). Therefore this study was carried out to document egret species abundance and diversity in POME ponds area.

2.2. Objectives

The objectives of this study are;

1. To determine relative abundance and diversity of various species of egrets that utilizes POME ponds area.

2. To study egrets preferences towards four POME ponds based on information derived from relative abundance and species diversity.

2.3. MATERIALS AND METHODS

2.3.1. Study Site

This study was conducted in Carey Island, Selangor. The island is separated from the mainland by the Langat River but is connected by a bridge at Chondoi or Teluk Panglima Garang near Banting. The island is located in the Kuala Langat district, in the state of Selangor, Peninsular Malaysia (Figure 2.1). It is located south to Port Klang and north to the Klang River (101°22′E and 2°52′N). Carey Island encompasses of 15,000ha. Most of the island area (80%) belongs to Sime Darby Plantation Berhad while the remaining is a state land. The island is two meters below sea level (during high tide) and encompass of diverse habitats such as narrow seashore, mudflats, sandy beach and mangrove swamp area. A total of 65 bird species has been recorded, out of which 44 species are residents, 12 species are migrants, 7 species are resident–migratory and 2 are introduced species (Ramli *et al.*, 2006).

There are four POME ponds available in the Carey Island (Figure 2.2–2.6). Each pond possesses different characteristics in term of size, water level, floating materials, vegetation covers and water physical parameters. Four POME ponds were selected due to the difference in water depth, water quality, organic floating material (effluent of oil mill) and vegetation structures to test which factors affecting the occurrence and distribution of egret species and also to examine which type of POME pond is more suitable as a foraging site for egret species (Table 2.1 and Figure 2.3 to 2.26).

Table 2.1: Comparison of four POME pond characteristics in Carey Island

Name of	Area (acre)	Water Depth (ft)	Surface Feature	Vegetation
Pond No. 1	1.05	3ft	Dominated by dense organic compacted waste material	Cattail (*Typha* sp.), Blush Macaranga (*Macaranga tanarius*), Oil Palm (*Elaeis guineensis*), Mangroves *Avicennia marina* and *Rhizophora apiculata*
Pond No. 2	1.00	4ft	Contained small size floating compacted organic waste materials	Cattail (*Typha* sp.), Blush Macaranga (*Macaranga tanarius*), Oil Palm (*Elaeis guineensis*),
Pond No. 3	1.17	3ft	Contained dead fallen trees and have small mud mounds in the center	Climbing Fern (*Stenochlaena palustris*) Three Square Bulrush (*Scirpus olneyi*).
Pond No. 4	1.25	5ft	Fully covered with algae	Climbing Fern, Blush Macaranga and Oil Palm trees.

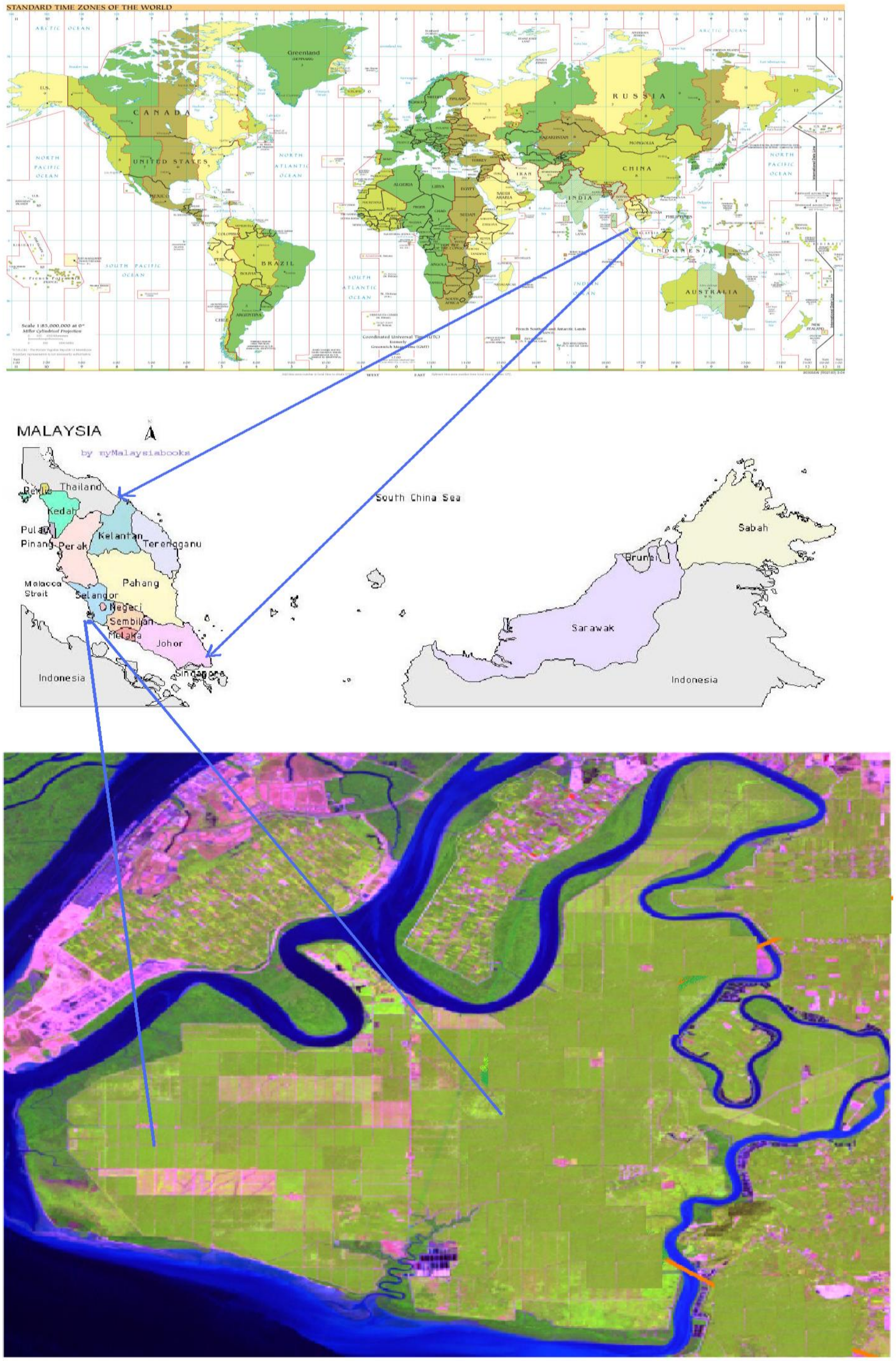

Figure 2.1. Location of study site in Carey Island, Selangor, Peninsular Malaysia

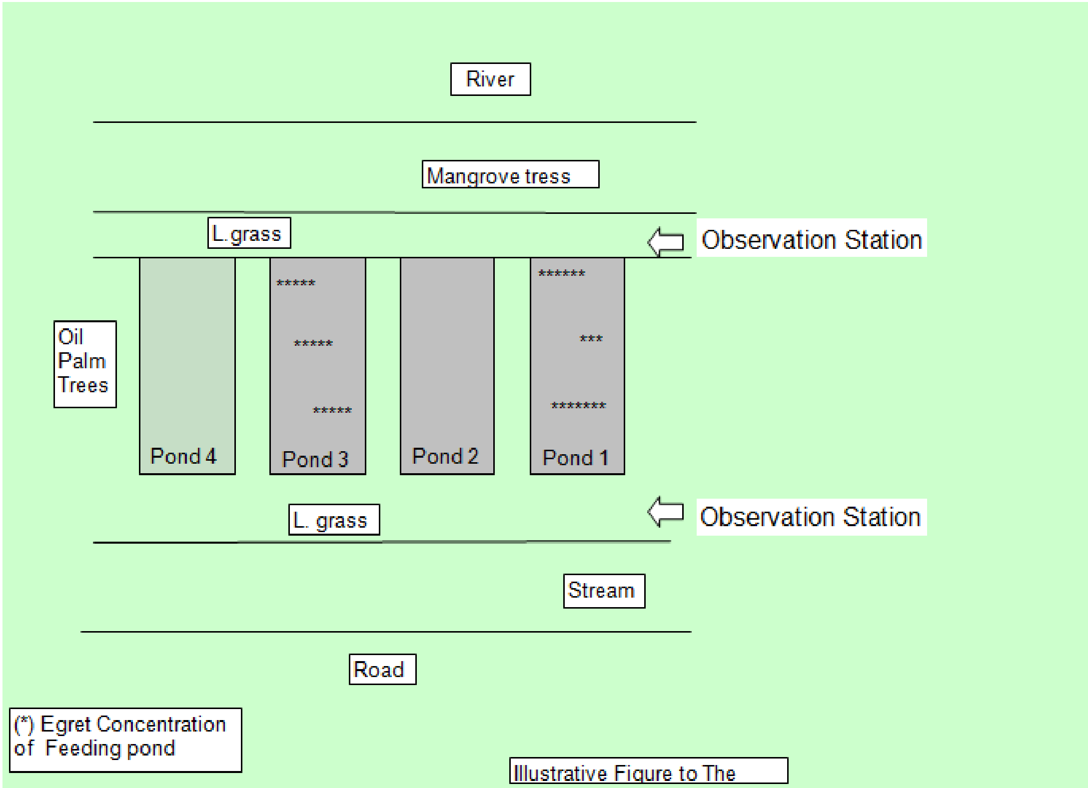

Figure 2.2: Location of POME ponds in Carey Island, Selangor, Peninsular Malaysia

Figure 2.3: Condition of POME pond number one of Carey Island, Selangor, Peninsular Malaysia

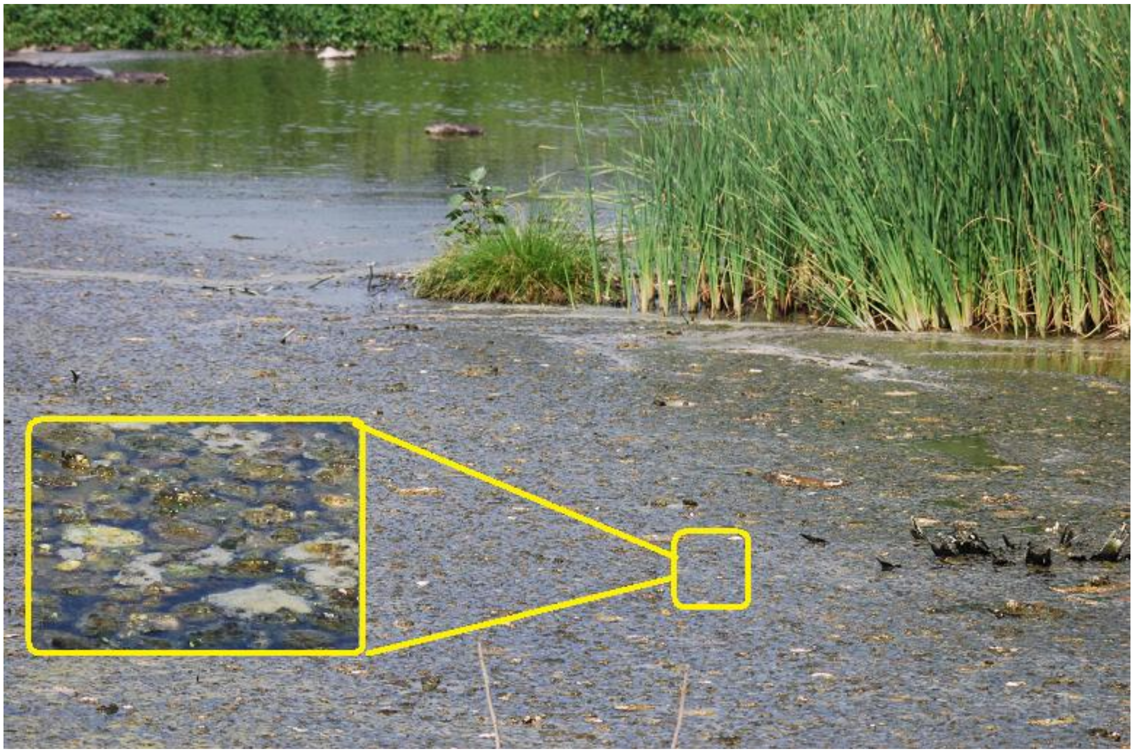

Figure 2.4: Condition of POME pond number two of Carey Island, Selangor, Peninsular Malaysia

Figure 2.5: Condition of POME pond number three of Carey Island, Selangor, Peninsular Malaysia

Figure 2.6: Condition of POME pond number four of Carey Island, Selangor, Peninsular Malaysia

2.3.2. Egrets Surveys

Bird survey was carried out at four POME ponds in Carey Island, Selangor, Peninsular Malaysia from January to December 2008 (detail field visits as presented in Bird survey schedule (Table 2.2). Direct observation method was used to determine species composition, relative abundance, and habitat preferences. Presence of egrets was recorded using binoculars (with 10X42 magnification) and magnify camera on hourly basis. Monthly and hourly egret's relative abundance were determined to understand the fluctuation in species abundance and peak period for habitat utilization. In addition, the hourly sighting of all egret species was also recorded to understand the fluctuation in relative abundance of each species during the day. The observation was carried out along the pond banks due to easy access. Observation session started at 0900 hours and ended at 1800 hours once a week for twelve consecutive months. Details about this methodology have been described in details by Tojo (1996), Richardson *et al.* (2001), and Yu-Seong *et al.* (2008).

Table 2.2: Bird Surveys Schedule.

Months	**Date**	**Number of days**	**Observations /hours**
January	2, 9, 16, 23, 30	5	36
February	6, 13, 20, 27	4	31
March	5, 12, 19, 26	4	34
April	2, 9, 16, 23, 30	5	35
May	7, 14, 21, 28	4	28
June	4, 11, 18, 25	4	33
July	2, 9, 16, 23	4	35
August	6, 13, 20, 27	4	34
September	3, 10, 17, 24	4	28
October	1, 8, 15, 22	4	32
November	5, 13, 20, 27	4	28
December	3, 10, 17, 24	4	31
	Total	**50**	**385**

2.4. Data Analysis

2.4.1. Egrets Relative Abundance

The relative abundance of five egret species at four POME ponds of Carey Island was determined using following expression:

$$n/N \times 100$$

Where n = number of particular egrets species and N = total number of recorded egrets individuals.

2.4.2. Analysis of Variance

The relative abundance of five egret species, i.e. Little Egret (*Egretta garzetta*), Great Egret (*C. albus*), Intermediate Egret (*M. intermedia*), Cattle Egret (*B. cormorandus*) and Chinese Egret (*E. eulophotes*) was compared using analysis of variance (ANOVA) and Tukey's (HSD) test. These tests were also used to compare the significant differences in egret's relative abundance among four POME ponds. ANOVA is a collection of statistical models, and their associated procedures, in which the observed variation in a particular variable is partitioned into components attributable to different sources of variation. Analysis of variance is a systematic procedure for obtaining two or more estimates of variance and comparing them. It is a powerful statistical technique that involves partitioning the observed variance into different components to conduct various significance tests (Montgomery, 2001).

The total variance of an observed data set is estimated using the following relationship:

$$s^2 = \frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n-1}$$

Where s is the standard deviation, y_i is the ith observation, n is the number of observations, and $\bar{y}$ is the mean of the n observations.

It is the sum of the deviations of all observations, Yi, from their mean, $\bar{y}$. The value in the numerator of the above equation is called the sum of squares. In the context of ANOVA, this value is called the total sum of squares (abbreviated SS_T) because it relates to the total variance of the observations. The denominator in the relationship of the sample variance is the number of degrees of freedom associated with the sample variance. The number of degrees of freedom associated with SS_T, dof (SS_T), is n-1. The sample variance is also referred to as a mean square because it is obtained by dividing the sum of squares by the respective degrees of freedom. Therefore, the total mean square (abbreviated MS_T) is:

$$MS_T = \frac{SS_T}{dof(SS_T)} = \frac{SS_T}{n-1}$$

Tukey "Honestly Significantly Different" (HSD) test was used to compare the mean of foraging strategy / minute of five egret species at POME ponds.

$$t_s = \frac{M_i - M_j}{\sqrt{\frac{MSE}{n_h}}}$$

Where, M_i - M_j is the difference between the i_{th} and j_{th} means, MSE (Mean Square Error), and n_h is the harmonic mean of the sample sizes of groups i and j. The Tukey HSD test was used because it keeps the EER (Experiment wise Error Rate) at the specified significance level (Altman, 1991; Bland and Altman, 1995; Montgomery, 2001).

2.4.3. Tukey's HSD Test

A multiple comparison procedure developed by Tukey is frequently used for testing the null hypothesis that all possible pairs of treatment means are equal when all samples are of the same size. Tukey's test, is usually referred to as the HSD (Honestly Significant Difference) test, makes use of a single value against all differences. This value, called the HSD, is calculated following this formula;

$$\mathrm{HSD} = q_{\alpha, k, N-k} \sqrt{\frac{\mathrm{MSE}}{n}}$$

where alpha is the chosen level of significance, k is the number of means in the experiment, N is the total number of observations in the experiment, n is the number of observations in a treatment, MSE is the error or within mean square.

2.4.4. Egrets Species Diversity

Species diversity incorporates the numbers of species and its relative abundance in an area. The index provides information about community structure such as rarity and commonness of a species than simply species richness. Diversity is a major aspect of species structure in an avian community because it indicates the importance of each habitat for different bird species.

The diversity value of egrets at all POME ponds was analyzed using the Community Analysis Package (CAP; Version 4.0) by Henderson and Seaby (2007). This analysis calculates diversity indices such as species diversity, species richness, and species evenness. These indices are used in understanding the pond's preferences by each egret species.

A diversity index is a mathematical measure of species variation in a community. Species diversity is an index that incorporates not only the numbers of species in an area but also takes into account species relative abundance. Therefore the index provides more information about community composition such as rarity and commonness of a species in a community. Two types of diversity indices were used in this study. These are:

i) Shannon's diversity index:

$$H = - \Sigma (n_i/n) \ln (n_i/n)$$

Where $n_i = \Sigma$ individuals of species i, and $n = \Sigma$ individuals of all species.

Species richness is the number of different species in a given area. It also provides information on homogeneity and rarity of species.

ii) Margalef's richness index:

$$R = S-1/\ln (n)$$

where $S = \Sigma$ species in plot; $n = \Sigma$ individuals of all species.

Evenness is a measure of the relative abundance of different species of the particular area.

2.5. RESULTS

2.5.1. Species Composition

A total of 14,077 sightings of five egrets species were recorded at four POME ponds in Carey Island. Little Egret was the most sighted species (5,608 observations; 39.84%) while Chinese Egret was the rarest sighted species (328 observations; 2.33%) in the study area. The variation in relative abundance of egrets is due to differences in residency status, i.e. between resident and migratory birds. Resident species such as Little and Great Egrets visit POME areas throughout the year while migratory species such as Cattle, Intermediate and Chinese Egrets visit POME areas only during migratory season, i.e. from September to March (Table 2.3).

Table 2.3: Relative abundance of egrets sighted in POME ponds from January to December, 2008.

	Common Name	Scientific Name	Total Observations	%
1	Little Egret	*E. garzetta*	5608	39.84
2	Great Egret	*C. albus*	4559	32.39
3	Cattle Egret	*B. cormorandus*	2260	16.05
4	Intermediate Egret	*M. intermedia*	1322	9.39
5	Chinese Egret	*E. eulophotes*	328	2.33
		Total	**14077**	

2.5.2. Hourly Relative Abundance

The results indicated that egrets were active during morning, i.e. from 0900 to 1000 hours (3,144 observations or 22.33%) and from 1000 to 1100 hours (2,609 observations or 18.54%) compared to afternoon, i.e. from 1600 to 1700 hours (1,351 observations or 9.60%) and mid-day i.e. from 1300 to 1400 hours (805 observations or 5.72%). Findings also revealed that egret's relative abundance varies during twelve months period due to the arrival and departure of migrant species. The highest egrets relative abundance was recorded in January (2140 sightings; 15.20%), February (1785 sightings; 12.68%), December (1753 sightings; 12.45%) and November (1640 sightings; 11.65%) respectively. In contrast, low relative abundance of egrets was detected in June (367 sightings; 2.61%), July (326 sightings; 2.32%) and August (321 sightings; 2.28%) (Table 2.4 and 2.5).

Table 2.4: Hourly and monthly relative abundance of all egret's species sighted at POME ponds in Carey Island.

Time (hours)	**MONTHS**												**TOTAL**	**%**
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
0900-1000	448	389	332	173	141	99	92	85	294	377	353	361	**3144**	22.33
1000-1100	389	319	277	143	105	74	68	67	245	308	308	306	**2609**	18.54
1100-1200	312	279	243	111	67	50	53	49	189	240	257	238	**2088**	14.83
1200-1300	203	142	153	53	42	33	27	27	141	130	157	173	**1281**	9.10
1300-1400	150	104	77	43	16	18	20	21	75	88	94	99	**805**	5.72
1500-1600	155	138	104	59	30	19	12	17	110	111	122	140	**1017**	7.22
1600-1700	209	186	129	80	44	30	23	21	145	145	149	190	**1351**	9.60
1700-1800	274	228	167	111	71	44	31	34	188	188	200	246	**1782**	12.66
TOTAL	**2140**	**1785**	**1482**	**773**	**516**	**367**	**326**	**321**	**1387**	**1587**	**1640**	**1753**	**14077**	

Table 2.5: Monthly relative abundance of resident and migrant egret's species sighted at POME ponds in Carey Island

Name of Species	MONTHS												TOTAL
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	
Resident Egrets													
Little Egret	809	600	532	431	282	197	193	197	573	600	603	610	5627
Great Egret	679	531	457	342	234	170	133	143	387	467	503	513	4559
Sub-Total	**1488**	**1131**	**989**	**773**	**516**	**367**	**326**	**340**	**960**	**1067**	**1106**	**1123**	**10186**
Migrant Egrets													
Cattle Egret	402	416	302	0	0	0	0	0	270	300	310	260	2260
Intermediate Egret	188	189	151	0	0	0	0	0	122	180	180	312	1322
Chinese Egret	62	49	40	0	0	0	0	0	35	40	44	58	328
Sub-Total	**652**	**654**	**493**	**0**	**0**	**0**	**0**	**0**	**427**	**520**	**534**	**630**	**3910**

2.5.3. Monthly and Hourly Relative Abundance

2.5.3.1. Monthly and Hourly Relative Abundance of Little Egret

The highest relative abundance of Little Egret was recorded in January (809 observations or 14.42%) but other months also show higher egrets abundance. These include December (610 observations or 10.87%), November (603 observations or 10.75%), February and October (600 observations or 10.70% each). On contrary, the rarest relative abundance of Little Egret was recorded in July (193 observations or 3.43%), June and August (each 197 observations or 3.50%). It was also observed that Little Egret was heavily used POME ponds in the morning from 0900 to 1000 hours (1,168 detections or 20.83%) and rarely used the pond during mid-day, i.e. from 1300 to 1400 hours (354 detections or 6.31%) (Table 2.6).

