NESTING ECOLOGY OF THE GREEN TURTLE, *Chelonia mydas* AND HAWKSBILL TURTLE, *Eretmochelys imbricata* ON THE WEST COAST OF PENINSULAR MALAYSIA

SARAHAIZAD BINTI MOHD SALLEH

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by

SARAHAIZAD BINTI MOHD SALLEH

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ANOVA	Analysis of Variance
AIC	Akaike Information Criterion
CEMACS	Centre for Marine and Coastal Studies
CI	Confidence interval
DoF	Department of Fisheries
HSCL	Hatchling straight carapace length
hw	Hatchling weight
IUCN	International Union for the Conservation of Nature
KFAS	Exponential Family State Space Models in R
KTCC	Kerachut Turtle Conservation Centre
K-S	Kolmogorov-Smirnov
PNP	Penang National Park

EKOLOGI BERSARANG PENYU AGAR, *Chelonia mydas* DAN PENYU KARAH, *Eretmochelys imbricata* DI PANTAI BARAT SEMENANJUNG MALAYSIA

ABSTRAK

Kedudukan geografi Pulau Pinang dan Melaka yang terletak di pantai barat Semenanjung Malaysia, merupakan lokasi penting untuk pendaratan penyu. Kajian telah dijalankan di kedua-dua lokasi ini, dan data taburan sarang penyu agar, *Chelonia mydas* di Pulau Pinang (dari tahun 2010 hingga 2014) dan penyu karah, *Eretmochelys imbricata* di Melaka (dari tahun 2013 hingga 2014) dibekalkan oleh Jabatan Perikanan Malaysia dengan kebenaran pihak Jabatan untuk menerbitkan keputusan kajian. Objektif kajian ini bertujuan untuk menentukan musim bersarang penyu agar di Pulau Pinang, menentukan kecenderungan pilihan ruang-masa (spatiotemporal) bagi sarang penyu karah di Melaka, menentukan tapak pemilihan sarang bagi penyu agar di Pulau Pinang, dan menentukan kajian keberjayaaan penetasan menggunakan Kaedah Rekaan Pecahan Telur. Jumlah sebanyak 265 sarang penyu agar telah dikenalpasti terdapat di Pulau Pinang dalam tempoh lima tahun (2010-2014). Jumlah sarang tertinggi dikenalpasti tertumpu di Kerachut, dan jumlah sarang kedua tertinggi dikenalpasti di Teluk Kampi, diikuti oleh Teluk Aling, Teluk Duyung, dan Pasir Pandak. Analisis menggunakan "Model Poisson State Space" menunjukkan turun-naik taburan jumlah sarang di Pulau Pinang adalah lebih berkait dengan faktor suhu berbanding faktor hujan. Dalam kajian ini, faktor suhu persekitaran berkemungkinan tidak memberi kesan langsung keatas fisiologi dan kelakuan sarang penyu agar, tetapi dianggap berkait rapat dengan suhu tanah dan suhu air laut. Bagi kajian tapak pemilihan sarang, didapati penyu agar lebih

cenderung membina sarang di kawasan yang mengandungi peratusan tinggi diameter saiz-partikel pasir 1 mm, berbanding saiz-partikel 2 mm, 425 µm, 250 µm, 125 µm, and 63 µm. Kaedah Rekaan Pecahan Telur telah dijalankan di Pulau Pinang, dimana keseluruhan telur dari satu sarang penyu agar dibahagikan kepada dua bahagian yang sama rata, dan sebahagian telur tersebut dieramkan di dalam kotak Sterofom, manakala sebahagian lagi di plot Kawasan Terbuka. Keberjayaan penetasan bagi sarang yang dieram di dalam plot Kawasan Terbuka menunjukkan peratusan yang agak tinggi berbanding sarang yang dieram di dalam kotak Sterofom. Di Melaka, jumlah sebanyak 481 sarang penyu karah telah di kenalpasti pada tahun 2013 dan sebanyak 463 sarang dikenalpasti pada tahun 2014. Taburan sarang penyu karah adalah tidak seragam diantara 20 pantai bersarang dikenalpasti di Melaka, dan jumlah sarang paling tinggi dikesan di Padang Kemunting, Kem Terendak, dan Pulau Upeh. Kuputusan penting dalam kajian ini adalah saiz populasi penyu karah di Melaka menunjukan sedikit peningkatan atau stabil dalam tempoh 25 tahun. Pendedahan terkini mengenai status peningkatan taburan sarang penyu karah di Melaka mungkin dapat membantu dari segi rujukan dalam program pemuliharaan penyu karah di pantai-pantai bersarang di serata dunia, kerana sifat penyu karah hanya bersarang di kawasan tertentu, selain disenaraikan sebagai spesies terancam kritikal oleh Kesatuan Antarabangsa untuk Pemuliharaan Alam Sekitar (IUCN). Diakhiran, pada waktu ini usaha pemuliharaan penyu agar di Pulau Pinang hanya tertumpu di Kerachut dan Teluk Kampi sahaja. Oleh itu, adalah dicadangkan pembinaan santuari kecil di pantai-pantai bersarang di Pulau Pinang dengan tujuan untuk menaik taraf perlindungan penyu agar ke tahap yang lebih tinggi.