2.5.3.2. Monthly and Hourly Relative Abundance of Great Egret

Great Egret heavily used POME ponds in January (679 observations or 14.89%) and rarely used the area in July (133 observations or 2.92%). The results showed that Great Egret was mostly abundant at POME pond during morning hours i.e. from 0900 to 1000 hours (998 sightings or 21.89%) and from 1000 to 1100 hours (838 sightings or 18.38%). Relative abundance was low from 1300 to 1400 hours (238 sightings or 5.22%) (Table 2.7).

Table 2.6: Monthly and hourly relative abundance of Little Egret 2008

Time (hours)	**MONTHS**												**TOTAL**	**%**
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
0900-1000	147	124	109	89	74	54	58	49	104	118	113	129	**1168**	20.83
1000-1100	129	106	92	74	56	41	39	38	93	98	98	113	**977**	17.42
1100-1200	112	94	83	63	32	29	31	26	80	74	86	79	**789**	14.07
1200-1300	98	56	69	26	22	18	22	21	69	63	75	56	**595**	10.61
1300-1400	82	33	28	33	8	6	12	13	31	38	38	32	**354**	6.31
1500-1600	59	39	39	41	17	10	3	6	50	54	49	49	**416**	7.42
1600-1700	78	65	47	49	28	14	11	9	64	68	63	65	**561**	10.00
1700-1800	104	83	65	56	45	25	17	16	82	87	81	87	**748**	13.34
TOTAL	**809**	**600**	**532**	**431**	**282**	**197**	**193**	**197**	**573**	**600**	**603**	**610**	**5627**	

Table 2.7: Monthly and hourly relative abundance of Great Egret 2008

Time	**MONTHS**												**TOTAL**	**%**
(hours)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
0900-1000	138	114	89	84	67	45	34	36	90	104	97	100	**998**	21.89
1000-1100	129	89	76	69	49	33	29	29	75	88	89	83	**838**	18.38
1100-1200	99	76	68	48	35	21	22	23	58	67	68	65	**650**	14.26
1200-1300	78	53	55	27	20	15	5	5	34	42	52	56	**442**	9.70
1300-1400	33	32	28	10	8	12	8	8	15	26	33	25	**238**	5.22
1500-1600	46	47	37	18	13	9	9	11	29	33	43	44	**339**	7.44
1600-1700	69	56	45	31	16	16	12	13	37	48	49	62	**454**	9.96
1700-1800	87	64	59	55	26	19	14	18	49	59	72	78	**600**	13.16
TOTAL	**679**	**531**	**457**	**342**	**234**	**170**	**133**	**143**	**387**	**467**	**503**	**513**	**4559**	

2.5.3.3. Monthly and Hourly Relative Abundance of Cattle Egret

Cattle Egret was abundant in February (416 sightings or 18.41%) and January (402 observations or 17.78%) but none was observed from April to August. Since this species is migratory, it only visits POME ponds area during migratory season (i.e. from September to March). The results also highlighted that the relative abundance of Cattle Egret may varies during the day (e.g. highest relative abundance of Cattle Egret was recorded from 0900 to 1000 hours (576 sightings or 25.49%), followed by 1000 to 1100 hours (487 sightings or 21.55%), and 1100 to 1200 hours (415 sightings or 18.36%). In contrast, no individual of Cattle Egret was observed from April to August, because they only arrived from September until March. Few egrets are active during mid-day from 1200 to 1300 hours (103 detections or 4.56%) (Table 2.8).

Table 2.8: Monthly and hourly relative abundance of Cattle Egret 2008

Time (hours)	MONTHS												TOTAL	%
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
0900-1000	99	97	84	0	0	0	0	0	64	91	89	52	**576**	25.49
1000-1100	87	82	71	0	0	0	0	0	52	76	76	43	**487**	21.55
1100-1200	72	75	63	0	0	0	0	0	32	68	69	36	**415**	18.36
1200-1300	12	15	9	0	0	0	0	0	25	4	8	30	**103**	4.56
1300-1400	18	23	13	0	0	0	0	0	20	9	12	16	**111**	4.91
1500-1600	29	31	16	0	0	0	0	0	17	13	15	21	**142**	6.28
1600-1700	36	42	21	0	0	0	0	0	26	16	18	27	**186**	8.23
1700-1800	49	51	25	0	0	0	0	0	34	23	23	35	**240**	10.62
TOTAL	**402**	**416**	**302**	**0**	**0**	**0**	**0**	**0**	**270**	**300**	**310**	**260**	**2260**	

2.5.3.4. Monthly and Hourly Relative Abundance of Intermediate Egret

Intermediate Egret is a migratory species. It visits Malaysian wetland areas such as POME ponds areas from September to March. The results highlighted that the relative abundance of Intermediate Egret may vary during the day (i.e. a total of 312 observations or 23.60%) and month (Intermediate egret was recorded in December but none was recorded during the period of April to August). During these months Intermediate Egret went back to their native habitat. Daily relative abundance for Intermediate Egret was recorded highest during morning, from 0900 to 1000 hours (319 observations or 24.13%) and 1000 to 1100 hours (243 observations or 18.38%). On contrary, the lowest daily relative abundance of Intermediate Egret was recorded during mid-day (i.e. from 1300 to 1400 hours; 78 sightings or 5.90%) (Table 2.9).

2.5.3.5. Monthly and Hourly Relative Abundance of Chinese Egret

A total of 62 observations or 18.90% of Chinese Egret were recorded in January and no individual was recorded from April to August. Chinese Egret prefer to use POME ponds from 0900 to 1000 hours (83 observations or 25.30%) and from 1700 to 1800 hours (77 observations or 23.48%) and rarely utilized the POME ponds during mid-day (i.e. from 1200 to 1300 hours; 23 observations or 7.01%). This indicates that this egret was actively foraged in POME ponds only during morning hours and their activities were reduced during afternoon, due to rise in temperature which forced them to the surrounding mangrove areas for perching or loafing (Table 2.10).

Table 2.9: Monthly and hourly relative abundance of Intermediate Egret 2008

Time (hours)	**MONTHS** JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**TOTAL**	**%**
0900-1000	49	45	39	0	0	0	0	0	26	51	41	68	**319**	24.13
1000-1100	32	34	30	0	0	0	0	0	17	37	36	57	**243**	18.38
1100-1200	20	29	23	0	0	0	0	0	14	24	28	49	**187**	14.15
1200-1300	8	15	18	0	0	0	0	0	10	19	21	26	**117**	8.85
1300-1400	13	10	5	0	0	0	0	0	8	14	8	20	**78**	5.90
1500-1600	17	13	9	0	0	0	0	0	12	9	12	23	**95**	7.19
1600-1700	21	19	12	0	0	0	0	0	16	11	15	29	**123**	9.30
1700-1800	28	24	15	0	0	0	0	0	19	15	19	40	**160**	12.10
TOTAL	**188**	**189**	**151**	**0**	**0**	**0**	**0**	**0**	**122**	**180**	**180**	**312**	**1322**	

Table 2.10: Monthly and hourly relative abundance of Chinese Egret 2008

Time (hours)	**MONTHS**												**TOTAL**	**%**
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
0900-1000	15	9	11	0	0	0	0	0	10	13	13	12	**83**	25.30
1000-1100	12	8	8	0	0	0	0	0	8	9	9	10	**64**	19.51
1100-1200	9	5	6	0	0	0	0	0	5	7	6	9	**47**	14.33
1200-1300	7	3	2	0	0	0	0	0	3	2	1	5	**23**	7.01
1300-1400	4	6	3	0	0	0	0	0	1	1	3	6	**24**	7.32
1500-1600	4	8	3	0	0	0	0	0	2	2	3	3	**25**	7.62
1600-1700	5	4	4	0	0	0	0	0	2	2	4	7	**28**	8.54
1700-1800	6	6	3	0	0	0	0	0	4	4	5	6	**77**	23.48
TOTAL	**62**	**49**	**40**	**0**	**0**	**0**	**0**	**0**	**35**	**40**	**44**	**58**	**328**	

2.5.4. Monthly Variation in Egrets Relative Abundance

The highest egrets relative abundance was recorded in January (2140 observations or 15.20%) and the lowest relative abundance was recorded in August (321 observations or 2.28%). Little Egret was the most abundant (5608 sightings or 39.84%) and Chinese Egret was the rarest (328 sightings or 2.33%) species in POME ponds. The fluctuation in egret's relative abundance is due to the arrival and departure of migratory species such as Cattle Egret, Intermediate Egret and Chinese Egret (Table 4.10). The relative abundance of Cattle Egret, Intermediate Egret and Chinese Egret was significantly different from Little Egret and Great Egret ($F_{4, 55} = 17.58$, $P < 0.05$) (Table 2.11 and Appendix 2.1).

2.5.5. Variation in Egrets Relative Abundance According to the Ponds.

The results highlighted that pond number one and three were heavily used by egrets (8,680 observations or 61.66% and 5,397 observations or 38.34% respectively). Little egret was the most abundant species and Cattle egret was the rarest species. However, no egrets were seen utilizing pond number two and four (Table 2.12).

Table 2.11: Monthly variation in egret's relative abundance at Carey Island 2008

Months	Little Egret	Great Egret	Cattle Egret	Intermediate Egret	Chinese Egret	Total Sightings	%
January	809	679	402	188	62	2140	15.20
February	600	531	416	189	49	1785	12.68
March	532	457	302	151	40	1482	10.53
April	431	342	0	0	0	773	5.49
May	282	234	0	0	0	516	3.67
June	197	170	0	0	0	367	2.61
July	193	133	0	0	0	326	2.32
August	178	143	0	0	0	321	2.28
September	573	387	270	122	35	1387	9.85
October	600	467	300	180	40	1587	11.27
November	603	503	310	180	44	1640	11.65
December	610	513	260	312	58	1753	12.45
Total	**5608**	**4559**	**2260**	**1328**	**328**	**14077**	**100.00**

Table 2.12: Comparison of relative abundance of five egret species recorded at POME ponds of Carey Island.

Name of Species	**Mean Relative Abundance**	**Standard Deviation**
Little Egret	467.33 a	207.53
Great Egret	379.92 a	176.48
Cattle Egret	188.33 b	172.37
Intermediate Egret	110.17 b	106.71
Chinese Egret	27.33 b	25.24

(Mean values in columns bearing same letter are not significant at $p = 0.05$, Tukey's HSD test.

2.5.5.1. Relative Abundance of Little Egret among Four POME Ponds for Twelve Consecutive Months

A total of 5,608 observations (36.68% of all detections) of Little Egret were recorded for 12 consecutive months from January to December, 2008. The highest relative abundance was recorded in POME pond number one (3455 observations or 61.61%) and POME pond number three (2153 observations or 38.39%). However, none of the Little Egret was recorded in pond number two and pond number four. The highest relative abundance for Little Egret was recorded in January (809 observations or 14.43%) and the lowest relative abundance was recorded in August (178 observations or 3.17%) (Table 2.13).

Table 2.13: Monthly relative abundance of Little Egret among four POME ponds of Carey Island in 2008

Month	Pond 1	Pond 2	Pond 3	Pond 4	Total	%
January	438	0	371	0	809	14.43
February	387	0	213	0	600	10.70
March	351	0	181	0	532	9.49
April	285	0	146	0	431	7.69
May	158	0	124	0	282	5.03
June	142	0	55	0	197	3.51
July	128	0	65	0	193	3.44
August	104	0	74	0	178	3.17
September	380	0	193	0	573	10.22
October	358	0	242	0	600	10.70
November	341	0	262	0	603	10.75
December	383	0	227	0	610	10.88
Total	**3,455**	**0**	**2,153**	**0**	**5,608**	**100.00**

2.5.5.2. Relative Abundance of Great Egret in Four POME Ponds for Twelve Consecutive Months

A total of 4,559 sightings (29.82% of all detections) of Great Egret were recorded at four POME ponds during study period. The results indicated that Great Egret prefers pond number one (2,817 sightings or 61.79%) and pond number three (1742 sightings or 38.21%) and avoided pond number two and pond number four. The highest relative abundance of Great Egret was recorded in January (679 detections or 14.89%) and the lowest relative abundance was recorded in July (133 detections or 2.92) (Table 2.14).

2.5.5.3. Relative Abundance of Cattle Egret at Four POME Ponds for Twelve Consecutive Months

The highest relative abundance of Cattle Egret was recorded in POME pond number one (1400 observations or 61.95%) and POME pond number three (860 observations or 38.05%). No Cattle Egret was recorded in pond number two and pond number four. The highest relative abundance of Cattle Egret was recorded in February (416 observations or 14.89%) and none was recorded from April to August (Table 2.15).

Table 2.14: Monthly relative abundance of Great Egret among four POME ponds of Carey Island.

Month	Pond 1	Pond 2	Pond 3	Pond 4	Total	%
January	408	0	271	0	679	14.89
February	328	0	203	0	531	11.65
March	274	0	183	0	457	10.02
April	213	0	129	0	342	7.50
May	165	0	69	0	234	5.13
June	113	0	57	0	170	3.73
July	78	0	54	0	133	2.92
August	102	0	39	0	143	3.14
September	249	0	138	0	387	8.49
October	270	0	197	0	467	10.24
November	293	0	213	0	503	11.03
December	324	0	189	0	513	11.25
Total	**2,817**	**0**	**1,742**	**0**	**4,559**	**100.00**

Table 2.15. Monthly relative abundance of Cattle Egret utilizing four POME ponds in Carey Island.

Months	Pond 1	Pond 2	Pond 3	Pond 4	Total No	%
January	259	0	143	0	402	17.79
February	249	0	167	0	416	18.41
March	174	0	128	0	302	13.36
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	0	0	0	0	0	0
July	0	0	0	0	0	0
August	0	0	0	0	0	0
September	165	0	105	0	270	11.95
October	181	0	119	0	300	13.27
November	202	0	108	0	310	13.72
December	170	0	90	0	260	11.50
Total	**1,400**	**0**	**860**	**0**	**2,260**	**100.00**

2.5.5.4. Relative Abundance of Intermediate Egret at Four POME Ponds for Twelve Consecutive Months

A total of 1,322 sightings of Intermediate Egret (i.e. 9.39% of all observations) were recorded at four POME ponds throughout study period. Most of the Intermediate Egret were recorded in pond number one (805 observations or 60.89%) and pond number three (517 observations or 39.11%) and no individual was sighted at pond number two and four. Intermediate Egret was frequently recorded in December (312 observations or 23.60%) but none was recorded from April to August (Table 2.16).

2.5.5.5. Relative Abundance of Chinese Egret at Four POME Ponds

Three hundred and twenty eight sightings of Chinese Egret were recorded in all POME ponds. The highest relative abundance of Chinese Egret was recorded in pond number one (222 detections or 67.68%) and three (106 detections or 32.32%), but no individual of Chinese Egret was recorded in pond number two and four. The highest relative abundance of Chinese Egret was recorded in January (62 detections or 18.90%) and December (58 detections or 17.68%). In contrast, no Chinese Egret was recorded from April to August (Table 2.17).

Table 2.16. Monthly relative abundance of Intermediate Egret in four POME ponds.

Month	Pond 1	Pond 2	Pond 3	Pond 4	Total	%
January	109	0	79	0	188	14.22
February	119	0	70	0	189	14.31
March	88	0	63	0	151	11.42
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	0	0	0	0	0	0
July	0	0	0	0	0	0
August	0	0	0	0	0	0
September	79	0	43	0	122	9.23
October	104	0	76	0	180	13.62
November	117	0	63	0	180	13.62
December	189	0	123	0	312	23.60
Total	**805**	**0**	**517**	**0**	**1,322**	**100.00**

Table 2.17. Monthly relative abundance of Chinese Egret at four POME ponds

Month	Pond 1	Pond 2	Pond 3	Pond 4	Total	%
January	46	0	16	0	62	18.90
February	34	0	15	0	49	14.94
March	29	0	11	0	40	12.20
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	0	0	0	0	0	0
July	0	0	0	0	0	0
August	0	0	0	0	0	0
September	23	0	12	0	35	10.67
October	26	0	14	0	40	12.20
November	25	0	19	0	44	13.41
December	39	0	19	0	58	17.68
Total	**222**	**0**	**106**	**0**	**326**	**100.00**

2.6. Egrets Diversity

2.6.1. Egrets Diversity among Four POME Ponds

Diversity analysis shows that POME pond number one had the highest species diversity (N_1 = 3.82) and species evenness (E = 0.83) compared to POME pond number three. In contrast, the highest species richness was also recorded in pond number three (R_1 = 0.46) compared to POME pond number one. The diversity value for pond number two and four was not analyzed because no egret was sighted (Table 2.18).

2.6.2. Diversity of Little Egret in all Ponds

The highest value of species diversity and species evenness of Little Egret was recorded in pond number one (N_1 = 10.97 and E = 0.96 respectively). Highest species richness for Little Egret was recorded in pond number three (R_1 = 1.43). The diversity value in pond number two and pond number four was not calculated because no Little Egret was sighted (Table 2.19).

Table 2.18. Diversity of egrets among four POME ponds in Carey Island.

Indices	Pond 1	Pond 2	Pond 3	Pond 4
Diversity indices				
Shannon's index (N_1)	3.82	0	3.68	0
Simpson's index (N_2)	3.36	0	3.33	0
Richness indices				
Margalef's index (R_1)	0.44	0	0.46	0
Menhinik's index (R_2)	0.05	0	0.06	0
Evenness indices				
McIntosh's index (E)	0.82	0	0.81	0
Pielou's J index (E)	0.83	0	0.82	0

Table 2.19. Diversity indices value of Little Egret utilizing four POME ponds in Carey Island.

Indices	POME 1	POME 2	POME 3	POME 4
Diversity indices				
Shannon's index (N_1)	10.97	0	10.56	0
Simpson's index (N_2)	10.37	0	9.67	0
Richness indices				
Margalef's index (R_1)	1.35	0	1.43	0
Menhinik's index (R_2)	0.20	0	0.26	0
Evenness indices				
McIntosh's index (E)	0.70	0	0.69	0
Pielou's J index (E)	0.96	0	0.95	0

2.6.3. Diversity of Great Egret in all POME Ponds

Highest values of species diversity (N_1 = 10.92) and species evenness (E = 0.97) of Great Egret were recorded in pond number one. Highest species richness of Great Egret was recorded in pond number three (R_1 = 1.47). Diversity values of Great Egret in pond number two and pond number four were not analyzed because no egret was sighted (Table 2.20).

2.6.4. Diversity of Intermediate Egret in all POME Ponds

The highest species diversity (N_1 = 6.74) and species evenness (J E = 0.77) for Intermediate Egret was recorded in pond number one. Highest species richness of Intermediate Egret was recorded in pond number three (R_1 = 0.96). The diversity of Intermediate Egret in pond number two and pond number four was not calculated because no egrets were sighted (Table 2.21).

Table 4.20. Diversity of Great Egret in all POME ponds of Carey Island.

Indices	POME 1	POME 2	POME 3	POME 4
Diversity indices				
Shannon's index (N_1)	10.92	0	10.46	0
Simpson's index (N_2)	10.25	0	9.65	0
Richness indices				
Margalef's index (R_1)	1.39	0	1.47	0
Menhinik's index (R_2)	0.23	0	0.29	0
Evenness indices				
McIntosh's index (E)	0.97	0	0.95	0
Pielou's J index (E)	0.96	0	0.94	0

Table 2.21. Diversity of Intermediate Egret in all POME ponds of Carey Island.

Indices	POME 1	POME 2	POME 3	POME 4
Diversity indices				
Shannon's index (N_1)	6.74	0	6.69	0
Simpson's index (N_2)	6.51	0	6.46	0
Richness indices				
Margalef's index (R_1)	0.90	0	0.96	0
Menhinik's index (R_2)	0.25	0	0.31	0
Evenness indices				
McIntosh's index (E)	0.63	0	0.64	0
Pielou's J index (E)	0.77	0	0.76	0

2.6.5. Diversity of Cattle Egret in all POME Ponds

The highest diversity value (N_1 = 6.89) and species evenness (J E = 0.78) for Cattle Egret were recorded in pond number one and the lowest species diversity and evenness values were recorded in POME pond number three. In contrast, the highest value for species richness was recorded in pond number three (R_1 = 0.89) and the lowest was recorded in POME pond number one. The diversity value of Cattle Egret utilizing pond number two and four was not analyzed because no Cattle Egret was sighted in that pond (Table 2.22).

2.6.6. Diversity of Chinese Egret in all POME Ponds

The results revealed that Chinese Egret had higher species diversity (N_1 = 6.87), species richness (R_1 = 1.29) and species evenness (E = 0.68) in pond number three and lowest species diversity (N_1 = 6.80), species richness (R_1 = 1.11) and species evenness (E = 0.65) in POME pond number one. The values for species diversity, richness and evenness of Chinese Egret in POME pond number two and four were not analyzed because no individual of Chinese Egret was observed (Table 2.23).

Table 2.22. Diversity of Cattle Egret in all POME ponds in Carey Island.

Indices	**POME 1**	**POME 2**	**POME 3**	**POME 4**
Diversity indices				
Shannon's index (N_1)	6.89	0	6.87	0
Simpson's index (N_2)	6.81	0	6.79	0
Richness indices				
Margalef's index (R_1)	0.83	0	0.89	0
Menhinik's index (R_2)	0.19	0	0.24	0
Evenness indices				
McIntosh's index (E)	0.63	0	0.64	0
Pielou's J index (E)	0.78	0	0.77	0

Table 2.23. Diversity of Chinese Egret in all POME ponds in Carey Island.

Indices	POME 1	POME 2	POME 3	POME 4
Diversity indices				
Shannon's index (N_1)	6.80	0	6.87	0
Simpson's index (N_2)	6.78	0	7.14	0
Richness indices				
Margalef's index (R_1)	1.11	0	1.29	0
Menhinik's index (R_2)	0.47	0	0.68	0
Evenness indices				
McIntosh's index (E)	0.65	0	0.68	0
Pielou's J index (E)	0.77	0	0.78	0

2.7. DISCUSSIONS

2.7.1. Species Abundance

Results indicated that egrets was heavily utilized pond number one and three (61.66% and 38.34% of total observations respectively) but totally avoiding pond number two and four. This indicates that the "productivity" of POME pond number one and three is more or less equal but higher than POME pond number two and four. This is because POME pond number one is rich in organic matter which was frequently received in the form of oil mills effluent (Ma, 2000; Rupani *et al.*, 2010). The organic matter become concentrated and compacted along the edges, providing a suitable base for foraging birds. Rich organic matter in POME pond number one had successfully attracted many aquatic invertebrates since it is rich in nutrients that offer plenty of food resources for aquatic invertebrates. This also offers suitable breeding ground for wide array of invertebrates. The abundance of food resources and suitable foraging area has attracted many egret species to the ponds (Paracuellos, 2006). Fallen trees and shallow water of POME pond number three have also successfully attracted many egrets. It was observed that egrets prefer shallow water along the edges and central vegetated areas for foraging and loafing. Shallow water along the edges is highly productive zone for plants, nekton, and invertebrates (Peterson and Turner, 1994; Chesney *et al.*, 2000, Minello and Rozas, 2002). Fallen trees provide suitable loafing sites for egrets while shallow water facilitate the capturing of aquatic invertebrates by egrets. These conditions allow easy access and facilitate prey capture.

On contrary, no egrets were recorded in POME ponds number two and four. Surface area of POME pond number two is covered by cattail plants and small compacted material which hinder egrets foraging activity. The surface of POME pond number four is dominated by algae and doesn't contain any fallen material to be used by egrets for loafing. In addition, no aquatic invertebrate was captured from POME pond number two and pond number four. The reason for avoiding these two POME ponds by egrets was the absence of food resources and suitable material for standing such as compacted waste material and dead fallen trees. Algae coverage also reduced visibility of aquatic invertebrates and prevents efficient foraging activity by egrets. POME pond number three and four were also suitable for ducks and grebes, because little grebes preferred deeper water bodies while ducks preferred vegetated area as they are omnivorous in nature.

Most egrets are active during morning hours, i.e. from 0900 to 1200 hours. During this period, most invertebrates are concentrated at water surface and can be easily caught. However, the invertebrates went deeper whenever the temperature rises which prevent easy detection by egrets. Previous studies have concluded that the occurrence and distribution of aquatic invertebrate are affected by fluctuation in temperature (Schindler, 1997; Poff *et al.*, 2002; Riordan, 2004; Corcoran, 2005). As a result, egrets have moved to the adjacent mangrove areas for loafing and foraging whenever the temperature is increased.

The monthly fluctuation in egret's relative abundance was mainly due to the migratory season. This is because Little Egret and Great Egret are resident species and they utilized POME ponds throughout the year. On contrary, Cattle Egret, Intermediate Egret and Chinese Egret are migratory species and they visit POME pond areas during migratory season. Migrants usually arrive in late September or early October and departed by the end of March or early April. The arrival and departure of migrant individuals caused fluctuation in relative abundance of egret species in the study area.

The edges and some parts of the POME pond number one and three are heavily covered by different vegetation such as Marsh Sedge (*S. purpurascens*), Climbing Fern (*S. palustris*), Three Square Bulrush (*S. olneyi*), Buffalo Grass (*Panicum repends*), Cattail (*Typha* sp.), Blush (*M. tanarius*), Oil Palm (*E. guineensis*), Timar (*A. marina*), and *R. apiculata*. Egrets have different preference towards habitats that have different vegetation composition. Habitats vegetated by blush, oil palm, timar and *Rhizophora* were utilized by egrets for loafing while habitats vegetated with marsh sedges and bulrush were used by egrets for foraging. The latter habitat has high diversity of invertebrates. Therefore, vegetation composition had influenced egret's distribution either directly or indirectly. Previous studies also recorded that vegetation structure and composition, wetland size and adjacent areas are affecting waterbird relative abundance and distribution (Paszkowski and Tonn, 2000; Gaston *et al.*, 2000; Froneman *et al.*, 2001; Riffell *et al.* 2001; Aynalem and Bekele, 2008; González–Gajardo *et al.*, 2009). The vegetation structure and food resources are assumed to be the primary proximate factors that determined where and how birds use resources (Block and Brenn, 1993). Vegetated areas are attracting prey species due to shelter from predators and richness of food sources. It also had been reported that prey abundance and vegetation structure have influenced waterbirds in choosing their foraging site (Danylow *et al.*, 2010). The differences in prey species composition and size between vegetated and un-vegetated sites are the key factor that affects foraging site selection among egret species (Stolen, 2006). Telleria *et al*. (2001) also reported that vegetation is a major factor that affects distribution of avian species by offering shelter, food and suitable nesting sites. Variation in different vegetation structure and composition, richness of food resources and prey accessibility, and capturing success are the key factors that influence avian relative abundance and species diversity (Jones, 2001; Doherty and Grubb, 2002; Isacch *et al*., 2005).

A difference in food sources and vegetation composition affects egret's abundance. Surrounding landscape such as agricultural field, oil palm plantation, mangrove vegetation and mudflat played important roles in attracting egrets to utilize these ponds. Oil palm and mangrove trees offer loafing sites for egrets. Egrets preferred to forage in POME ponds during morning and afternoon but moved to mangrove areas during mid day to avoid heat. In addition, weather, social interactions and predators also affects distribution, foraging and roosting behaviour of avian species (Haukos *et al.*, 1998; Butler and Vennesland, 2000). Vegetation physiognomy and structure are important factors in determining habitat use by birds (Block and Brennan, 1993).

2.7.2. Species Diversity

POME pond number one had higher egret's species diversity and evenness than pond number three. Egret's species diversity and richness are affected by POME pond characteristics such as availability and distribution of food resources and presence of suitable loafing and roosting sites. POME pond number one is rich in compacted waste material that provide suitable foraging sites while POME pond number three had dead fallen trees that offer suitable loafing sites.

The highest species diversity, richness, and evenness were recorded for Little Egret followed by Great Egret. This is because Little Egret and Great Egret are resident species; they occur throughout the year in POME pond areas whereas Cattle Egret, Intermediate Egret and Chinese Egret are migrant species, which only present in POME pond areas during migratory season. It shows that arrival and departure of migratory species have influenced species diversity, richness and evenness of egrets in POME pond areas.

The results show that richness of food resources, occurrence of foraging sites, habitat variation (such as nearby oil palm plantations and mangrove forest), have influenced egrets diversity and richness. The results are consistent with previous studies that reported wetland birds diversity and richness are closely associated with diversity and abundance of food resources (Suter, 1994), shallowness of water (Colwell and Taft, 2000), size of wetland (Hoyer and Canfied, 1994), habitat variation (Buffington *et al.*, 1997; Jobin *et al.*, 2001), and surrounding landscape (Pearson, 1993; Koopowitz *et al.*, 1994; Vos and Stumpe, 1995).

CHAPTER 3

DIVERSITY OF AQUATIC INSECTS AS FOOD RESOURCES FOR EGRETS THAT UTILISE POME PONDS

3.1. Introduction

Food resources are generally distributed heterogeneously; both in time and space and foraging animals show flexible responses to this heterogeneity (Guillemain and Fritz, 2002). Waterbirds such as egrets foraged on various food items and their diet consists primarily of invertebrates (e.g. locusts, grasshoppers, beetles, dragonfly larvae, mole crickets, water bugs, Lepidoptera, and Hemiptera), crustaceans (e.g. prawn, amphipods, phylopods and crabs), molluscs (snails and bivalves), amphibians (frogs and tadpoles), fish (eels, perch, carps, catfish and mosquito fish), reptiles (snakes and lizards), small birds, rodents and plant materials (Kushlan and Hancock, 2005; McKenna, 2011; Steele, 2011). The occurrence of food resources is a key factor that influences the habitat selection and reproductive success of waterbirds including egrets.

Previous study revealed that Cattle Egret (*Bubulcus ibis*) gut consists of orthopterans (50.38%), invertebrates (21.75%), isopterans (16.79%), vertebrates (6.04%), unidentified animal remains (3.44%), acarina (0.98%) and plant materials (0.62%) (Sharah *et al*., 2008). On contrary, Birdlife International (2012d) had documented that diet of Cattle Egret consists primarily of invertebrates (such as locusts, grasshoppers, beetles, Lepidoptera, Hemiptera, and dragonflies) but other animals (such as centipedes, worms, spiders, crustaceans, frogs, tadpoles, molluscs, fish, lizards, small birds, and rodents) and vegetable matters (e.g. palm-nut pulp) were also detected. Steele (2011) reported that Great Egret (*C. albus*) feed mostly on fish but will also take amphibian (frogs), aquatic invertebrates (invertebrates, crayfish), and reptiles (snakes). However, during drier months, the bird will stalk small mammals, snails and nesting birds (Tan, 2001; Steele, 2011).

In this study, the food resources that were studied consist of aquatic invertebrates inhabiting POME (Palm Oil Mills Effluent) ponds. Invertebrates are the most abundant and diverse organisms in various types of wetlands. Aquatic invertebrates are often the most abundant macro-fauna in wetland habitat and have been considered as a key element in wetland food webs (Brooks, 2000). Its form major food resource for egrets and its abundance plays a vital role in egret's distribution, reproductive success and habitat selection (Erman, 1997; Backwell *et al.,* 1998; RSPB, 2011). Invertebrate distribution, diversity and richness are affected by water level fluctuation, water quality, vegetation composition and temperature (Sharitz and Batzer 1999; de Neiff *et al.*, 2009). The occurrence of aquatic invertebrates is associated with environmental gradients or ecosystem disturbance (Adamus, 1996; Rosenberg and Resh, 1996; Gernes and Helgen, 2002).

Although these invertebrates form a major food resource for a variety of animals including waterbird species (Magee, 1993), the information on invertebrate assemblages in POME ponds is not sufficiently recorded. Therefore, monitoring available food resources for egrets in the form of species composition, relative abundance, diversity and differences among insect species that presence in POME ponds is very important.

3.2. Objectives

The main objectives of this study are:

3.2.1. To determine the species composition of aquatic insects in various POME ponds.

3.2.2. To determine relative abundance of aquatic insects occurs in POME ponds.

3.3. MATERIALS AND METHODS

3.3.1. Study Site

The study was conducted in four POME ponds located in Carey Island, Selangor, Malaysia. A detail about study site is presented in section 2.3.1 on page 22–23 and Figure 2.1 on page 24.

3.3.2. Sampling Food Resources

Many devices and techniques (such as sweep net, drift net, pitfall trap, pan trap, dip net, frame box and scoop net) have been applied in sampling aquatic insect (Turner and Trexler, 1997; Hanson *et al*., 2000; Sychra and Adámek, 2010). The presence of invertebrates in POME ponds was sampled to determine species composition and relative abundance. The invertebrates in POME ponds were sampled using scoop net. The invertebrates were sampled twice in a month from January to June, 2010 from 0900 to 1400 hours. During each sampling, four water samples were collected from each POME pond using metal container (20 cm X 20 cm) along the edges of ponds and were transferred into plastic containers (Figure 3.2). In addition, scoop net was used to sample the insects along the edges of each POME pond to obtain reliable results (Figure 3.1) The plastic containers were brought back to the laboratory and the water was sieved using nylon net. After sieving, the insects were sorted in a white tray. All insects were counted and preserved in 70% alcohol for identification. The insects were counted and identified based on field guide (Voshell and Wright, 2002), personal confirmation with experts and comparison with museum specimens. The methodology followed was described in detail by Voslamber *et al.* (2010).

3.4. DATA ANALYSIS

3.4.1. Relative Abundance

The relative abundance of aquatic insect was determined using the following expression:

$$n/N \times 100$$

Where n is the number of particular aquatic insect species and N is the total number of all recorded aquatic insect species.

Figure 3.1: Scoop net and square metal container.

Figure 3.2: Plastic containers that contain water samples of POME pond’s.

3.4.2. Diversity Indices

The aquatic insect diversity was determined using Henderson and Seaby's Community Analysis Package (CAP, Version 4.0; 2007). This analysis is to understand the variation of aquatic insect species among two POME ponds. Diversity indices were discussed in detail in section 2.4.4 on page 34.

3.4.3. Testing significance differences

One-way analysis of variance (ANOVA) and Tukey's (HSD) test were used to test significant differences among aquatic insects relative abundance in POME pond. Analysis of variance was discussed in an earlier chapter. For detailed please refer to section 2.4.2 on page 31 and 2.4.3 in chapter two on page 33.

3.4.4. Correlation Between Egret and Relative Abundance of Aquatic Insects

Pearson's Correlation Coefficient (PCC) was used to determine the correlation between egret relative abundance and water quality parameters or invertebrate relative abundances in POME pond number one and pond number three in order to understand the relationship of egrets with water quality and food resources.

$$r = \frac{\sum_{i=1}^{n} \left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right)}{\sqrt{\sum_{i=1}^{n} \left(X_i - \overline{X}\right)^2}\sqrt{\sum_{i=1}^{n} \left(X_i - \overline{Y}\right)^2}},$$

Where Xi = standard score, $\overline{X}$ = sample mean, n = total number of observations.

3.5. RESULTS

3.5.1. Aquatic Insect Species Composition and Relative Abundance

A total of 119,126 aquatic insect individuals belongs to twelve species were sampled from POME pond number one and three but not sampled in this study from ponds number two and four. Aquatic insects that were captured in large quantity were mosquito (*Aedes* sp.) larvae (48,493 individuals or 40.71%), hoverfly (*Eristalis* sp.) larvae (21,044 individuals or 17.67%) and water beetles (*Stenolopus* sp.) (12,214 individuals or 10.25%). On the contrary, predacious diving beetles (*Cybister* Sp.) (3,614 individuals or 3.03%), horse fly (*Tabanus* sp.) maggot (3,563 individuals or 2.99%) and water scavenger beetles (*Hydrophilus* sp.) (3,003 individuals or 2.52%) were the rarest invertebrate's species presence in POME ponds (Table 3.1).

Table: 3.1: List of aquatic insects species sampled from POME pond 1 & 2.

Common Name	**Scientific Name**	**Total captured**	**%**
Mosquito larvae	*Aedes* sp.	48,493	40.71
Hoverfly larvae	*Eristalis* sp.	21,044	17.67
Water beetles	*Stenolopus* sp.	12,214	10.25
Water diving beetles	*Eretes* sp.	6,078	5.10
Water bugs	*Sphaerodema* sp.	6,078	5.10
Solitary midges	*Thaumalea* sp	5,700	4.78
Midge fly larvae	*Chironomus* sp.	4,125	3.46
Great diving beetles	*Dytiscus* sp.	3,920	3.29
Predaceous diving beetle	*Cybister* sp.	3623	3.04
Horse fly maggots	*Tabanus* sp.	3,614	3.03
Watersnipe fly larvae	*Atherix* sp.	3563	2.99
Water scavenger beetle	*Hydrophilus* sp.	3,003	2.52
	Total	**119,126**	**100**

Mosquito (*Aedes* sp.) Larvae

Aedes larvae was the most dominant aquatic insect species occupy POME pond area, i.e. pond number one (19.46%) and pond number three (21.25%). For POME pond number one, the highest relative abundance of *Aedes* larvae was recorded in January (18.90%) and February (19.46%) while from POME pond number three relative abundance was a little bit different, i.e. the highest relative abundance was recorded in January (21.31%) and March (19.89%). In contrast, for POME pond number one, the lowest relative abundance was recorded in May (14.89%) and for pond number three in June (12.47%).

Figure 3.3: Larva of *Aedes* sp.

Hoverflies (*Eristalis* sp.)

It is a large, brown and orange species with a very broad black face stripe, and very obvious hair patches on the eyes. Hoverflies larvae are commonly known as 'rat-tailed maggots’ (Figure 3.4). It’s developed either in organic material which is very wet or in water. They are able to do well in sewage water with high organic content and lacking oxygen. They are aquatic and breathe through long snorkel-like appendages. The larvae are detritus feeders (Perrett, 2000).

Hoverfly larva were the second most abundant aquatic insects (17.67%) in POME pond areas, i.e. 8.34% in pond number one and 9.32% in pond number three. The highest relative abundance of hoverfly larvae in POME number one was recorded in June (28.28%) and the lowest relative abundance was recorded in January (6.86%).

Likewise, the highest relative abundance of hoverfly larvae in POME pond number three was recorded in June (27.80%) and the lowest relative abundance was recorded in January (7.66%).

Figure 3.4: Hoverfly (*Eristalis sp.*) larvae

Water Beetles (*Stenolopus* sp.)

Water beetles are found in a wide range of aquatic habitats. Most larval and adult beetles are tolerant to wide ranges of pH and dissolved oxygen. Many adults cannot use dissolved oxygen and must rise to the surface to respire atmospheric oxygen. Water beetle larvae (Figure 3.5) are well known for their piercing mandibles, inject proteolytic enzymes into their prey or human hand, resulting in either subsequent ingestion of internal tissues or excruciating pain. Larvae prey on small vertebrates such as fish and tadpoles (Williams and Feltmate, 1992).

Water beetles were the third dominant invertebrates (10.25%) in POME pond areas i.e. 5.09% in pond number one and 5.16% in pond number three. The water beetles were higher in June (31.14%) but rare in January (6.62%) in POME number one, while in POME pond number three, the relative abundance was high in May (27.09%) but low in January (4.88%).

Figure 3.5: Water beetle (*Stenolophus* sp.) larvae

Water Diving Beetle (*Eretes* sp.)

The larvae of water diving beetle (Figure 3.6) are more common and noticeable than other larvae. This larva is a fierce animal and sometimes was referred as water tiger. With its large, powerful jaws, it attacks and eats various animals as large as itself. Large larvae will even eat its siblings and fight with other larvae of its own size until one has killed another. Its jaws have grooves through which it sucks the juices of the victims. It breathes at the surface of the water. When it needs oxygen, it will swim near the surface and poke it’s tail out of the water, taking in air through two breathing tubes at the ends of its long bodies.

Water diving beetles were quite abundant in POME pond area. Its occupy 5.10% of all aquatic insects abundance, i.e. 2.97% in pond number one and 2.16% in pond number three. The highest relative abundance of water diving beetles (36.92%) was recorded in June (36.92%) in POME pond number one but no individual was recorded in January. Likewise, the relative abundance of water diving beetles in POME pond number three was highest in May (26.75%) and not a single individual was recorded in January.

Figure 3.6: Water diving beetle (*Eretes* sp.)

Solitary Midges (*Thaumalea* sp.)

Midges can be easily mistaken for mosquitoes but this fly does not bite (except the biting midge which was also called no-seeums). It has small (3–4 mm) and stocky body with yellow to brown colour. It is one of the most abundant organisms in aquatic habitats. Larvae are scavengers and feed on debris at the bottom of the water. Midge larvae (Figure 3.7) are an important source of food for larger aquatic invertebrates and fish.

The population of solitary midges in POME pond area was low (1.97% in pond number one and 1.18% in pond number three). The relative abundance was high in June i.e. 41.29% in POME pond number one and 33.74% in POME pond number three. However, no solitary midge was sampled during January and February in all POME ponds.

Figure 3.7. Solitary midges (*Thaumalea* sp).

Midge Fly (*Chironomus* sp.) Larvae

The body of midge fly larvae is more slender and varies in size (from 2 – 30 mm). The midge fly larvae (Figure 3.8) account for most of the macro-invertebrates in the freshwater environment. In many aquatic habitats this group constitutes more than half of the total number of macro-invertebrate species. They are diverse in form and size and found in the shallow to deep waters. This larvae are extremely important part of aquatic food chains, serving as prey for many other invertebrates and food for most fishes. They are opportunistic omnivores feeding on diatoms, detritus, and other small plants and animals. Midge fly larvae exhibit a variety of feeding habits (Narf, 1997; Diggins and Stewart, 1998).

The relative abundance of midge fly larvae was slightly higher (3.46%) than other aquatic insects in the POME pond area (its abundance in POME pond number one was 1.89% while in pond number three was 1.58%). The highest relative abundance of midge fly larvae was recorded in June (31.45%) in POME pond number one and 27.70% in POME pond number three. However, midge fly larvae were absent from samples collected in January on POME ponds number one and three.

Figure 3.8: Midge fly (*Chironomus* sp.) larvae

Great Diving Beetles (*Dytiscus* sp.)

Great diving beetles are voracious predator, hunts a wide variety of prey, including invertebrates, tadpoles and small fishes. They are cannibalistic in nature, i.e. they eat their siblings. Their body colour is dark, olive-brown, almond-shaped, and about three centimeters long (Figure 3.9). They spend most of their time in standing water with vegetation. The larvae can grow up to 6 cm in length and often look like a scorpion in the water because they move with tail extended upward. They frequently come to the surface, extruding the tip of the abdomen to replenish atmospheric oxygen through the terminal spiracle (Williams and Feltmate, 1992).

Great diving beetles constitute only 3.29% of all aquatic insect species occurs in POME pond areas (1.58% in POME pond number one and 1.71% in pond number three). The highest relative abundance for great diving beetles was recorded in April (30.70% in POME pond number one) and in March (31.66% in pond number three). In contrast, no individual was sampled in January and February at both POME ponds.

Figure 3.9: Great diving beetles (*Dytiscus* sp.) larvae

Water Bugs (*Sphaerodema* sp.)

Water bugs have oval body and are relatively large aquatic insect (approximately 2 cm or more in body length) with jointed, sharp, sucking nose, breathe air, and undergo gradual metamorphosis (Figure 3.10). They are fierce predators which stalk, capture and feed on aquatic crustaceans, fish and amphibians. They often lie motionless at the bottom of water body, attached to various objects, where they wait for prey to come near. They will strike the prey, injecting powerful digestive saliva with their mandibles and suck out the blood of their prey. Their bite is considered as one of the most painful that can be inflicted by any invertebrates. Adults cannot breathe under water and must periodically come to surface for air. Occasionally when encounter by a larger predator, such as human, they have been known to "play dead" and emit a fluid from their anus. Due to this they are assumed dead by humans only to "come alive" later with painful results.

Water bugs presented only 3.15% of all aquatic insect species occurs in POME pond areas. Their relative abundance was higher in March (31.40% in POME pond number one) and May (27.73% in POME pond number three). However, they are absent from POME pond number one and three in January and February respectively.

Figure 3.10: Water bugs (*Sphaerodema* sp.)

Watersnipe Fly (*Atherix* sp.) Larvae

Watersnipe fly larvae may vary in colour from pale to green and usually 12-18 mm long (Figure 3.11). They have segmented, soft and fleshy body tapered at the head end with two feather-like horns at the back. The body is supported by many pairs of caterpillar-like legs i.e. tiny soft pairs of fleshy filaments extended from the top and side of the body.

Watersnipe fly larvae present only small amount compared to other aquatic insect species recorded in POME pond areas (1.57% was recorded in POME pond number one while 1.45% was collected from pond number three). Their highest relative abundance is 35.62% and was recorded in POME pond number one in June and pond number three in May (31.79%). However, no larva was recorded in both POME ponds in January.

Figure 3.11: Watersnipe flies (*Atherix* sp.) larva

Predaceous Diving Beetle (*Cybister* sp.)

Predaceous Diving Beetle is also known as Diving/True Water Beetle. It has oval or flat body which range from 1.5 mm to more than 35 mm (Figure 3.12). It is well adapted to an aquatic environment. The pair of hind legs is long, flattened, and fringed to provide surface area that aids in flotation and swimming. Its prey ranges from invertebrates to small fishes.

Predaceous diving beetle contributed only 3.03% to aquatic insect diversity in POME ponds. Their relative abundance in POME pond number three was little bit higher (i.e. 1.53%) than POME pond number one (1.51%). The relative abundance of predaceous diving beetle was recorded highest in POME pond number one in June (33.98%) and in May (26.70% for POME pond number three). In contrast, no predaceous diving beetle was recorded in both POME ponds in January.

Figure 3.12: Predaceous Diving Beetle (*Cybister* sp.)

Horsefly (*Tabanus* sp.) Larvae

The larval stage of horsefly is aquatic. The female drops the eggs into the water or soil where their larvae become voracious predators of other invertebrates or small vertebrates. The larvae are white to tan, with a slender, cylindrical body that is slightly tapered at the head (Figure 3.13). The head contains two sharp, slender mandibles that possess a hollow canal for transmitting venom into their prey. They can inflict a very painful bite to their prey. The larvae undergo several molts as it grows and depending on the species, the larval stage may last several months or as long as two to three years. Once the larvae are fully developed it moves into drier soil to pupate. Depending on the species, the pupal stage lasts approximately 5-21 days, and then the adult flies emerge from the soil. Mating occurs shortly after the adults emerge. Female laid their eggs on vegetation until a host (of a blood meal) wanders into range. Females are attracted to large, dark, moving objects and CO_2.

Horsefly larvae form only a small percentage of aquatic insect community in POME ponds. Only 1.47% of this invertebrate was sampled from POME pond number one belong to this species while 1.56% of sampled invertebrates from pond number three was horsefly larvae. In total, this represented only 2.99% of invertebrates sampled from POME ponds. The highest relative abundance of horsefly larva was recorded in both POME ponds in June (28.16% and 29.46% in POME pond number one and three respectively). In contrast, the lowest relative abundance of horsefly larva was recorded in January in both POME ponds (1.22% and 5.47% in pond number one and three respectively).

Figure 3.13: Horsefly (*Tabanus* sp.) larvae

Water Scavenger Beetle (*Hydrophilus* sp.)

The adults of water scavenger beetles are black and shiny (Figure 3.14). It hangs at the surface with head up. Its antennae are very short and club-shaped. Legs are flattened and fringed with hair that provides a wider surface for pushing against the water. Water-scavenger beetle swims down into the water; carry a large bubble of air from the surface, which gives a shining, silvery appearance to its body. The adults usually foraged on algae, while their larvae are carnivorous and preyed on other invertebrate's nymphs or larvae, tadpoles, beetles and snails.

Water scavenger beetles was the rarest aquatic insect species in POME pond area, represented only a small proportion (i.e. 2.52%; 1.21% in POME pond number one and 1.31% in pond number three). Their highest relative abundance was recorded in both

POME ponds in June (i.e. 43.19% in POME pond number one and 36.47% in pond number three). However, no individual of water scavenger beetles was recorded in POME pond number one or three either in January or February.

Figure 3.14: Water scavenger beetles (*Hydrophilus* sp.)

3.5.2. Aquatic Insects Relative Abundance

No aquatic insect was recorded from pond number two and pond number four. On the contrary, a total of 119,126 individuals of 12 species of aquatic insects was recorded from pond number one (57,900 individuals) and number three (61,226 individuals) during the study period. Similar species were recorded in both ponds while the number of individuals varies from species to species. Mosquito larvae (*Aedes* sp.) was recorded in large numbers in pond number one (23,180 larvae or 19.46%) and three (25,313 larvae or 21.25%). A substantial amount of Hoverfly larvae (*Eristalis* sp.) were recorded in pond number one (9,941 larvae or 8.34%) and pond number three (11,103 larvae or 9.32%).

On the contrary, less water scavenger beetles (*Hydrophilus* Sp.) were recorded in pond number one (only 1,440 individuals or 1.21%) and three (1,563 individuals or 1.31%) (Table 3.2).

Table: 3.2: List of aquatic insect species with relative abundance recorded from all POME ponds.

Invertebrates Species	**Pond 1**	**%**	**Pond 2**	**Pond 3**	**%**	**Pond 4**
Aedes sp.	23,180	19.46	0	25,313	21.25	0
Eristalis sp.	9,941	8.34	0	11,103	9.32	0
Stenolopus sp.	6,067	5.09	0	6,147	5.16	0
Eretes sp.	3,543	2.97	0	2,157	2.16	0
Thaumalea sp.	2,347	1.97	0	1,402	1.18	0
Chironomus sp.	2,248	1.89	0	1,877	1.58	0
Dytiscus sp.	1,886	1.58	0	2,034	1.71	0
Sphaerodema sp.	1,866	1.57	0	4,212	3.54	0
Atherix sp.	1,833	1.54	0	1,730	1.45	0
Cybister sp.	1,795	1.51	0	1,828	1.53	0
Tabanus sp.	1,754	1.47	0	1,860	1.56	0
Hydrophilus sp.	1,440	1.21	0	1,563	1.31	0
Total	**57,900**	**100**	**0**	**61,226**	**100**	**0**

3.5.3. Monthly Relative Abundance of Aquatic Insects in POME Pond Number One

The highest relative abundance of Mosquito larvae (*Aedes* sp.) was recorded in February while Hoverfly larvae (*Eristalis* sp.), Water Beetles (*Stenolopus* sp.), Water Diving Beetle (*Eretes* sp.), Solitary Midges (*Thaumalea* sp.), Midge Fly Larvae (*Chironomus* sp.), Watersnipe Fly Larvae (*Anterix* sp.), Predaceous Diving Beetle (*Cybister* sp.), Housefly Maggots (*Tabanus* sp.) and Water Scavenger Beetle (*Hydrophilus* sp.) were recorded in June. Largest number of Great Diving Beetle (*Dytiscus* sp.) was recorded in April and for Water Bugs (*Sphaerodema* sp.) in March. However, eight aquatic insect species were not recorded in January and four species were not recorded in February (Table 3.3).

The relative abundance of *Aedes* sp. in POME pond number one was significantly different from *Eristalis* sp. and *Sphaerodema* sp. ($F_{11, 60} = 37.86$, $P < 0.05$; Table 3.4; Appendix 3.1).

Table: 3.3: Monthly relative abundance of invertebrates recorded in POME pond number one from January to June 2010.

Species Name	**January**	**February**	**March**	**April**	**May**	**June**	**Total**
Aedes sp.	4,381	4,511	3,645	3,541	3,452	3,650	23,180
Eristalis sp.	682	931	905	1,866	2,746	2,811	9,941
Stenolopus sp.	402	964	887	860	1,065	1,889	6,067
Eretes sp.	0	387	520	587	741	1,308	3,543
Thaumalea sp.	0	0	301	335	742	969	2,347
Chironomus sp.	0	245	316	367	613	707	2,248
Dytiscus sp.	0	0	301	579	500	506	1,886
Sphaerodema sp.	0	0	586	367	421	492	1,866
Atherix sp.	0	108	367	303	402	653	1,833
Cybister sp.	0	112	302	367	404	610	1,795
Tabanus sp.	27	283	293	316	341	494	1,754
Hydrophilus sp.	0	0	113	315	390	622	1,440
Total	**5,492**	**7,541**	**8,536**	**9,803**	**11,817**	**14,711**	**57,900**

Table 3.4: Comparison of relative abundance of invertebrates in POME pond number one at Carey Island, Peninsular Malaysia

Invertebrate Name	**Mean Relative Abundance**
Aedes sp.	3863.3 a
Eristalis sp.	1656.8 b
Stenolopus sp.	1011.2 b
Sphaerodema sp.	590.50 c
Eretes sp.	391.17 c
Dytiscus sp.	374.67 c
Chironomus sp.	314.33 c
Tabanus sp.	311.00 c
Cybister sp.	305.50 c
Atherix sp.	299.17 c
Hydrophilus sp.	292.33 c
Thaumalea sp.	240.00 c

(The mean values in columns with same letter are not significant at P = 0.05, Tukey's HSD test; Critical Value, 819.32)

3.5.4. Monthly Relative Abundance of Aquatic Invertebrates in POME Pond Number Three

The highest relative abundance of Mosquito (*Aedes* sp.) larvae was recorded in January and Great Diving Beetle (*Dytiscus* sp.) was recorded in March. The highest relative abundance of six aquatic insect species i.e. Hoverfly (*Eristalis* sp.) larvae, Water Beetles (*Stenolopus* sp.), Midge Fly (*Chironomus* sp.) larvae, Horsefly (*Tabanus* sp.) larvae, Water Scavenger Beetle (*Hydrophilus* sp.) and Solitary Midges (*Thaumalea* sp.) were recorded in June. Similarly, the highest relative abundance of four aquatic insect species namely Water Bug (*Sphaerodema* sp.), Water Diving Beetle (*Eretes* sp.), Predacious Diving Beetle (*Cybister* sp.) and Watersnipe Fly (*Anterix* sp.) larvae were recorded in May. Eight aquatic insect species were not recorded in January and four species were not recorded in February (Table 3.5).

The results showed that the *Aedes* sp. relative abundance in pond number three was significantly different from *Eristalis* sp., *Stenolopus* sp., *Sphaerodema* sp., *Eretes* sp., *Dytiscus* sp., *Chironomus* sp., *Tabanus* sp., *Cybister* sp., *Atherix* sp., *Hydrophilus* sp. and *Thaumalea* sp. ($F_{11, 60} = 34.23$, $P < 0.05$; Table 3.6; Appendix 3.2).

Table 3.5: Monthly relative abundance of aquatic insects inhabiting POME pond number three sampled from January to June 2010.

Species Name	**January**	**February**	**March**	**April**	**May**	**June**	**Total**
Aedes sp.	5,393	3,752	4,753	5,034	3,225	3,156	25,313
Eristalis sp.	851	1,023	1,215	2,064	2,863	3,087	11,103
Stenolopus sp.	298	683	1,167	714	1,665	1,620	6,147
Sphaerodema sp.	0	0	1,087	906	1,168	1,051	4,212
Eretes sp.	0	332	327	364	577	557	2,157
Dytiscus sp.	0	0	644	396	447	547	2,034
Chironomus sp.	0	336	272	374	375	520	1,877
Tabanus sp.	24	275	286	326	401	548	1,860
Cybister sp.	0	181	361	315	488	483	1,828
Atherix sp.	0	199	203	282	550	496	1,730
Hydrophilus sp.	0	0	188	349	456	570	1,563
Thaumalea sp.	0	0	174	351	404	473	1,402
Total	**6,566**	**6,781**	**10,677**	**11,475**	**12,619**	**13,108**	**61,226**

Table 3.6: Comparison of aquatic insects relative abundance in POME pond number three at Carey Island, Peninsular Malaysia

Invertebrate Name	**Mean Relative Abundance**
Aedes sp.	4,218.8 a
Eristalis sp.	1,850.5 b
Stenolopus sp.	1,024.5 b
Sphaerodema sp.	702.00 c
Eretes sp.	359.50 c
Dytiscus sp.	339.00 c
Chironomus sp.	312.83 c
Tabanus sp.	310.00 c
Cybister sp.	304.67 c
Atherix sp.	288.33 c
Hydrophilus sp.	260.50 c
Thaumalea sp.	233.67 c

(The mean values in column with same letter are not significant at P = 0.05, Tukey's HSD test; Critical Value, 953.82).

3.5.5. Diversity Indices of Aquatic Insects

3.5.5.1. Diversity of Aquatic Insects in POME Pond Number One

The diversity value indicated that aquatic insect species diversity, richness and evenness varied from January to June. For example, the highest species diversity (N_1 = 2.21) and species evenness (E = 0.89) were recorded in POME pond number one in June but the highest aquatic insect species richness was recorded in May (R_1 = 1.73). In contrast, the lowest aquatic insect species diversity (N_1 = 0.66), species richness (R_1 = 0.35), and species evenness (E = 0.47) were recorded in January at POME pond number one (Table 3.7).

3.5.5.2. Diversity of Aquatic Insects in POME Pond Number Three

The highest aquatic insect species diversity (N_1 = 2.17) and evenness (E = 0.87) were recorded in June and the lowest aquatic insect species diversity (N_1 = 0.59) and evenness (E = 0.42) were recorded in January (in POME pond number three). Likewise, the highest species richness (R_1 = 1.19) was recorded in March and the lowest (R_1 = 0.34) was recorded in January (Table 3.8).

Table 3.7: Comparison of aquatic insects diversity from January to June 2010 in POME pond number one

Indices	**January**	**February**	**March**	**April**	**May**	**June**
Diversity indices						
Shannon's index (N_1)	0.66	1.34	1.96	2.05	2.11	2.21
Richness indices						
Margalef's index (R_1)	0.35	0.78	1.22	1.20	1.73	1.45
Evenness indices						
Pielou's J index (E)	0.47	0.64	0.79	0.82	0.85	0.89

Table 3.8: Comparison of aquatic insects diversity from January to June 2010 in POME pond number three

Indices	**January**	**February**	**March**	**April**	**May**	**June**
Diversity indices						
Shannon's index (N_1)	0.59	1.47	1.88	1.89	2.14	2.17
Richness indices						
Margalef's index (R_1)	0.34	0.79	1.19	1.18	1.17	1.16
Evenness indices						
Pielou's J index (E)	0.42	0.71	0.75	0.76	0.86	0.87

3.5.6.1. Correlation between Little Egret's and Relative Abundance of Aquatic Insects in POME Pond Number One

Pearson's correlation coefficient (PCC) was used to determine the correlation between Little Egret relative abundance and aquatic insects abundance. Pearson test highlighted a weak correlation between Little Egret relative abundance and aquatic insects in POME pond number one (Table 3.9) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Table 3.9: Pearson's correlation coefficient between Little Egret relative abundance and aquatic insects relative abundance in POME pond number one

Scientific Name	**Pearson's Correlation Coefficient (PCC)**
Aedes sp.	($r = -0.5499$, $P > 0.05$)
Eristalis sp.	($r = -0.3331$, $P > 0.05$)
Stenolopus sp.	($r = -0.4006$, $P > 0.05$)
Eretes sp.	($r = -0.2883$, $P > 0.05$)
Sphaerodema sp.	($r = -0.2648$, $P > 0.05$)
Thaumalea sp	($r = -0.1882$, $P > 0.05$)
Chironomus sp.	($r = -0.2844$, $P > 0.05$)
Dytiscus sp.	($r = -0.2397$, $P > 0.05$)
Cybister sp.	($r = -0.$ 2495, $P > 0.05$)
Tabanus sp.	($r = -0.3176$, $P > 0.05$)
Atherix sp.	($r = -0.2484$, $P > 0.05$)
Hydrophilus sp.	($r = -0.1590$, $P > 0.05$)

3.5.6.2. Correlation between Little Egret's and Relative Abundance of Aquatic Insects in POME Pond Number Three

Pearson's correlation coefficient (PCC) showed that Little Egret relative abundance has a weak correlation with aquatic insects in POME pond number three (Table 3.10) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Table 3.10: Pearson's correlation coefficient between Little Egret relative abundance and aquatic insects relative abundance in POME pond number three

Scientific Name	**Pearson's Correlation Coefficient (PCC)**
Aedes sp.	($r = -0.5437$, $P > 0.05$)
Eristalis sp.	($r = -0.3426$, $P > 0.05$)
Stenolopus sp.	($r = -0.3602$, $P > 0.05$)
Eretes sp.	($r = -0.3536$, $P > 0.05$)
Sphaerodema sp.	($r = -0.2833$, $P > 0.05$)
Thaumalea sp	($r = -0.2284$, $P > 0.05$)
Chironomus sp.	($r = -0.3639$, $P > 0.05$)
Dytiscus sp.	($r = -0.2935$, $P > 0.05$)
Cybister sp.	($r = -0.3295$, $P > 0.05$)
Tabanus sp.	($r = -0.3532$, $P > 0.05$)
Atherix sp.	($r = -0.2915$, $P > 0.05$)
Hydrophilus sp.	($r = -0.2153$, $P > 0.05$)

3.5.6.3. Correlation between Great Egret's and Relative Abundance of Aquatic Insects in POME Pond Number One

Pearson test indicates a weak correlation between Great Egret relative abundance and aquatic insects relative abundances in POME pond number one (Table 3.11) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Table 3.11: Pearson's correlation coefficient between Great Egret relative abundance and aquatic insects relative abundance in POME pond number one

Scientific Name	**Pearson's Correlation Coefficient (PCC)**
Aedes sp.	($r = -0.5478$, $P > 0.05$)
Eristalis sp.	($r = -0.3344$, $P > 0.05$)
Stenolopus sp.	($r = -0.4045$, $P > 0.05$)
Eretes sp.	($r = -0.3028$, $P > 0.05$)
Thaumalea sp.	($r = -0.2103$, $P > 0.05$)
Chironomus sp.	($r = -0.3190$, $P > 0.05$)
Dytiscus sp.	($r = -0.2773$, $P > 0.05$)
Sphaerodema sp.	($r = -0.3053$, $P > 0.05$)
Atherix sp.	($r^2 = -0.2903$, $P > 0.05$)
Cybister sp.	($r = -0.2935$, $P > 0.05$)
Tabanus sp.	($r = -0.3768$, $P > 0.05$)
Hydrophilus sp.	($r = -0.1972$, $P > 0.05$)

3.5.6.4. Correlation between Great Egret's and Relative Abundance of Aquatic Insects in POME Pond Number Three

Pearson's correlation coefficient (PCC) showed a weak correlation between Great Egret relative abundance and aquatic insects relative abundance in POME pond number three (Table 3.12) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Table 3.12: Pearson's correlation coefficient between Great Egret relative abundance and aquatic insects relative abundance in POME pond number three

Scientific Name	**Pearson's Correlation Coefficient (PCC)**
Aedes sp.	($r = -0.5415$, $P > 0.05$)
Eristalis sp.	($r = -0.3409$, $P > 0.05$)
Stenolopus sp.	($r = -0.3583$, $P > 0.05$)
Eretes sp.	($r = -0.3650$, $P > 0.05$)
Thaumalea sp.	($r = -0.2495$, $P > 0.05$)
Chironomus sp.	($r = -0.3817$, $P > 0.05$)
Dytiscus sp.	($r = -0.3035$, $P > 0.05$)
Sphaerodema sp.	($r = -0.2837$, $P > 0.05$)
Atherix sp.	($r = -0.3079$, $P > 0.05$)
Cybister sp.	($r = -0.3464$, $P > 0.05$)
Tabanus sp.	($r = -0.3711$, $P > 0.05$)
Hydrophilus sp.	($r = -0.2295$, $P > 0.05$)

3.5.6.5. Correlation between Cattle Egret's and Relative Abundance of Aquatic Insects in POME Pond Number One

Pearson's correlation test showed a weak correlation between Cattle Egrets and aquatic insects in POME pond number one (Table 3.13) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Table 3.13: Pearson's correlation coefficient between Cattle Egret relative abundance and aquatic insects relative abundance in POME pond number one

Scientific Name	**Pearson's Correlation Coefficient (PCC)**
Aedes sp.	($r = -0.5344$, $P > 0.05$)
Eristalis sp.	($r = -0.3187$, $P > 0.05$)
Stenolopus sp.	($r = -0.3758$, $P > 0.05$)
Eretes sp.	($r = -0.2755$, $P > 0.05$)
Thaumalea sp.	($r = -0.1887$, $P > 0.05$)
Chironomus sp.	($r = -0.2899$, $P > 0.05$)
Dytiscus sp.	($r = -0.2537$, $P > 0.05$)
Sphaerodema sp.	($r = -0.2821$, $P > 0.05$)
Atherix sp.	($r = -0.2669$, $P > 0.05$)
Cybister sp.	($r = -0.2706$, $P > 0.05$)
Tabanus sp.	($r = -0.3557$, $P > 0.05$)
Hydrophilus sp.	($r = -0.1783$, $P > 0.05$)

3.5.6.6. Correlation between Cattle Egret's and Relative Abundance of Aquatic Insects in POME Pond Number Three

PCC revealed weak correlation between Cattle Egret and aquatic insects in POME pond number three (Table 3.14) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Table 3.14: Pearson's correlation coefficient between Cattle Egret relative abundance and aquatic insects relative abundance in POME pond number three

Scientific Name	**Pearson's Correlation Coefficient (PCC)**
Aedes sp.	($r = -0.5354$, $P > 0.05$)
Eristalis sp.	($r = -0.3339$, $P > 0.05$)
Stenolopus sp.	($r = -0.3464$, $P > 0.05$)
Eretes sp.	($r = -0.3489$, $P > 0.05$)
Thaumalea sp.	($r = -0.2484$, $P > 0.05$)
Chironomus sp.	($r = -0.3675$, $P > 0.05$)
Dytiscus sp.	($r = -0.2928$, $P > 0.05$)
Sphaerodema sp.	($r = -0.2738$, $P > 0.05$)
Atherix sp.	($r = -0.2988$, $P > 0.05$)
Cybister sp.	($r = -0.3344$, $P > 0.05$)
Tabanus sp.	($r = -0.3574$, $P > 0.05$)
Hydrophilus sp.	($r = -0.2243$, $P > 0.05$)

3.5.6.7. Correlation between Intermediate Egret's and Relative Abundance of Aquatic Insects in POME Pond Number One

In POME pond number one, a weak correlation between Intermediate Egret relative abundance and aquatic insects was detected (Table 3.15) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Table 3.15: Pearson's correlation coefficient between Intermediate Egret relative abundance and aquatic insects relative abundance in POME pond number one

Scientific Name	**Pearson's Correlation Coefficient (PCC)**
Aedes sp.	($r = -0.5235$, $P > 0.05$)
Eristalis sp.	($r = -0.3013$, $P > 0.05$)
Stenolopus sp.	($r = -0.3459$, $P > 0.05$)
Eretes sp.	($r = -0.2363$, $P > 0.05$)
Thaumalea sp.	($r = -0.1412$, $P > 0.05$)
Chironomus sp.	($r = -0.2339$, $P > 0.05$)
Dytiscus sp.	($r = -0.1951$, $P > 0.05$)
Sphaerodema sp.	($r = -0.2234$, $P > 0.05$)
Atherix sp.	($r = -0.2055$, $P > 0.05$)
Cybister sp.	($r = -0.2078$, $P > 0.05$)
Tabanus sp.	($r = -0.2905$, $P > 0.05$)
Hydrophilus sp.	($r = -0.1121$, $P > 0.05$)

3.5.6.8. Correlation between Intermediate Egret's and Relative Abundance of Aquatic Insects in POME Pond Number Three

Weak Pearson's correlation coefficient was recorded between Intermediate Egret relative abundance and aquatic insects in POME pond number three (Table 3.16) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Table 3.16: Pearson's correlation coefficient between Intermediate Egret relative abundance and aquatic insects relative abundance in POME pond number three

Scientific Name	Pearson's Correlation Coefficient (PCC)
Aedes sp.	($r = -0.5288$, $P > 0.05$)
Eristalis sp.	($r = -0.3224$, $P > 0.05$)
Stenolopus sp.	($r = -0.3261$, $P > 0.05$)
Eretes sp.	($r = -0.2982$, $P > 0.05$)
Thaumalea sp.	($r = -0.1854$, $P > 0.05$)
Chironomus sp.	($r = -0.3102$, $P > 0.05$)
Dytiscus sp.	($r = -0.2466$, $P > 0.05$)
Sphaerodema sp.	($r = -0.2495$, $P > 0.05$)
Atherix sp.	($r = -0.2430$, $P > 0.05$)
Cybister sp.	($r = -0.2780$, $P > 0.05$)
Tabanus sp.	($r = -0.2998$, $P > 0.05$)
Hydrophilus sp.	($r = -0.1701$, $P > 0.05$)

3.5.6.9. Correlation between Chinese Egret's and Relative Abundance of Aquatic Insects in POME Pond Number One

PCC test shows a weak correlation between Chinese Egret relative abundance and food diversity in POME pond number one (Table 3.17) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Table 3.17: Pearson's correlation coefficient between Chinese Egret relative abundance and aquatic insects relative abundance in POME pond number one

Scientific Name	**Pearson's Correlation Coefficient (PCC)**
Aedes sp.	($r = -0.5245$, $P > 0.05$)
Eristalis sp.	($r = -0.3079$, $P > 0.05$)
Stenolopus sp.	($r = -0.3567$, $P > 0.05$)
Eretes sp.	($r = -0.2583$, $P > 0.05$)
Thaumalea sp.	($r = -0.1744$, $P > 0.05$)
Chironomus sp.	($r = -0.2727$, $P > 0.05$)
Dytiscus sp.	($r = -0.2408$, $P > 0.05$)
Sphaerodema sp.	($r = -0.2696$, $P > 0.05$)
Atherix sp.	($r = -0.2544$, $P > 0.05$)
Cybister sp.	($r = -0.2587$, $P > 0.05$)
Tabanus sp.	($r = -0.3468$, $P > 0.05$)
Hydrophilus sp.	($r = -0.1693$, $P > 0.05$)

3.5.6.10. Correlation between Chinese Egret's and Relative Abundance of Aquatic Insects in POME Pond Number Three

Pearson correlation analysis indicates weak relationship between Chinese Egret relative abundance and food resources in POME pond number three (Table 3.18) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Table 3.18: Pearson's correlation coefficient between Chinese Egret relative abundance and aquatic insects relative abundance in POME pond number three

Scientific Name	Pearson's Correlation Coefficient (PCC)
Aedes sp.	($r = -0.5281$, $P > 0.05$)
Eristalis sp.	($r = -0.3234$, $P > 0.05$)
Stenolopus sp.	($r = -0.3282$, $P > 0.05$)
Eretes sp.	($r = -0.3089$, $P > 0.05$)
Thaumalea sp.	($r = -0.2087$, $P > 0.05$)
Chironomus sp.	($r = -0.3232$, $P > 0.05$)
Dytiscus sp.	($r = -0.2591$, $P > 0.05$)
Sphaerodema sp.	($r = -0.2544$, $P > 0.05$)
Atherix sp.	($r = -0.2592$, $P > 0.05$)
Cybister sp.	($r = -0.2924$, $P > 0.05$)
Tabanus sp.	($r = -0.3133$, $P > 0.05$)
Hydrophilus sp.	($r = -0.1890$, $P > 0.05$)

3.7. DISCUSSION

Aquatic insects are invertebrates that spent most of its life-cycle in the water (Budin *et al.*, 2007) and play an important role in the structuring and functioning of wetland ecosystem (Mitsch and Gosselink 2000). They are an essential component of the diet of wetland dependent birds (Anderson and Smith 2000; Davis and Bidwell, 2007).

The recording of twelve species of aquatic insects in two POME ponds showed that the ponds are able to provide suitable habitat for a wide array of aquatic insects. It was recorded that aquatic insects abundance changes dramatically from January to June and vary among two POME ponds. However, there was a fluctuation in aquatic insect occurrence among ponds during the sampling period. For example, only four invertebrate species were recorded in January while four aquatic insect species were absent from all POME ponds in February. Moreover, many aquatic insects are highly sensitive to changes in water chemistry, substrate composition, and plant community structure (Batzer *et al*., 1999). The changes in the occurrence and abundance in aquatic insects population is due to fluctuation in water level (Mitsch and Gosselink, 2000), water temperature (Manikannan *et al*., 2012), and effluent from palm oil mill that affects water quality (for detail please refer table 5.5). Chotwattanasak and Puetpaiboon (2011) had reported that the invertebrate population may change due to fluctuation in temperature, electric conductivity, salinity, dissolve oxygen, pH, ammonium, and turbidity.

A change in aquatic insects occurrence among four POME ponds was clearly recorded. Ponds number one and three provided most attractive habitat for aquatic insects. This is because pond number one is rich with compacted material and pond number three contained dead or decomposed vegetative materials. This provides ideal habitat for invertebrates and protect them from predators and harsh weather (Harris and Strayer, 2011).

POME pond number one was rich in mosquito larvae and heavily utilized by egrets compared to other ponds. Trocki and Paton (2006) reported that ditches that are rich in mosquito often provide suitable foraging habitat for egrets. This study shows that egrets are avoiding ponds that have Cattail plant (*Phragmities* sp.) such as POME pond number two. Preys in vegetated area are less visible and inaccessible to predators (Benoit and Askins, 1999; Shriver and Vickery, 2001).

It was observed that effluent from oil mills are affecting water quality (such as water temperature) and eventually influence the distribution of aquatic invertebrates. The results also indicated that the abundance and richness of invertebrates have affected the distribution of egrets in POME ponds. For example no egret was seen foraging in POME ponds number two and four. This was due to the absence of aquatic insects in POME ponds number two and four. Therefore the availability of food resources such as aquatic insects is highly important in egrets' habitat selection and distribution. Previous findings also indicated that invertebrates such as beetles, locusts, grasshoppers, dragonfly larvae, mole crickets, crickets, crustaceans, molluscs, spiders, leeches, water bugs, and worms are major part of the diet of egrets (Voisin, 1991; del Hoyo *et al.*, 1992; Hockey *et al.*, 2005; Kushlan and Hancock, 2005; McKenna, 2011). The results indicated that aquatic insects are abundantly present in POME ponds number one and three but none from ponds number two and four. In addition, food abundance and prey availability in feeding and breeding grounds are important factors that influence colony size, distribution and richness of avian species such as White Storks (*Ciconia ciconia*) (Goriup and Schulz, 1991), wading birds (Hafner, 1997), and Great Blue Heron (*A. herodias*) (Gibbs and Kinkel, 1997).

In this study it was founded that less vegetated areas have higher abundance of aquatic insects. This might be due to occurrence and richness of organic material which provide plenty of food and shelter for aquatic insects. The richness of organic matter that discharged from the oil mill offers a suitable environment for aquatic insects. POME ponds number one and three for example have more aquatic insects compared to POME ponds number two and four. This is in contrast with Longcore *et al.* (2006), Kostecke *et al.* (2005), Masifwa *et al.* (2001) and Sharitz and Batzer (1999) which stated that vegetated wetlands may harbour more invertebrates than non-vegetated wetlands because vegetation provides food, cover and breeding habitat. Likewise, Olson *et al*. (1995) stated that invertebrate biomass, density and diversity may depend on the aquatic plant composition and physiognomic characteristics of the pond, e.g., surface area. de Szalay and Resh (2000) demonstrated that some aquatic insects communities such as mosquitoes (Culicidae), brine flies (Ephydridae) and hover flies (Syrphidae) were positively correlated with amount of plant cover while other communities such as water boatmen (Corixidae), midges (Chironomidae) and water scavenger beetles (Hydrophilidae) were negatively correlated with plant cover.

CHAPTER 4

FORAGING STRATEGY OF EGRETS IN POME PONDS

4.1. Introduction

Foraging behavior is one of the most important activities for any avian species as it is important for survival and reproduction (Yu-Seong *et al.*, 2008). The method used by birds to search for food determines how and which kind of prey they will encounter. This was reflected by different foraging strategies used by the species. Detailed study on foraging strategy provides broader information about foraging behaviour and tactics used by various bird species in particular habitats. Approximately 41 foraging strategies based on movement, body and head postures, and use of wing or feet have been reported in the family Ardeidae that include egrets, herons and bitterns (Appendix 2.1; Kushlan and Hancock, 2005; Mckilligan, 2005).

The foraging ecology is often characterized by food selection, habitat preferences and prey capturing tactic or behaviour. The emphasis in avian foraging ecology was focused on prey capturing technique and pattern of distribution or abundance of bird species in particular area. The foraging behavior can be broadly defined as the allocation, acquisition and assimilation of food by avian species. It is an essential aspect of avian species in which they obtained and consumed their food sources using various tactics.

The foraging ecology of egrets such as food intake, prey capture rate, and percentage of successful pecks had been investigated in various habitats such as rice fields, freshwater marshes, salt marshes, rivers, and estuaries (Custer *et al.*, 2004; Trocki and Paton, 2006; Taylor and Schultz, 2008). Diamalexis *et al.* (1997) determined the foraging strategies employed by Grey Heron (*Ardea cinerea*), Great Egret (*C. albus*), and Little Egret (*E. garzetta*) such as strike rate, foraging effort per minute and effort per strike as well as parameters of foraging efficiency such as striking efficiency, captures per unit effort and biomass intake per unit. Their results indicated that each species had adopted different foraging strategies and had achieved various degrees of efficiencies depending on lake characteristics, habitat conditions and prey characteristics. Little Egret adopted greatest plasticity in foraging strategy, with regard to mobility and prey preference. Great Egret and Grey Heron consumed larger amounts of biomass per unit effort as compared to Little Egret.

Scientists have been monitoring egrets foraging behavior in different habitats. These include Great Egret feeding on dragonflies in Florida, USA (Stolen, 2005), Cattle Egret foraging in solid municipal waste dump area in Kerala, India (Seedikkoya *et al*., 2007), Great Egret (*A. alba*) and Snowy Egret (*E. thula*) utilizing two different water bodies in Kansas (Maccarone and Brzorad, 2007), Cattle Egret (*B. ibis*) feeding behavior in Nigeria (Sharah *et al*., 2008), Cattle Egret forages on maggots in Kerala state, India (Seedikkoya and Azeez, 2009), Great Egret and Snowy Egret forage in specific site within National Wildlife Refuge, Florida (Lantz *et al*., 2010), and Great Egret and Snowy Egret forage in New York–New Jersey region (Brzorad *et al*., 2004).

Many researchers have reported strong association between wading birds and prey abundance. For example, Richardson *et al.* (2001) assessed the adequacy of irrigated rice fields as substitutes for natural wetlands for foraging egrets in Southeast Australia. The densities of Intermediate Egret and Great Egret reached maximum after four to six weeks of crop sowing, then declined. The reduction in densities was due to decrease in prey capture rates that caused diet shift from vertebrate to invertebrate. Sharah *et al.* (2008) studied foraging and nesting ecology of Cattle Egret in pastures, farmlands and grasslands alongside grazing livestock of Nigeria. Other studies reported that the selection of foraging habitat is important in ensuring foraging success and affects the survival of both juvenile and adult birds (Hafner and Fasola, 1992; Frederick and Spalding, 1994).

Egrets are gregarious birds and forage on various food items that occur in shallow wetland habitat (Frederick, 2002). Unfortunately, research on foraging behavior of egrets in various habitats particularly POME (Palm Oil Mill Effluent) ponds, lakes, wetlands and aquacultural ponds in Malaysia is lacking. Information on egrets foraging strategy in POME ponds area is unavailable, even though these species commonly occurs in variety of aquatic habitats. To date no detail study has been done to examine the foraging strategies of egrets in POME area.

4.2. Objectives

The main objectives of this study are:

1. To determine foraging strategies (such as probing per minute, walking slowly or quickly, stand and wait or stand and feed, wing flick and foot shuffle) adopted by five species of egrets in the POME pond area.

2. To study temporal and spatial relationships of foraging strategy of various egret species in the POME pond area.

4.3. Materials and Methods

4.3.1. Study Site

A detail about study site is presented in section 2.3.1 on page 24.

4.3.2 Observations on Egrets Foraging Strategy

Foraging strategies (such as probing, walking slowly, walking quickly, lean and wait, stand and wait, stand and feed, wing flick, foot shuffle, gleaning, and aggressive behaviour) of egrets were observed using binoculars (10X42 magnification). In addition, digital video camera was also used to record egrets foraging activity. A tent was setup in dense vegetation along the bank (Figure 4.1) and was used as a hide to minimize the effect of human presence on egret behaviours. Observations were conducted from 0900 to 1800 hours and categorized hourly to identify daily pattern of foraging activity. Foraging strategy was recorded from January to December, 2008. The methodology was described in detail by Kushlan (2007), Sharah *et al.* (2008), Yu-Seong *et al.* (2008) and Choi *et al*. (2010).

Figure 4.1: A tent was used as a hide during observation sessions

Egrets are active forager. They employ various foraging strategies and prey capture techniques in particular habitat or under specific condition. This allow them to walk slowly, standing and wait, and also to detect the prey items which occur at various water depths. The examples of foraging strategies and its brief explanation are listed below:

Probing per minute: It is an exploratory action done by egrets to exploit the food sources (such as worms, crustaceans and invertebrates) in mud and shallow water for a minute.

Stand and Wait: Egrets stand and wait motionlessly in the water or on river bank for a long period, waiting for prey to come within the range of their neck and sharp bill. When it spots a prey, it quickly stabs at it. There are two basic postures in stand and wait behaviour, i.e. upright posture and crouched posture. In upright posture the body is held erect, head and neck are fully extended angled away from the body while in crouched posture the body is held horizontal to the water surface, legs are bent, and the head and neck are partially retracted. The upright posture allowed egrets to detect prey at greater depth. The stand and wait method is best used for catching relatively large prey in deep waters or to detect hidden or cryptic prey (Tojo, 1996; Richardson *et al.*, 2001). Variation can be observed in stand and wait behavior such as bill vibrating or tongue flicking (bill tip is submerged in water, open and closed rapidly to attract the prey), baiting (a bait is put into the water to attract the prey) and fly catching (catching flying invertebrates) (McKenna, 2011; Steele, 2011).

Gleaning: Egrets pick their prey from object above the ground or water (Stolen, 2005).

Walk Slowly: Egrets move slowly to stalk their prey. Walking becomes slower as the egrets examine prey items or areas of interest. Walking method is appropriate for catching sedentary or slow moving prey in shallow water (Dimalexis *et al.,* 1997).

Walk Quickly: Egrets walk thoroughly in shallow water to catch prey that was disturbed (Brzorad *et al.*, 2004).

Wing Flicking: Egrets walk slowly in an upright posture with extended wings to chase their prey in shallow waters (McKenna, 2011).

Foot Stirring or Shuffling: Egrets extend its leg forward and vibrates its foot to rake the substrate with its toes while wading in shallow water to disperse the prey such as benthic invertebrates that are resting at the bottom of the pond or sometimes to attract small fishes. Foot stirs mostly used in muddy shallow waters along the edges and submerged vegetated materials. They use their feet to stir up the water and scare intended prey (McKenna, 2011; Steele, 2011).

4.4 DATA ANALYSIS

4.4.1 Relative Abundance of Foraging Strategies

The recorded foraging strategies of five egret species were analyzed according to hours, and the hourly frequency was determined by;

$$n/N \times 100$$

Where n is the number of particular foraging activity per minute for each species and N is total recorded foraging strategy per minute.

4.4.2. Analysis of Variance

The significant difference in mean foraging strategy per minute among five egret species was compared by applying the one-way analysis of variance (ANOVA) and Tukey's (HSD) test. The analysis of ANOVA and Tukey's (HSD) test was discussed in detail in section 2.4.2 on page 31 and 2.4.3 on page 33.

4.4.3. Correlation between Egret Foraging Strategy and Relative Abundance of Aquatic Insects

Pearson's Correlation Coefficient (PCC) was used to determine the correlation between egret foraging strategy and aquatic insect relative abundances in POME ponds (for details please refer Chapter 3, section 3.4.4. page 75).

4.5. RESULTS

A total of five species of egrets was recorded frequenting POME pond in Carey Island, Selangor. They were studied for a total of 48 days (i.e. once a week or four days a month) at all POME ponds, which were identified as pond number one to pond number four. Egrets were recorded presence in pond number one and pond number three but totally absent from pond number two and pond number four. Therefore, the information on foraging strategies of egrets in POME area was derived from observations made in ponds number one and three only.

Although previous studies have documented 41 different foraging strategies employed by egrets in catching their prey, only nine foraging strategies were adopted by egrets that utilizing POME ponds in Carey Island. Among these strategies, it was observed that probing was the most commonly used technique.

4.5.1. Probing Per Minute

The results indicate that Little Egret had higher mean probing activity during morning i.e. from 0900 to 1000 hours (52 times per minute) followed by 1000 to 1100 hours (46 times per minute) and 1100 to 1200 hours (42 times per minute). The lowest probing activity was recorded during afternoon i.e. 1700 to 1800 hours (only 4 times per minute) (Table 4.1).

A total of 1186 sightings of Cattle Egret was recorded throughout the study period. The highest mean probing activity was recorded during morning hours i.e. 42 times per minute (0900 to 1000 hours), 37 times per minute (1000 to 1100 hours) and 33 times per minute (1100 to 1200 hours). On the contrary, the lowest probing activity was recorded in the afternoon, during 1700 to 1800 hours (Table 4.1).

Intermediate Egret was also abundantly sighted (956 recorded sightings). Its highest mean probing activity was 20 times/minute and was recorded in the morning from 0900 to 1000 hours. The lowest probing activity was three times/minute which was recorded in the afternoon i.e. from 1700 to 1800 hours (Table 4.1).

A total of 1023 sightings of Great Egret involved in probing activity was recorded. The results show that Great Egret had higher probing activity during 0900 to 1000 hours (i.e. 5 probes/minute) and lowest probing activity during 1700 to 1800 hours (i.e. 0.4 probes/minute; Table 4.1).

A total of 262 sightings of Chinese Egret that related to probing activity were observed. The results indicated that Chinese Egret had higher probing activity (19 probes/minute) from 0900 to 1000 hours and its lowest probing activity (one probe/minute) was from 1700 to 1800 hours (Table 4.1).

The results showed that Little Egret had the highest probing activity (232 probes per minute) while Great Egret had the lowest probing activity (19 probes per minute). Cattle Egret, Intermediate Egret and Chinese Egret recorded second, third and fourth highest probing activity with 175, 83 and 74 probes/minute respectively. All egrets exhibited highest probing activities between 0900 to 1000 hours and lowest probing activity between 1700 to 1800 hours. They showed similar activity pattern from morning to afternoon. Among the egrets, the highest probing activity was observed in the morning by Little Egret (52 probes per minute) and the lowest probing activity was shown by the Great Egret (0.4 probe per minute) at 1700-1800 hours. The results showed that the mean probing activity per minute for Little Egret, Intermediate Egret and Great Egret was significantly different ($F_{4,\ 35} = 8.22$, $P < 0.05$) (Table 4.2).

Table 4.1: Average of daily sightings and mean probing activity (in parenthesis) of egrets utilizing POME ponds at different hours.

Time (Hours)	Little Egret	Intermediate Egret	Cattle Egret	Great Egret	Chinese Egret
0900-1000	270 (52)	178 (20)	232 (42)	185 (5)	65 (19)
1000-1100	220 (46)	165 (15)	184 (37)	168 (4)	44 (15)
1100-1200	190 (52)	140 (13)	156 (33)	144 (3)	35 (13)
1200-1300	160 (24)	125 (12)	142 (21)	125 (3)	32 (10)
1300- 1400	108 (36)	86 (9)	100 (18)	98 (2)	26 (7)
1500-1600	120 (21)	74 (7)	112 (14)	85 (1)	20 (5)
1600-1700	135 (11)	80 (4)	124 (8)	100 (0.6)	18 (4)
1700-1800	145 (4)	108 (3)	136 (2)	118 (0.4)	22 (1)
Total	1348 (236)	956 (83)	1186 (175)	1023 (19)	262 (74)

Table 4.2: Comparison of probing activity per minute between five egret species at POME ponds in Carey Island, Selangor.

Species Name	Mean Probing Per Minute
Little Egret	29.50 a
Cattle Egret	21.88 a
Intermediate Egret	10.78 b
Chinese Egret	9.25 b
Great Egret	2.38 c

(The mean values bearing similar letter are not significant at P = 0.05, Tukey's HSD test; Critical Value, 15.39)

4.5.2. Other Foraging Strategies Employed by Egrets

Additional foraging strategies showed by egrets include walking slowly or quickly, stand and wait or stand and feed, wing flick and foot shuffle. Among these strategies, the most frequent strategies used by Great Egret were walking slowly (52.6%) and stand and wait (25.3%). Sometimes egrets followed their prey quickly (1.4%). For Little Egret, walking quickly (38.2%) and stand and wait (23.3%) were the most dominant foraging strategies and it was the only species that employs foot shuffling technique.

For Intermediate Egret, the major foraging techniques were walked slowly (38.2%) and lean and wait (31.0%). The key foraging behaviour for Cattle Egret was walking slowly

(48.0%) but sometimes they also glean their prey hidden under soft mud. Walk slowly (46.6%) was the dominant foraging behaviour of Chinese Egret (Table 4.3).

Table 4.3: Frequency of foraging strategies employed by egrets species in POME ponds of Carey Island, Peninsular Malaysia (n = total number of sightings).

Method Employed By Egrets During Foraging	Species Name				
	Great Egret (n = 860)	Little Egret (n = 1080)	Intermediate Egret (n = 620)	Cattle Egret (n = 740)	Chinese Egret (n = 180)
Walk Slowly (WS)	52.6%	38.2%	38.2%	48.0%	46.6%
Walk Quickly (WQ)	1.4%	5.4%	3.4%	3.3%	2.0%
Lean and Wait (LW)	15.0%	5.2%	31.0%	16.0%	06.4%
Stand and Wait (SW)	25.3%	7.6%	17.6%	12.5%	19.8%
Stand and Feed (SF)	4.7%	23.3%	7.3%	15.0%	21.2%
Wing Flick (WF)	-	2.3%	1.3%	2.0%	3.0%
Foot Shuffling (FS)	-	16.0%	-	-	-
Gleaning (G)	-	-	-	2.2%	-
Aggressive (A)	1.0%	2.0%	1.2%	1.0%	1.0%

4.5.3. Correlation between Egret Probing Rate and Relative Abundance of Aquatic Invertebrate in POME Pond Number One and Pond Number Three

A weak Pearson correlation was recorded between egret probing rate and relative abundance of aquatic insects i.e. for Little Egret ($r = -0.0665$, $P > 0.05$), Intermediate Egret ($r = -0.0655$, $P > 0.05$), Great Egret ($r = -0.0651$, $P > 0.05$), Cattle Egret ($r = -0.0663$, $P > 0.05$), and Chinese Egret ($r = -0.0655$, $P > 0.05$) in POME pond number one (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Likewise, a weak Pearson correlation was also recorded between egret probing rate and relative abundance of aquatic insects such as Little Egret ($r = -0.1060$, $P > 0.05$), Intermediate Egret ($r = -0.1049$, $P > 0.05$), Great Egret ($r = -0.1045$, $P > 0.05$), Cattle Egret ($r = -0.1057$, $P > 0.05$), and Chinese Egret ($r = -0.1050$, $P > 0.05$) in POME pond number three (for aquatic insect relative abundance please refer section 3.5.2 page 93).

4.5.4. Correlation between Egret Foraging Strategies and Relative Abundance of Aquatic Invertebrate in POME Pond Number One and Pond Number Three

A weak positive correlation was observed between egret foraging activities (such as probing, walking slowly, walking quickly, lean and wait, stand and wait, stand and feed, wing flick, foot shuffle, gleaning, and aggressive) and relative abundance of aquatic insects such as Little Egret ($r = 0.0427$, $P > 0.05$), Intermediate Egret ($r = 0.0434$, $P >$

0.05), Great Egret (r = 0.0429, P > 0.05), Cattle Egret (r = 0.0429, P > 0.05), and Chinese Egret (r = 0.0430, P > 0.05) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

Similarly, a weak positive correlation between egret foraging strategies and aquatic insects was recorded in a POME pond number one i.e., Little Egret (r = 0.0760, P > 0.05), Intermediate Egret (r = 0.0764, P > 0.05), Great Egret (r = 0.0761, P > 0.05), Cattle Egret (r = 0.0761, P > 0.05), and Chinese Egret (r = 0.0762, P > 0.05) in POME pond number three (for aquatic insect relative abundance please refer section 3.5.2 page 93).

4.6. DISCUSSION

Egrets are gregarious and cosmopolitan species that are generally associated with wetland habitat. They usually stalk on a wide array of aquatic invertebrates (such as invertebrate larvae, crustaceans, shrimps, and worms) and vertebrates (such as fishes, amphibians and reptiles) that are available in the wetland area (Kushlan and Hancock, 2005; Moran, 2010). Probing is a non-visual, tactile foraging technique by which egrets quickly and repeatedly move its bill into and out of the water or substrate while preying (Kushlan, 2011). The highest probing technique was recorded for little egret followed by cattle egret while the lowest probing/minute was recorded for great egret. This might be due to food selection and movement behaviour i.e., little egret is and cattle egret are an active forager always keep moving while foraging. In contrast, great egret prefers stand and waiting technique that food may come closer to him within the range of their beak and prefer to hunt larger prey as compared to little egret and cattle egrets.

Overall, the results of this study indicated that egrets are active forager i.e. employs several foraging strategies such as probing, walking, waiting, wing flicking, and foot shuffling to detect available prey items in the POME ponds. Results also indicated that foraging strategy and prey capture technique employed by egrets varies between species. This is because different species of egrets have various lengths of beak, neck, and tarsus which allow them to employ different foraging techniques to capture invertebrates at various water levels. It was recorded that all egrets are using a combination of walking slowly, walking quickly, standing and wait, standing and feed, and aggressive technique during their foraging activity. In addition to these techniques, Little Egret also practiced foot shuffling while Cattle Egret used gleaning method during food searching process. The foot shuffling behaviour employed by Little Egret was aimed to disperse hidden invertebrates in deposited or decomposed materials at the bottom or submerged vegetation. On the contrary, gleaning technique employed by Cattle Egret was to expose invertebrates that were hidden in soft mud and substrates. Only Great Egret does not use wing flicking movement while foraging. This is because most Great Egret patiently waited for their prey to come within the range of their beak. The slowly walking movement was heavily utilized by Great Egret while quickly walking movement was used by Little Egret. Having a small body allows Little Egret to agily move in catching smaller prey while Great Egret is large birds that slowly move while focusing on larger prey. Differences in strategy affected egrets probing activity. Whenever prey items were abundantly distributed, Little Egret will quickly chase and gulp the prey items, denying other egrets. This explains why the mean probing rate was higher for Little Egret.

It was observed that egrets foraging areas were mostly along the pond's edges, in shallow water, or on floating objects such as compacted waste material or dead/fallen trees. This could be due to higher intensities of prey in these sites which lead to easy catch. Food resources in deeper water are widely distributed and more difficult to catch. On the contrary, invertebrates in shallow waters were more concentrated because the water is densely covered with vegetation that provides suitable habitat and protection for invertebrates. Egrets' preference to forage in the edge area is mainly due to the distribution and diversity of invertebrates that utilized edges for feeding, sheltering and breeding (Moreno *et al*., 2005; Hassan-Aboushiba *et al*., 2011). Egrets frequently peer nearby vegetated areas in an upright posture and scanned larger area. Sometimes, they also hunt invertebrates that were sighted within one or two meters by quickly moving for it. Egrets are able to do this because they have a good sense of vision which allows them to detect food resources from a distance (Martin and Katzir, 1994). The larger preys caught were killed with a sharp bill by smashing them on the ground and tearing them into pieces before swallowing. Larger preys were smashed into hard objects to break its shell to facilitate swallowing. In addition, small size diets can be easily digested and quickly assimilated.

Results have shown that Little Egret is the most active egrets in the POME area. This bird employed nine foraging strategies such as walking slowly, walking quickly, lean and wait, stand and wait, stand and feed, wing flick, foot shuffling, gleaning, and aggressive behaviour. Little Egret possesses yellow feet (in contrast to other egrets that have black feet) and this was used to lure aquatic invertebrates or affecting invertebrates movement (Morcombe, 2003). It was observed that once the invertebrates were dispersed, Little Egret quickly picks and gulps them. Little Egret walks slowly and sometime quickly in shallow water with raise wing to chase the invertebrates. In stand and wait technique, Little Egret wait for prey to come within the range of their beak. Most of the time Little Egret used compacted waste material that was floating in the center of the POME pond or somewhere deposited along the banks of the POME ponds for loafing. Such type of foraging strategy employed by Little Egret was recorded in previous studies (Wong *et al*., 2000; Tourenq *et al*., 2001; Yukiko, 2003; Kushlan, 2007).

Intermediate Egret usually forages in open shallow water area that was located along the edges and soil deposition inside the ponds. These areas have less vegetation, allowing egrets to easily obtain its prey. Thick vegetation generally reduced the visibility of prey and inhibits forager from locating and catching the prey. While foraging alone, Intermediate egret usually uses stand and wait behavior. The egret will catch its prey whenever they come within the range of egret's pointed beak and long neck. However, when foraging in a group, the egret will use walking strategy. They will slowly or quickly walk to their prey. Both ponds that were used for foraging are rich with compacted decomposed materials (pond 1) or dead fallen trees (pond 3) that offer suitable place for loafing and foraging. Similar patterns of foraging strategy also have been recorded in previous studies (Stolen, 2006; Yu-Seong *et al*., 2008; Choi *et al*., 2010).

Great Egret mostly forages by using stand and wait method but sometimes also uses walks slowly technique. The latter technique was usually used when it tries to catch larger invertebrates such as beetles, water bugs and fly larvae. Since Great Egret is an opportunistic forager (McCrimmon *et al.*, 2001), it patiently wait for larger prey to come within the range of their beak and neck. Great Egret also forages in the deep water area since it has longer tarsus than other egrets. They caught their prey in fully erect position by extending their neck and hold their beak perpendicular to the ground (Sherry, 2006). However, Great Egret does forages in shallow water when the preys are visible and easy to catch. Furthermore, most invertebrates are congregated in shallow water along the edges due to plentiful of food items. Great Egret also hunted invertebrate in crouch position by extending their beak and hold back against their body. Foraging in crounch position promise successful catch and minimizing disturbance on other prey items. Sometimes Great Egret holds their head close to the water surface to reduce glare effect caused by the bright sun and increase rate of capture success. Previous study of agricultural landscape indicated that Great Egret also utilized similar foraging strategy (Yu-Seong *et al*., 2008).

Great Egret is known to attract other egret species into their foraging areas (Master, 1992; Bildstein *et al.*, 1994; Gawlik, 2002). Other egret species are active foragers (Yu-Seong *et al*., 2008). They will disturb the food resources and allow Great Egret to catch more prey items. Therefore, Great Egret enjoys better foraging success whenever they forage in mixed groups. These egrets prefer larger prey and it was recorded in some occasion when they snatch larger prey from other egrets.

Cattle Egret prefers to forage along wet soil at the edges. It is easier to catch invertebrates on wet soil than the one that hides in the mud. Cattle Egret will walk slowly or quickly and glean invertebrates from low vegetation by rapid pecks. During their movement the invertebrates will disperse which allow Cattle egret to hunt them easily. They prefer to follow cattle that grazing on grasses along the banks of POME ponds while hunting for invertebrates that were disperse due to cattle movement. Cattle Egret will quickly chase any moving invertebrates whenever it was detected.

Chinese Egret prefers to forage extensively along the pond edges that were surrounded by mangrove vegetation and mudflats. It will walks swiftly in shallow water, along the edges and over open tidal-flats to stabs the prey at the mud surface. Any invertebrates on this surface can be easily detected and catched.

Overall, results indicated that egrets are using different types of foraging strategies to catch prey that are available at various sites within POME pond areas such as edges, compacted waste material, and surrounding landscape (i.e. mangroves, oil palm plantation and mudflats). It was discovered that POME pond area is rich in aquatic invertebrates that can be easily detected by egrets. Compacted waste material in POME ponds provides suitable sites for egrets to stand while foraging even in deep water. Furthermore, these compacted waste materials are floating allowing egrets to freely move to various parts of POME ponds. Egrets also prefer to forage in flocks in the morning but opt for solitary foraging during midday. Prey items (e.g. mosquito larvae, hoverfly larvae, water beetles and midge fly larvae) were plentiful and concentrated at water surface during the morning but slowing disappears during midday. As temperature rise, the aquatic insects dive deeper or hide in the substrate or decomposed materials which make them more difficult to be detected. Foraging in aggregation is an important behaviour for egrets. They can minimize searching time and reduce risk of not obtaining any food. Therefore, aggregation behavior can increase foraging success. However, egrets were only concentrated in a particular area or time whenever the prey is abundant. Similar findings were also recorded in Little Egret (Wong *et al*., 2000; Yukiko, 2003), shorebirds (Yates *et al.*, 1996), Grey Plovers (Turpie and Hockey, 1996), and wading birds (Pierce and Gawlik, 2010).

CHAPTER 5

THE QUALITY OF WATER OF VARIOUS POME PONDS

5.1. INTRODUCTION

Nowadays water scarcity and pollution are the most intricate environmental problems in the world and it is becoming more complex due to rapid increase in population and industrialization (Foo and Hameed, 2010). Agricultural industry such as oil palm plantation had growth exponentially to fulfill the demand of increasing human population. Over the last four decades, the palm oil industry had enjoyed a remarkable growth and become a very important agricultural based industry in Malaysia (Chan *et al*., 2010).

Currently a total of 6.6 million hectares or 20% of total Malaysia land area are used for agriculture. In 2008, 4.7 million hectares (or 13.6% of the total land area; 71% of agricultural area) are planted with oil palm. To support this industry, Malaysia has 418 mills, 43 crushers, 59 refineries, 57 downstream industries, and 18 oleochemical plants throughout the country (Figure 5.1; Dompok, 2009). These services have generated 32 million tons of solid biomass and 30 million tons of POME each year (Raja Ehsan Shah and Kaka Singh, 2004; Yacob *et al*., 2005).

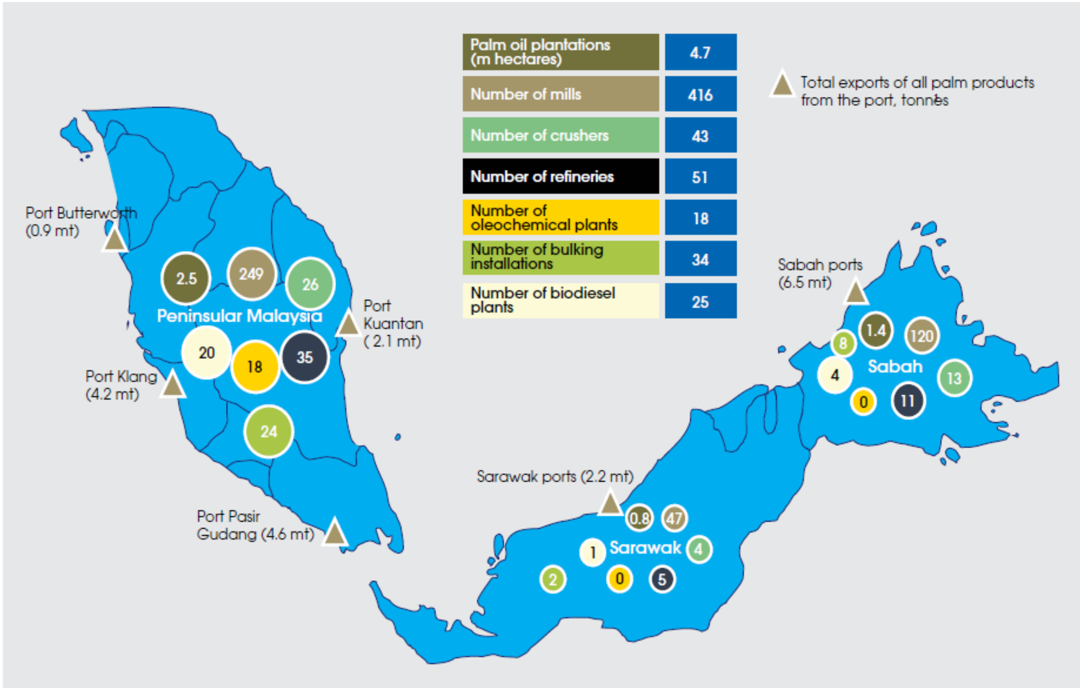

Figure 5.1: Number of mills, crushers and refineries in Malaysia (from Dompok, 2009).

POME is the wastewater from palm oil industry. It is a colloidal suspension consists of 95-96% of water, 0.6-0.7% of oil and 4-5% of total solids including 2-4% of suspended solids. The content of POME is originating from the mixing of sterilizer, separator sludge and hydro–cyclone wastewater (Onyia *et al*., 2001). POME contain an essential amount of amino acids, inorganic nutrients (sodium, potassium, calcium, magnesium, manganese, and iron), short fibers, nitrogenous constituents, free organic acids and an assembly of carbohydrates ranging from hemicelluloses to simple sugars (Santosa, 2008). The percolation of palm oil mill effluents into the waterways and ecosystems is a fastidious concern towards the public health and food chain interference. The palm oil industry in Malaysia is identified as a single largest source of water pollution (Abdullah *et al*., 2004) because it contributes a significant pollution load into the rivers and highest share of solid waste material (POME) in the country (Singh *et al*., 2011). POME has been identified as one of the major sources of water pollution due to its high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Lorestani *et al*., 2006; Chan *et al*., 2010). It has been reported that 2.5 to 3 tons of Palm Oil Mill Effluent (POME) is generated for every ton of crude palm oil produced (Ahmad *et al*., 2005; Kutty *et al*., 2011).

The changes in water quality can influence ecological processes such as vegetation pattern, aquatic productivity, and avian distribution (Davis and Ogden, 1994; Sklar *et al.*, 2001; Bolduck and Afton, 2004). Budin *et al.* (2007) reported that dissolved oxygen (DO), water temperature, total suspended solid (TSS), turbidity (T) and pH are the crucial indicator of water quality. Dissolved oxygen (DO) is the most fundamental parameter in water quality and major element for the survival of aquatic organism inhabiting different aquatic habitats such as ponds, wastewater treatments, rivers, lakes, wetlands, streams, etc. Major sources of dissolve oxygen in water are atmosphere and photosynthesis by aquatic vegetation (CCME, 1999). Oxygen is needed by virtually all living organisms for respiration and many chemical reactions that are important to the function of aquatic ecosystem. Dissolved oxygen concentration changed dramatically with water depth and it also influenced by temperature, amount of pollutants and density of aquatic organisms occur in aquatic environment (Michaud, 1991).

Water temperature is a physical property that quantitatively expresses the common notions of hot and cold. Water temperature is a driving force in aquatic life because its effects growth and survival of aquatic vegetation and aquatic animals (Gadowaski and Caddell, 1991). Water temperature affects the ability of water to hold oxygen, the rate of photosynthesis by aquatic plants and the metabolic rates of aquatic animals. Weather, removal of shading stream bank vegetation, impoundments, and discharge from industrial plants, domestic sewage and runoff from agricultural field may cause fluctuation in water temperature.

Turbidity is a measure of the amount of particulate matter (organic and inorganic particles, suspended matter, and dissolved substances) that is suspended in water and contribute the color of water. High and sustained levels of sediemnts may caused permanent alteration in community structure, diversity, density, biomass, growth and reproduction rate of aquatic organims (Henely *et al.*, 2000). Water that has high turbidity appears cloudy or opaque. High turbidity can cause increased water temperatures because suspended particles absorb more heat and can also reduce the amount of light penetrating the water. Turbidity is affected by concentration of silt, microorganisms, aquatic vegetation, wood ashes and chemicals discharged from industrial waste. Rowe *et al.* (2002) examined the effects of high turbidity levels on the survival of six species of aquatic invertebrate (i.e. caddis flies, damselfly, mayflies and crayfish) and found that aquatic invertebrates were sensitive to the increase in turbidity. High turbidity can reduce invertebrate abundance and diversity by (a) smothering and abrading, (b) reducing the periphyton food supply, and (c) affecting interstitial habitat of aquatic invertebrates (Death, 2000). It also has been reported that high turbidity also often results in sediment deposition, altering substrate composition and changing substrate suitability for aquatic invertebrates (Wood and Armitage, 1997). Sedimentation and turbidity are major factors that decreased the quality of habitat by reducing food availability for zooplankton, insects, and mollusk (Henely *et al.*, 2000). This ultimately will cause population of aquatic organism to decline (Richter *et al.*, 1997).

pH is an index of the concentration of hydrogen ions (H^+) in the water. It is defined as – log (H^+). pH is a measure of the acidity or alkalinity of water, expressed in terms of concentration of hydrogen ions. pH of the water determine the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.) (Michaud, 1991). Changes in pH are not likely to have a direct impact on aquatic life but it will greatly influences the availability and solubility of all chemical forms and may aggravate nutrient problems. For example, a change in pH may increase the solubility of phosphorus, making it more available for plant growth and resulting in a greater long-term demand for dissolved oxygen (Michaud, 1991). pH of water is influenced by temperature, pollution and suspended solids. Suspended solids produce two main ecological effects that can affect aquatic invertebrate communities such as an increased turbidity of water and siltation (Rowe *et al.*, 2002). It also has been reported that pH of wetlands water have profound influence on avian population characteristics (Manikannan *et al*., 2012)

Conductivity is a measure of the capacity of water to conduct electrical current. It is directly related to the concentration of dissolved solids in the water such as chloride, sulfate, sodium, calcium and others. The higher value of electric conductivity affects distributions and populations of macro-invertebrate such as arthropods (mayflies, mites and crustaceans), mollusks (gastropods and bivalves), anellids (oligochaetes), nematoda, and platyhelminthes in water bodies (Pamplin *et al*., 2006; TTASM, 2013).

A wide range of approaches for the treatment of POME have been developed to alleviate the pollution problem caused by palm oil industry. The most frequently used method in treating raw effluent (POME) is a pond system comprising of three phases, i.e. anaerobic, facultative, and algae processes. Although this system takes longer retention time (that can be completed in 40 days), it is less sensitive to environment changes, stable, efficient and could guarantee excellent pollutant biodegradation efficiency of above 95% (Baharuddin *et al*., 2009). Three-phase-decanter ponding system is an effective method to reduce the biological and chemical constituents of POME. The system removes 60 - 80% of chemical oxygen demand (COD), turbidity, color, and suspended solids (Raja Ehsan Shah and Kaka Singh, 2004). In Malaysia, ponding system is the most common treatment method for POME treatment (Wu *et al.*, 2010) and more than 85% of the palm oil mills have adopted open pond system due to low capital and operating cost (Ma *et al*., 1993; Lorestani, 2006; Alawi *et al.*, 2009; Baharuddin *et al*., 2010).

5.2. Objectives

The objective of this study is to measure various parameters of water quality such as temperature (^{0}C), conductivity (µs), dissolve oxygen (mg/l), pH, ammonium concentration (mg/l) and turbidity (NTU) of four POME ponds that are available in Carey Island. Findings of this study will enhance the understanding on the effects of water quality on egret’s distribution.

5.3. MATERIALS AND METHODS

5.3.1. Study Site

A detail about the study site is presented in section 2.3.1 page 24.

5.3.2. Measurement of Water Parameters

The water quality parameters such as temperature (^{0}C), conductivity (μs), dissolve oxygen (mg/l), pH, ammonium (mg/l), and turbidity (NTU) were measured using multi probe YSI model 6600 (Figure 5.2). The water was sampled four times from 0900 to 1300 hours every two weeks in January and February, 2010. Water quality data was averaged for each POME ponds.

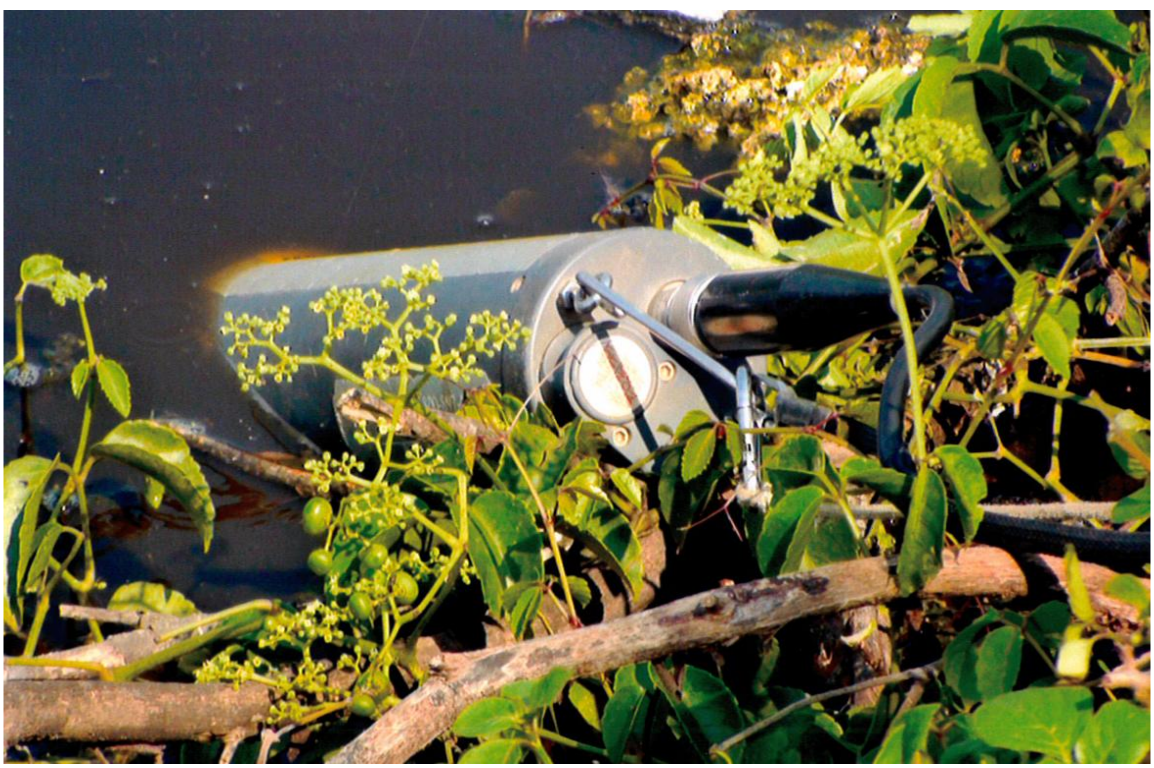

Figure 5.2: Water quality sampling using YSI 6600 Multi Parameters

Figure 5.3: YSI 6600 Multi Parameters

5.4. Data Analysis

5.4.1. Standard Deviation

Variation in water quality parameters of four POME ponds was measured by using standard deviation. The standard deviation is the square root of variance as in this formula:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2}$$

Where; σ = standard deviation, x_i = each value of dataset, x (with a bar over it) = the arithmetic mean of the data, N = the total number of observations and $\sum (xi - \mu)^2$ = the sum of $(x_i - \mu)^2$ for all data points.

5.4.2. Correlation between Egret's Relative Abundance and Water Quality Parameters

Pearson's Correlation Coefficient (PCC) was used to determine the correlation between egret relative abundance and water quality parameters in POME ponds (for detail please view chapter two, section 3.4.4, page 75).

5.5. RESULTS

5.5.1. Water Quality Parameters of POME Pond Number One

The results of water quality parameters of POME pond number one indicate that there was a fluctuation in the water quality parameters. The highest value for water temperature (35.36^{0}C), conductivity (5685 µs), and turbidity (89.6) was recorded in POME pond number one during first week of January while the highest value for dissolve oxygen (3.73mg/l), pH (8.97), and ammonium concentration (28.05mg/l) was recorded in the first week of February. In contrast, the lowest value for water temperature (34.43^{0}C), dissolve oxygen (3.43mg/l), ammonium concentration (26.18mg/l) and turbidity (88.2^0) was recorded in second week of January, while the lowest value for conductivity (5564 µs) and pH (8.57) was recorded in second week of February (Table 5.1).

Table 5.1. The value of various water parameters sampled from POME pond number one in Carey Island.

S. No	Water Parameters	Schedule of water sampling				Mean Value
		01-01-2010	15-01-2010	01-02-2010	15-02-2010	
1	Temperature (^{0}C)	35.36^{0}C	34.43^{0}C	35.16^{0}C	34.76^{0}C	34.93^{0}C
2	Electric Conductivity (µs)	5685 µs	5602 µs	5593 µs	5564 µs	5611 µs
3	Dissolve Oxygen (mg/l)	3.62mg/l	3.34mg/l	3.73mg/l	3.69mg/l	3.60mg/l
4	pH	8.76	8.83	8.97	8.57	8.78
5	Ammonium (mg/l)	26.18mg/l	27.17mg/l	28.05mg/l	27.45 mg/l	27.21mg/l
6	Turbidity (NTU)	89.6	88.7	88.9	88.2	88.85

5.5.2. Water Quality Parameters of POME Pond Number Two

The highest value for water temperature (32.64^{0}C) and conductivity (3211 µs) for POME pond number two was recorded in second week of January and the lowest value was recorded in second week of February. The highest value for pH (8.60) and ammonium concentration (21.50 mg/l) was recorded in second week of February and the lowest value was recorded in second week of January. Furthermore, the highest value for dissolve oxygen (2.84mg/l) and turbidity (56.0) was recorded in first week of February. In contrast, the lowest value for salinity (1.6%), dissolve oxygen (2.65mg/l) and turbidity (55.2) was recorded during second week of February (Table 5.2).

5.5.3. Water Quality Parameters of POME Pond Number Three

High value for water temperature (36.56^{0}C), electric conductivity (5213 µs), dissolve oxygen (3.28mg/l), ammonium concentration (27.74mg/l), pH (8.60), and turbidity (89.2) was recorded in second week of February. In contrast, the lowest value for temperature, conductivity, dissolve oxygen, pH and turbidity was recorded in second week of January (Table 5.3).

Table 5.2. The value of various water parameters sampled from POME pond number two in Carey Island.

S. No	Water Parameters	Schedule of water sampling				Mean Value
		01-01-2010	15-01-2010	01-02-2010	15-02-2010	
1	Temperature (^{0}C)	31.36^{0}C	32.64^{0}C	32.46^{0}C	31.26^{0}C	31.93 ^{0}C
2	Electric Conductivity (µs)	3211 µs	3134 µs	3140 µs	3064 µs	3137.25
3	Dissolve Oxygen (mg/l)	2.69mg/l	2.74mg/l	2.84mg/l	2.65mg/l	2.73mg/l
4	pH	8.48	8.45	8.58	8.60	8.53
5	Ammonium (mg/l)	21.43mg/l	21.27mg/l	21.38mg/l	21.50 mg/l	21.40mg/l
6	Turbidity (NTU)	55.4	55.8	56.0	55.2	55.6

Table 5.3. The values of various water parameters sampled from POME pond number three in Carey Island

S. No	Water Parameters	Schedule of water sampling				Mean Value
		01-01-2010	**15-01-2010**	**01-02-2010**	**15-02-2010**	
1	Temperature (^{0}C)	36.53^{0}C	36.14^{0}C	36.36^{0}C	36.56^{0}C	36.40^{0}C
2	Electric Conductivity (µs)	5156 µs	5097 µs	5134 µs	5213 µs	5150 µs
3	Dissolve Oxygen (mg/l)	3.22mg/l	3.18mg/l	3.24mg/l	3.28mg/l	3.23mg/l
4	pH	8.84	8.75	8.70	8.79	8.73
5	Ammonium (mg/l)	27.52mg/l	27.64mg/l	27.47mg/l	27.74 mg/l	27.59mg/l
6	Turbidity (NTU)	88.3	87.9	88.6	89.2	88.55

5.5.4. Water Quality Parameters of POME Pond Number Four

The results show that water quality parameters of POME pond number four fluctuate. The highest conductivity was recorded during first week of February and the lowest value was recorded in second week of February. Highest value for dissolve oxygen, pH, ammonium concentration and turbidity was recorded during second week of January. In contrast, the lowest value of dissolve oxygen, pH, ammonium concentration and turbidity was obtained during first week of January (Table 5.4).

5.5.5. Mean Water Quality Parameters and Their Standard Deviation

The highest value of water temperature (36.46^{0}C) was recorded in pond number three and the lowest value of water temperature (30.26^{0}C) was recorded in pond number four. The highest value for conductivity (5611µs), dissolve oxygen (3.60mg/l), turbidity (88.5^0), and pH (8.78) was recorded in pond number one and lowest value for conductivity (1668 µs), dissolve oxygen (1.64mg/l), turbidity (48.35^0) and pH (6.66) was recorded in pond number four. The highest value for ammonium concentration (27.59mg/l) was recorded in pond number three and the lowest value for ammonium concentration (18.32 mg/l) was recorded in pond number four. In addition, the highest value for salinity was recorded in pond number one and the lowest value for salinity was recorded in pond number two (Table 5.5).

Table 5.4: The values of various water parameters sampled from POME pond number four in Carey Island

S. No	Water Parameters	Schedule of water quality survey				Mean Value
		01-01-2010	15-01-2010	01-02-2010	15-02-2010	
1	Temperature (^{0}C)	30.35^{0}C	30.24^{0}C	30.42^{0}C	30.29^{0}C	30.33^{0}C
2	Electric Conductivity (µs)	1654 µs	1684 µs	1700 µs	1634 µs	1668 µs
3	Dissolve Oxygen (mg/l)	1.52mg/l	1.78mg/l	1.64mg/l	1.62mg/l	1.64mg/l
4	pH	6.58	6.74	6.64	6.69	6.66
5	Ammonium (mg/l)	18.17mg/l	18.54mg/l	18.35mg/l	18.22 mg/l	18.32mg/l
6	Turbidity (NTU)	47.8	48.9	48.5	48.2	48.35

Table 5.5: Value of various water parameters sampled from POME ponds in Carey Island.

S. No	Water Parameters	Average Values					Standard Deviation
		Pond 1	Pond 2	Pond 3	Pond 4	Mean Temp.	
1	Temperature (^{0}C)	34.93^{0}C	31.93 ^{0}C	36.40^{0}C	30.33^{0}C	33.40 ^{0}C	2.815
2	Electric Conductivity (µs)	5611 µs	3137.25	5150 µs	1668 µs	3891.56 µs	1841.1
3	Dissolve Oxygen (mg/l)	3.60mg/l	2.73mg/l	3.23mg/l	1.64mg/l	2.8mg/l	0.836
4	pH	8.78	8.53	8.73	6.66	8.18	1.041
5	Ammonium (mg/l)	27.21mg/l	21.40mg/l	27.59mg/l	18.32mg/l	23.63mg/l	4.225
6	Turbidity (NTU)	88.85	55.6	88.55	48.35	70.34	21.776

5.6.1. Correlation between Little Egret Relative Abundance and Water Quality Parameters in POME Pond Number One

Pearson test indicates negative correlation between Little Egret relative abundance and water quality parameters i.e., water temperature ($r = -0.0736$, $P > 0.05$), electric conductivity ($r = -0.5271$, $P < 0.05$), dissolve oxygen ($r = -0.0293$, $P > 0.05$), pH ($r = -0.0365$, $P > 0.05$), Ammonium ($r = -0.0622$, $P > 0.05$) and turbidity ($r = -0.1560$, $P > 0.05$) in POME pond number one (for egret relative abundance please refer section 2.5.5.1, page 49).

5.6.2. Correlation between Little Egret Relative Abundance and Water Quality Parameters in POME Pond Number Three

Pearson's correlation coefficient (PCC) showed a negative correlation between Little Egret relative abundance and water quality parameters in POME pond number three such as water temperature ($r = -0.1128$, $P > 0.05$), electric conductivity ($r = -0.5100$, $P < 0.05$), dissolve oxygen ($r = -0.0904$, $P > 0.05$), pH ($r = -0.0525$, $P > 0.05$), Ammonium ($r = -0.0932$, $P > 0.05$) and turbidity ($r = -0.2359$, $P > 0.05$) (for egret relative abundance please refer section 2.5.5.1, page 49).

5.6.3. Correlation between Great Egret Relative Abundance and Water Quality Parameters in POME Pond Number One

Overall a negative correlation between Great Egret relative abundance and water quality parameters such as water temperature ($r = -0.1199$, $P > 0.05$), electric conductivity ($r = -0.5256$, $P < 0.05$), dissolve oxygen ($r = -0.0641$, $P > 0.05$), pH ($r = -0.0731$, $P > 0.05$), Ammonium ($r = -0.1054$, $P > 0.05$) and turbidity ($r = -0.2235$, $P > 0.05$) was recorded in POME pond number one (for egret relative abundance please refer section 2.5.5.2 page 51).

5.6.4. Correlation between Great Egret Relative Abundance and Water Quality Parameters in POME Pond Number Three

Pearson's correlation coefficient (PCC) showed a negative correlation between Great Egret relative abundance and water quality parameters such as water temperature ($r = -0.1509$, $P > 0.05$), electric conductivity ($r = -0.5082$, $P < 0.05$), dissolve oxygen ($r = -0.0601$, $P > 0.05$), pH ($r = -0.0746$, $P > 0.05$), Ammonium ($r = -0.1261$, $P > 0.05$) and turbidity ($r = -0.3038$, $P > 0.05$) in POME pond number three (for egret relative abundance please refer section 2.5.5.2 page 51).

5.6.5. Correlation between Cattle Egret Relative Abundance and Water Quality Parameters in POME Pond Number One

Pearson test indicates positive correlation between Cattle Egret relative abundance and electric conductivity ($r = 0.5164$, $P < 0.05$) but a negative correlation was recorded with water temperature ($r = -0.1218$, $P > 0.05$), dissolve oxygen ($r = -0.0429$, $P > 0.05$), pH ($r = -0.0556$, $P > 0.05$), Ammonium ($r = -0.1015$, $P > 0.05$) and turbidity ($r = -0.2594$, $P > 0.05$) in POME pond number one (for egret relative abundance please refer section 2.5.5.2 page 51).

5.6.6. Correlation between Cattle Egret Relative Abundance and Water Quality Parameters in POME Pond Number Three

Pearson's correlation coefficient (PCC) showed a negative correlation between Cattle Egret relative abundance and water quality parameters such as water temperature ($r = -0.2200$, $P > 0.05$), electric conductivity ($r =- 0.5033$, $P < 0.05$), dissolve oxygen ($r = -0.0817$, $P > 0.05$), pH ($r = -0.1042$, $P > 0.05$), Ammonium ($r = -0.1831$, $P > 0.05$) and turbidity ($r = -0.4117$, $P < 0.05$) in POME pond number three (for egret relative abundance please refer section 2.5.5.2 page 51).

5.6.7. Correlation between Intermediate Egret Relative Abundance and Water Quality Parameters in POME Pond Number One

Pearson test indicates weak positive correlation between Intermediate Egret relative abundance and positive correlation with dissolve oxygen (r = 0.1386, $P > 0.05$), pH (r = 0.1175, $P > 0.05$), Ammonium (r = 0.0454, $P > 0.05$) and water temperature (r = 0.0127 $P > 0.05$). On contrarily, a negative correlation with electric conductivity (r = −0.5087, $P < 0.05$), and turbidity (r = −0.2006, $P < 0.05$) was recorded in POME pond number one (for egret relative abundance please refer section 2.5.5.4 page 54).

5.6.8. Correlation between Intermediate Egret Relative Abundance and Water Quality Parameters in POME Pond Number Three

Pearson's correlation coefficient (PCC) showed positive correlation between dissolve oxygen (r = 0.1043, $P > 0.05$) and pH (r = 0.0716, $P > 0.05$). In contrast, a negative correlation was recorded between water temperature (r = −0.1037, $P > 0.05$), electric conductivity (r = −0.4969, $P > 0.05$), Ammonium (r = −0.0476, $P > 0.05$) and turbidity (r = −0.3505, $P < 0.05$) in POME pond number three (for egret relative abundance please refer section 2.5.5.4 page 54).

5.6.9. Correlation between Chinese Egret Relative Abundance and Water Quality Parameters in POME Pond Number One

Pearson's correlation coefficient (PCC) showed a negative correlation between Chinese Egret relative abundance and water temperature ($r = -0.4653$, $P < 0.05$), electric conductivity ($r = -0.5094$, $P < 0.05$), dissolve oxygen ($r = -0.0799$, $P > 0.05$), pH ($r = -0.1628$, $P > 0.05$), Ammonium ($r = -0.4058$, $P < 0.05$) and turbidity ($r = -0.5481$, $P < 0.05$). However, no positive relationship was recorded with any water quality parameters in POME pond number one (for egret relative abundance please refer section 2.5.5.4 page 54).

5.6.10. Correlation between Chinese Egret Relative Abundance and Water Quality Parameters in POME Pond Number Three

Pearson test indicates weak positive correlation between relative abundance and dissolve oxygen ($r = 0.0297$, $P > 0.05$) and negative correlation with water temperature ($r = -0.4755$, $P < 0.05$), electric conductivity ($r = -0.4973$, $P < 0.05$), dissolve oxygen ($r = 0.0297$, $P > 0.05$), pH ($r = -0.1497$, $P > 0.05$), Ammonium ($r =- 0.4436$, $P < 0.05$) and turbidity ($r = -0.5034$, $P < 0.05$) in POME pond number three (for egret relative abundance please refer section 2.5.5.4 page 54).

5.6.11. Correlation between Aquatic Insect Relative Abundance and Water Quality Parameters in POME Pond Number One and Three

The Pearson test indicates a positive correlation between mean aquatic insects relative abundance and mean water quality parameters in POME pond number one (r = 0.0679, P < 0.05) and number three (r = 0.469, P < 0.05) (for aquatic insects relative abundance please refer section 3.5.2 page 93) (for aquatic insect relative abundance please refer section 3.5.2 page 93).

5.7. DISCUSSION

The results showed that the value of various water parameters of four POME ponds was varied during the sampling period. It was observed that water quality parameters of POME ponds fluctuated from time to time. The fluctuation was due to vegetation i.e. high density of algae coverage that hinders the activity of the aquatic invertebrates and egret species. For example, water temperature was highest in the first week of February and the lowest value was observed in the second week of January. This happens whenever POME was discharged into the pond. After discharge period, the organic matter will settle down and water became less polluted as compared to fresh discharge. This is because fresh POME contains a higher concentration of organic material and rich in gasses such as CH_4, $S0_2$, NH_3, CO_2 and halogens (Wong *et al.* 2002; Yacob *et al.*, 2005; Igwe and Onyegbad, 2007). This was indicated by the fluctuation in water parameters value based on POME discharge amount. The fluctuation in water quality parameter was affected by a newly discharged POME (into pond number one) before it has been transferred into other ponds (pond number two).

The results show that the water temperature of pond number one and three was higher compared to pond number two and four. This is because the water is rich with solid substance that absorbed heat. Water temperature is a key factor that affects the aquatic organisms through various ways such as photosynthesis rate of aquatic vegetation and metabolic rates of aquatic animals (Londagin, 2007). It also affects the solubility of dissolved oxygen since dissolved oxygen is inversely proportional to temperature. Therefore any increase in water temperature will caused decreased oxygen level. Most aquatic invertebrates are poiklothermic animals; therefore surrounding waters always affect its capability in thermoregulation. In this condition, temperature will influence aquatic life-forms activity and growth (Michaud, 1991). The fluctuation in water temperature had caused physiological changes of aquatic organism and affects its dispersal (Lessard and Hayes, 2003; Grand *et al.*, 2006).

Dissolved oxygen was also crucial in aquatic environments and play a significant role in the life cycle of aquatic invertebrates and affects its richness, distribution and survival (Vincent *et al.*, 2008). The highest percentage of dissolved oxygen was recorded in the POME ponds number one and three. The amount of dissolved oxygen depends on aquatic vegetation, water temperature and pollutants. The photosynthesis process of macrophytes influences on the dissolved oxygen level in water that influence on the distribution of aquatic invertebrates. For example, soon after sunrise, the photosynthesis process of macrophytes occurs in the presence of sunlight, that increases the amount of dissolved oxygen in the water that enable the aquatic invertebrate to return to greater water depths. In addition, temperature affects the growth of algae and growth of algae affects the level of oxygen in water (Nielsen et al., 2002; Ma et al., 2010). The requirement of dissolved oxygen by aquatic organism may vary from species to species depends upon its physical state (metabolism rate). The dissolve oxygen of 5.0 to 9.0 ppm is considered ideal for aquatic life (Zimmermann, 2009). Oxygen is the single most important component of water for self-purification processes and the maintenance of aquatic organisms which utilize aerobic respiration. Low concentration of dissolved oxygen was recorded in POME pond number two and numbers four while low aquatic invertebrate distribution was recorded in both ponds. This indicated that low concentration of dissolved oxygen had caused lethal effects on aquatic animals such as stoneflies, mayflies, caddis flies and midges. This explains why egret avoided POME pond number two and four because the survival of aquatic invertebrates depends on a sufficient level of dissolved oxygen (Irving *et al.,* 2004; MPCA, 2009). Low concentration of dissolved oxygen had caused excessive growth of algae (MPCA, 2009). Previous study by Irving *et al.* (2004) noted that lawn shrimp (*Hyalella azteca*) was less tolerant to hypoxia (reduced dissolved oxygen content) while midge larvae (*Chironomus tentans*) mortality was low dissolve oxygen. Photosynthesis may stop and algae (a major producer of dissolved oxygen in the aquatic environment) will die if light levels get too low. The number of species, abundance, and biomass of benthic macro-fauna were declined abruptly at approximately 2 mg/l DO. Similar results were also obtained by Nilsson and Rosenberg (1994) who found that the structure of the benthic community had changed during hypoxia.

The highest pH value was recorded in POME pond number one and three and lower pH value was recorded in pond number two and four. This indicated that water of POME pond number one and number three are more alkalinitic where as pond number two and four has more acidic water. Aquatic organisms differ in the range of pH in which they can flourish. Lower pH destroys ecosystems by killing lower organisms of the food chain due to higher acidity, such as mayflies that are particularly vulnerable to acidic water. This is because lower sodium in blood that can harm fertilized eggs, resulting in failure to hatch or deformed offspring with little chance of survival due to stunted growth (Addy et al., 2004; McGann, 2013).

Water with low pH usually has certain chemicals or metals that become toxic and affecting aquatic animals including invertebrates (Robertson–Bryan, 2004). On the contrary, aquatic invertebrates such as mayflies and midges are able to tolerate higher levels of pH.

Water of POME pond number one has very turbid water while pond number three has shallow water. The major source of turbidity of water in POME pond number one was the effluent discharged from oil mill. Turbid water provides an ideal hiding place for aquatic invertebrates since it reduced light penetration and therefore reducing water temperature. It has been reported that turbidity affects aquatic organism such as mayfly (*Leptophlebia nebulosa*) and midges (*Tanytarsus dissimilis*) by interference with sunlight penetration (Rowe *et al.*, 2002). Of diverse aquatic invertebrates had attracted many egrets to utilize POME pond number one. POME pond number one and three lack vegetation but are rich in decomposed material from mill effluent. Pond that rich in organic material not only provides ideal habitat for aquatic invertebrates but also plenty food resources for egrets. This indicates that turbidity may allow many invertebrate species to flourish in ponds number one and three which attracted to egrets to utilize the POME ponds. Hence, it indicates that turbidity is good water quality parameter for insects that indirectly affects on egret distribution and diversity. In addition, it also has been reported that suspended particles such as sediments may provide a breeding ground for bacteria (Jana and Majumder, 2010; DCNR, 2012) and turbidity is the key factor that affects the production of bacteria and algae which is the main food source for invertebrates (Batzer and Wissinger, 1996; Robinson *et al.,* 2000). Water loses its transparency due to the presence of suspended particles. Occurrence of suspended particles blocked light penetration into a water body, affecting photosynthesis and oxygen production. As a result, photosynthesis process is halted. This kills aquatic plants and caused lower oxygen concentrations and large carbon dioxide concentrations in water that affects aquatic invertebrates. High turbidity affects the abundance and diversity of amphipods, snails, midges and worms by reducing food supply and habitat (Rowe *et al*., 2002). High turbidity also caused sediment deposition, altering substrate composition and changing the substrate (Wood and Armitage, 1997).

Water quality parameters are the key factor that affects species composition and abundance of birds either directly or indirectly (Briggs *et al.*, 1998; Osiejuk *et al*., 1999). This is because changes in water quality parameters affecting the physical structure of the habitats and the availability of food resources (Clausen, 2000). It has been reported that water quality parameters such as dissolve oxygen and temperature have potential impact on prey behavior and availability (Kersten *et al*., 1991; Frederick and Loftus, 1993). pH, phosphorous, and nitrates influence the diversity and density of waterbird such as spoonbill, terns, cormorants, plovers, herons, storks, egrets, shanks, open-bills, and lapwings (Nagarajan and Thiyagesan, 1996; Sandilyan, 2010). Manikannan *et al*. (2012) discovered that physico-chemical parameters (such as calcium, chloride, dissolved oxygen, electrical conductivity, magnesium, nitrate, nitrite, pH, phosphate, total dissolved solids, salinity, sulphate, turbidity, water depth and water temperature) play a major role in regulating waders community (egrets, plovers, herons, ibis, godwit, spoonbill, whimbrel, curlew, shank, flamingo, sandpipers, tern, stilt, stint, and lapwing). Changes in water quality also influenced ecological processes such as vegetation pattern, aquatic productivity, and avian distribution (Davis and Ogden, 1994; Sklar *et al.*, 2001; Bolduck and Afton, 2004). Water quality parameters also affect the richness and distribution of benthic invertebrates and planktons, primary food of waterbirds (Bolduc and Afton, 2008). Waterbirds acquire important nutrients from feeding on benthic fauna and plankton that are influenced by physical-chemical variables.

Aquatic invertebrate assemblages such as Ephemeroptera (mayflies), Hemiptera (bugs), Coleoptera (beetles), Trichoptera and Diptera are often considered as key elements in food webs (Brooks, 2000). Their richness and distribution have changed dramatically throughout the year due to fluctuation in water level, desiccation, temperature, chemical gradient, and predation (Wellborn *et al*., 1996; Williams, 1996; Batzer *et al.*, 2005). In addition, variation in decomposed materials and seasonal changes of water level and vegetation composition have affected abundance and richness of invertebrate assemblages (Merritt and Lawson, 1992; Richardson *et al*., 2004).

Invertebrates also regulate rates of primary production, decomposition, water clarity, thermal stratification, and nutrient cycling in aquatic habitats, as well as play a vital role in food web (Mazumder *et al.*, 1990). The physical properties (such as temperature) and chemical characteristics (such as oxygen) of water are affecting distribution and richness of invertebrate, zooplankton and nekton. All these are major food source for waterbirds (Daily and Ehrlich, 1994; Weller, 1995; Roshier *et al.*, 2002). Therefore, presence of many egrets in some POME ponds indicates that the food resources are abundance (Andrikovics *et al*., 2006).

CHAPTER 6

GENERAL DISCUSSION

Bird distributions are influenced by various environmental factors (Deshkar *et al*., 2010). Food availability is one of the most important factors that determine bird distribution (Evans and Dugan, 1984). Different bird species exploits different niche of particular habitat by utilizing different foraging habitats (e.g. substrate depth exploitation) and feeding techniques (to catch various prey sizes). In addition, habitat structure also influences foraging behavior of bird species by means of food richness and distribution.

Egret assemblages are affected by various factors such as food availability and prey size, wetland size, water quality and depth, vegetation structure and composition, occurrence of other foragers, and predation risk (Paracuellos, 2004; Stolen, 2006). The climatic factors and seasonal changes also influenced density, diversity and distribution of egrets in the wetlands (Jaksic, 2004; Lagos *et al*., 2008). In this study five egrets species, i.e. Little Egret (*E. garzetta*), Great Egret (*C. albus*), Intermediate Egret (*M. intermedia*), Cattle Egret (*B. cormorandus*) and Chinese Egret (*E. eulophotes*) were discovered to employ variety of foraging strategies such as probing, slow walk, quick walk, lean and wait, stand and wait, stand and feed, wing flick, foot shuffling and gleaning in four POME ponds.

It was observed that inter-specific variation in foraging strategies employed by egrets were considerably different. Difference in foraging strategies was due to variation in beak length and width, tarsus length, colour of the feet, and body size. The study had recorded various aquatic invertebrates in POME ponds number one and three. These two ponds were also heavily utilized by egrets. This indicates egrets forage aquatic invertebrates as reported earlier (Mincy, 2006). This also shows that egrets only choose habitat with various food resources or has suitable foraging and loafing sites. Most of the egrets were observed to forage along the pond's edges. This microhabitat provided low-energy area where detritus may accumulate and serve as a nursery or refuge for wide array of aquatic invertebrates which formed major food source for waterbirds (O'Connell, 2001). Edge preferences behaviour has been recorded in Snowy Egret (*E. thula*), Great Egret (*A. alba*), Eastern Great Egret (*A. modesta*), and Intermediate Egret (*E. intermedia*) (Strong *et al.*, 1997; Taylor and Schultz, 2008). Other free-ranging wading birds also show edge preference behavior. These include White Ibis (*Eudocimus albus*), Wood Stork (*Mycteria Americana*), Glossy Ibis (*Plegadis falcinellus*), Tricolored Heron (*E. tricolor*), Great Blue Heron (*A. herodias*), and Little Blue Heron (*E. caerulea*) (Gawlik, 2002; Werner *et al.*, 2007; Taylor and Schultz, 2008).

This study observed that egrets prefer to forage in POME ponds number one and three. These ponds are full with aquatic invertebrates such as mosquito larvae, maggots, beetles, midges and waterbugs during morning and evening hours. These invertebrates serve as food resources for egrets. Therefore, egrets show high intensity of foraging activities in these ponds and recorded high abundance either during morning or afternoon hours.

It was also found that egret's relative abundance increased during migratory season i.e. from September to March due to arrival of migrant species that forages in same area.

Recording of the eleven foraging strategies of five egret species while foraging on aquatic insects in POME pond number one and three indicated that POME pond one and three are suitable foraging habitat for egrets. These ponds can accommodate different foraging strategies used by various species of egrets. Higher relative abundance of egrets in POME pond number one and three was due to richness of food resources that offers suitable foraging site for egrets. This indicates that egrets are more likely to distribute according to the availability of food resource as reported earlier (Kersten *et al*., 1991; Martinez *et al*., 2005).

Overall, Pearson's Correlation Coefficient (PCC) revealed that egrets have weak correlation with water quality parameters such as water temperature, electric conductivity, dissolve oxygen, pH, Ammonium and turbidity. Egrets are indirectly related with water and used POME pond as foraging sites while feeding on various species of aquatic invertebrates. Therefore, direct fluctuation in water quality parameters didn't influence their occurrence or distribution in POME ponds.

Pearson correlation analysis also showed negative relationship between egret's relative abundance and invertebrate's abundance. This indicates that egret relative abundance was not associated with relative abundance of aquatic insects. Aquatic insects richness occurs with suitability of habitats that provide ideal foraging, breeding and shelter for them. Fruthermore, invertebrates such as *Aedes* sp., *Eristalis* sp., *Stenolopus* sp., *Eretes* sp., *Thaumalea* sp., *Chironomus* sp., *Dytiscus* sp., *Sphaerodema* sp., *Atherix* sp., *Cybister* sp., *Tabanus* sp. and *Hydrophilus* sp. inhabited in deep water or water body edges. The egrets only forage in those sites where invertebrates are visible and easy to catch.

Pearson correlation analysis indicates a weak positive relationship between egret foraging activities (such as probing, walking slowly, walking quickly, lean and wait, stand and wait, stand and feed, wing flick, foot shuffle, gleaning, and aggressive) and aquatic invertebrate's relative abundance. This is because egrets employed different foraging techniques depending on richness, distribution and size of aquatic invertebrates to ensure successful catch.

It is almost impossible to catch the egrets, therefore further study on their morphological and stomach contents cannot be conducted. The individuals of egrets also cannot be marked to facilitate identification of species individuals. The presence of venomous snake such as cobra in plantation area also poses dangerous situation for researchers.

CONCLUSION

Results of this study indicated that POME ponds number one and three provide ideal foraging sites for five egret species (i.e. 14,077 sightings of various egrets, i.e. Little Egret (39.84%), Great Egret (32.39%), Cattle Egret (16.05%), Intermediate Egret (9.39%) and Chinese Egret (2.33%). Results also show that POME ponds provide diverse food resources (i.e. twelve species of insects), suitable foraging habitats for egrets (POME ponds number one and three) for loafing and perching sites (such as mangroves, oil palms, dead fallen trees and compacted waste material floating in POME pond number one). However, it was founded that egret relative abundance may vary from species to species in POME pond number one and three. In addition, it was also founded that egret foraging strategies may vary from species to species while obtaining food resources such as only Little Egret employs foot shuffling technique while preying and Cattle Egret was the only species which glean their prey hidden under soft mud.

SIGNIFICANCE OF THE RESEARCH

a. The study had recorded 14,077 sightings of egrets which belong to five species, i.e. Little Egret (*Egretta garzetta*), Great Egret (*Casmerodius albus*), Cattle Egret (*Bubulcus cormorandus*), Intermediate Egret (*Mesophoyx intermedia*) and Chinese Egret (*Egretta eulophotes*) indicated that POME pond number one and three of Carey Island are ideal habitat for egrets. They provide diverse food resources, suitable foraging, loafing and perching sites for various species of egrets.

b. The highest relative abundance of egrets was recorded in January (14.00%) while the lowest abundance was recorded in August (3.36%). It was recorded that more egrets have visited POME pond areas during January and less were recorded in August. It was also found that egrets were active during morning (from 0900 to 1000 hours) but less active during mid-day (1300 to 1400 hours).

c. The higher egret's relative abundance was recorded in POME ponds number one and three but no egrets were utilizing POME ponds number two and four.

d. The highest egrets species diversity ($N_1 = 3.82$) and species evenness ($E = 0.83$) was recorded in POME number one. On the contrary, the highest egrets species richness was noticed in pond number three ($R_1 = 0.46$). However, egret species diversity for ponds number two and four was not analyzed because no egrets was sighted due to lack of food resources. POME ponds number one and three are the most suitable foraging sites for egrets. Therefore, more studies need to be conducted in POME ponds number one and three to understand its characteristics in attracting waterbirds population especially egrets.

e. Results of this study indicated that egrets are active foragers. They are employing different foraging strategies to capture and consume their prey. Probing is the most popular technique and was mostly used by Little Egret (52 probes/minute) while Great Egret (5 probes/minute) was minimally used this technique. Little Egret was the only species that employ foot shuffling technique and Cattle Egret was the only species that glean the prey hidden under soft mud while foraging.

f. Scoop net recorded a total of 119,126 invertebrates (or larvae) from POME ponds, which belong to twelve species. It indicated that POME ponds of Carey Island are rich in aquatic invertebrates, which forms major food resources for egrets. The highest number of invertebrates (or larvae) was captured in POME pond number three (51.40%), followed by pond number one (48.60%). On the contrary, no insect was captured from POME ponds number two and four. Mosquito (*Aedes* sp.) larvae were the most abundant (40.71%) and water scavenger beetles (*Hydrophilus* sp.) were the rarest (2.52%).

g. The highest invertebrate species diversity was recorded in POME ponds number one (Shannon's N_1 = 2.21) and three (N_1 = 2.17) in June while highest species evenness was recorded in June (Pielou's E = 0.89 in pond number one and E = 0.87 in pond number three). POME ponds number one and three were highly utilized by egrets. Egrets avoided POME ponds number two and four due to the absence of insects. This indicates that food was a major reason for egrets to select any habitat.

h. The highest value for water temperature (35.36^0C), conductivity (5685 µs), and turbidity (89.6^0) were recorded in POME pond number one in January while the highest value for dissolve oxygen (3.73mg/l), pH (8.97), and ammonium concentration (28.05mg/l) were recorded in February. Therefore, water quality parameters fluctuate in POME ponds.

i. Based on the above findings, it is strongly recommended that POME pond areas should be properly maintained to attract more waterbirds.

BENEFITS OF THE STUDY

a. Establishment of baseline data on egret species utilizing POME pond area.

b. Highlighting the importance of POME ponds area for egrets.

c. Findings of this study can be used by researchers, policy makers, wildlife officers and students to obtain more information on egrets foraging behavior and site selection, prey capturing techniques, the abundance and diversity of aquatic invertebrate, and water quality parameters of POME ponds.

d. The findings can be used to support regional management and conservation activities in POME area of Malaysia, especially in managing waterbirds such as egrets that utilize POME pond areas.

RECOMMENDATIONS FOR FUTURE CONSERVATION AND MANAGEMENT OF POME PONDS OF CAREY ISLAND, PENINSULAR MALAYSIA

1. The master plan management should be developed to carry out future research activities on avian biology such as population trends, food resources, water level and quality of POME pond, vegetation composition and structures of POME ponds and surrounding area, discharge amount and chemical composition of POME.

2. The research should focus on discharge flow of POME (frequency of inflows, duration, depth of water, outflows from one pond to other, duration of POME settlements), chemical composition of POME in detail, fauna diversity (macro-invertebrates, birds, frogs, fish, insects and aquatic invertebrates), vegetation covers (water plants, terrestrial plants, trees, shrubs, grasses, weed, herbs and climbers), traces elements, edaphic factures (soil texture, soil structure and nutrients contents), and environmental variables (temperature, relative humidity, rainfall, sunshine and wind speed).

3. If priority is not given to conserve POME pond habitats, there will be adverse consequences on waterbirds population, reproduction and productivity particularly egrets, ducks, grebes, waterhens, and other terrestrial birds that utilize POME ponds.

4. Fruiting trees (such as *Ficus* sp., *Cinamomum* sp., and *Syzygium* sp.) and shrubs (such as *Dillenias* sp., *Melastoma* sp. and *Caryota* sp.) should be planted along the side of POME ponds to provide variety of food sources, suitable loafing and nesting sites for wide array of birds species.

5. Some parts of the POME ponds should be modified to enhance the aesthetic value and to provide safe nesting and roosting sites for waterbirds species such as egrets, herons and ducks.

6. Dead trees inside the water body should be left intact to provide loafing sites for ducks, egrets, bitterns and herons.

7. A small meteorological station should be established in POME pond area in order to record the microclimatic data such as rainfall, sunlight, relative humidity and wind speed. Microclimate is highly important factor that influence distribution, relative abundance, species composition, diversity and density of bird species. The microclimatic data will be highly useful in future research in POME ponds.

8. Detailed inventory programme should be launched to assess the ecological importance of POME ponds for effective conservation and better management of waterbird species. Detailed inventory should provide essential data and baseline information that will help in management decision.

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APPENDICES

Appendix 2.1: List of foraging behaviors employed by members of family Ardeidae (adopted from Kushlan and Hancock, 2005).

S. No	Type of Behaviour	Description
1	Aerial Flycatching	Flight pursue to capture flying invertebrate
2	Baiting	Foraging by stand and wait where bait was placed in the water to attract prey to its foraging location
3	Bill Vibrating	Crouched posture stands with bill tip submerged in water and rapidly opens and closes its bill creating a disturbance that attracts the prey
4	Canopy Feeding	Running with wings extended, stops, looks into water, and brings its wings forward forming a canopy above its head. It may hold this pose for several minutes
5	Crouched Posture	The body is held horizontal to perch, legs are bent, head and neck is partially retracted
6	Dipping	Flying low to catch prey above the water surface while continuing in direct flight without hovering
7	Diving	Perched on branches overhanging the water, dive head first from its perch into the water
8	Feet First Diving	Alights on the water feet first, usually from hovering position, and usually stab at prey immediately on

		landing.
9	Foot Dragging	Flying in direct flight near the surface of the water drags the toes or foot of one or both legs in the water
10	Foot Paddling	Rapidly moves feet up and down on the substrate to disturb prey
11	Foot Probing	Extends one leg forward and slowly probes substrate, vegetation or litter
12	Foot Raking	Extends one leg forward and rakes the substrate with its toes or rakes with it feet while walking forward.
13	Foot Stirring	Extends one leg forward and vibrates its leg and foot, or vibrates it foot while wading forward to attract prey.
14	Gleaning	Pick prey from objects above the ground or water
15	Groping	Lure prey as if to commit some unwelcome act.
16	Head Swaying	Submerged belly in the water, rapidly swaying its body laterally while holding its head and most of the extended neck still above the water. This body swaying motion will flush out the prey.
17	Head Swinging	A rhythmic forward and backward movement of the head during bipedal walking on the ground.
18	Hopping	Jumps into the air and flies a short distance to potential prey and simultaneously stabs while landing
19	Hovering	Hovers over a single spot and reaches down with bill to capture prey
20	Hovering Stirring	Hovering above the surface of the water while

		extending one foot and pats the surface of the water or stirs or rakes vegetation or floating debris
21	Hovering Scraping	Strikes prey from the hovering position
22	Jumping	Jumps from a perch with foot touch the water first.
23	Leapfrog Feeding	Repeatedly fly forward in a foraging flock
24	Neck Swaying	Submerged its neck into water and rapidly swaying its body to flush the prey
25	Open Wing	Running, walking slowly or standing while completely extends one or both wings and then retracts them
26	Pecking	Grasp and pick up small sparing bits, nibble with beak
27	Plunging	Dives head first into the water from forward flight or hovering position to catch prey
28	Prey Dropping	Bird repeatedly dropping a prey item rather than consuming it.
29	Probing	A bird explore the prey items under soil or vegetation through digging by peak
30	Upright Running	Moves quickly after a specific prey item or runs from a place to another to disturb prey
31	Stand and Wait	Stands motionless in water or on land waiting for prey to approach
32	Standing Flycatching	Stand and wait behavior to catches flying invertebrate
33	Stealing	Birds stealing food from other birds and some time from fisherman boats.
34	Swimming Feeding	Swimming at the surface of the water and strikes

		nearby prey
35	Tongue Flicking	Egrets use tongue to lure or flush hiding fish
36	Under Wing Feeding	Extends wings completely while walking and holding them above the head under and stabs the prey
37	Upright Running	Body is held in erect, head and neck are extended to follow the prey
38	Walk Quickly	Walks through shallow water or fields catching prey that disturbed by its movement
39	Walk Slowly	Walk very slowly for several steps to stalk the prey
40	Wing Flicking	Walking slowly in an upright posture and suddenly extends and retracts its wings in a flicking action, usually repeated several times
41	Upright Posture	Body is held erect, head and neck are fully extended angled away from the body

Appendix 3.1: Analysis of variance of relative abundance of invertebrates in POME pond number one at Carey Island, Peninsular Malaysia.

DF	SS	MS	F	P
11	7.258E + 07	6.597918	37.86	0.0000
60	1.046 E + 07	174277		
71	8.303 E + 07			

Appendix 3.2: Analysis of variance of relative abundance of invertebrates in POME pond number three at Carey Island, Peninsular Malaysia

DF	SS	MS	F	P
11	8.895 E + 07	8086085	34.23	0.0000
60	1.417 E + 07	236195		
71	1.031 E + 08			