NESTING ECOLOGY OF THE GREEN TURTLE, *Chelonia mydas* AND HAWKSBILL TURTLE, *Eretmochelys imbricata* ON THE WEST COAST OF PENINSULAR MALAYSIA

ABSTRACT

The geographic locations of Penang Island and Melaka along the west coast of Peninsular Malaysia provide important nesting beaches for marine turtle nesting. A study was conducted at these two nesting beaches, and nesting data of the green turtle, *Chelonia mydas* in Penang Island (from 2010 until 2014) and hawksbill turtle, *Eretmochelys imbricata* in Melaka (from 2013 until 2014) was supplied by the Department of Fisheries, and permission granted to publish the results. The objectives of the study were to determine the seasonality of green turtle nesting in Penang Island, spatiotemporal preferences in nesting of hawksbill turtle in Melaka, nest site selection of green turtle in Penang Island, and hatching success of green turtle by using a Split Clutch Design Method. A total of 265 green turtle nests were identified in Penang Island within a five-year period (2010-2014). The highest number of nests was observed at Kerachut, and the second highest total was observed at Teluk Kampi, followed by Teluk Aling, Teluk Duyung, and Pasir Pandak. Poisson State Space Modeling indicated that the fluctuations in the number of nests in Penang Island relates to temperature rather than precipitation. The air temperature investigated in this study might not directly affect the physiology and behaviour of nesting green turtles, but is assumed to closely relate to sand and water temperature. Green turtle tend to build nests at nesting sites that are composed of a high percentage of 1 mm diameter sand particle-size, compared to 2 mm, 425 µm, 250 µm, 125 µm, and 63 µm. A Split Clutch Design Method was conducted in

Penang Island, where clutch size of green turtle was split into two equal half of eggs and incubated in Styrofoam boxes and Open Area plot. Hatching success produced in the Open Area nest was slightly higher in percentage compared to hatching success of nest from Styrofoam box. In Melaka, a total of 481 hawksbill nests were observed in 2013 and 463 nests were observed in 2014. The distribution of hawksbill turtle nests in Melaka was not uniformly distributed among the 20 nesting beaches, and a high number of nests were observed in Padang Kemunting, Kem Terendak, and Pulau Upeh. Results of this study indicate the population size of hawksbill turtles in Melaka to increase slightly or have been stable in the last 25 years. The current increasing nesting status of hawksbill turtle in Melaka might be helpful for reference purposes for hawksbill conservation programme at nesting beaches in this world, because the hawksbill turtle is known to nest at restricted areas and is listed as a critically endangered species by the International Union for Conservation of Nature (IUCN). The current conservation efforts of green turtle in Penang Island is focused mainly at Kerachut and Teluk Kampi; therefore, it is recommended small sanctuaries be set aside at identified nesting beaches of Penang Island improve the protection of green turtle to a higher level.

CHAPTER 1. INTRODUCTION

1.1. Overview of marine turtles in Malaysia

There are four species of marine turtles in Peninsular Malaysia; the leatherback turtle (*Dermochelys coriacea*), the green turtle (*Chelonia mydas*), the olive ridley turtle (*Lepidochelys olivacea*), and the hawksbill turtle (*Eretmochelys imbricata*) (Chan & Liew, 1989). The green turtle is widely distributed in Malaysia. It can be found around Penang Island, Terengganu, Pahang, Perak, Sipadan Island (Sabah), and Turtle Islands (Sarawak) (Chan, 2006). There are only two remaining influential nesting populations for the hawksbill turtles, which are in Sabah Turtle Island (primarily at Gulisan Island) and Melaka with fragment recognized in Terengganu and Johor (Chan, 2006). For the leatherback turtle, they nest primarily in Terengganu, and olive ridley remote nesting has been reported to nest in Sarawak Turtle Island, Penang Island, Terengganu, and Kelantan which show that the status is disjointed (Chan, 2006). The current status of the green turtle has been classified as a globally endangered species by International Union for Conservation of Nature (IUCN, 2015) with an estimated 37-61% decline worldwide (Mortimer *et al.*, 2011). However, there are major green turtle nesting populations in the world, which have been increasing over the past two to three decades following the protection from human hazards such as exploitation of eggs and turtles (Chaloupka *et al.*, 2008). These locations are Ogasawara (Japan), Hawaii (USA), Great Barrier Reef (Australia), Florida (USA), and Tortuguero (Costa Rica) (Chaloupka *et al*. 2008). The rest of the species has been listed as critically endangered species for hawksbill turtle

(Mortimer & Donnelly, 2008) and vulnerable species for olive ridley and leatherback turtles (IUCN, 2015). Overall, the conservation of marine turtles in Peninsular Malaysia is under the management of Department of Fisheries (DoF), State Park for Sabah (Turtle Islands Park), and Sarawak Forestry for Sarawak (Talang-Satang National Park).

Only two species of turtles, which are the green and olive ridley turtles have been confirmed to land in Penang Island. The green turtle is more widely distributed in Penang Island compared to olive ridley that exists in a very small population (Department of Fisheries, 2016). For the reason to protect these marine turtle species from extinction in Penang Island, Kerachut Turtle Conservation Centre (KTCC) has been established at Kerachut, Penang Island. Through the establishment of KTCC by DoF (Penang branch), successful conservation efforts to preserve the marine turtles have been made in recent years since 1995 until present (Department of Fisheries, personal communication). Hawksbill turtle is mainly distributed in Melaka with no evidence of green turtle landed (Mortimer *et al.*, 1993). In Melaka, the protection of marine turtle is under the management of Padang Kemunting Turtle Conservation Centre and DoF (Melaka branch).

The study was conducted in Penang Island and Melaka, and the current nesting data of green and hawksbill turtle were accessed from DoF (Penang branch) and DoF (Melaka branch) with their permission to publish the results. There is limited information and publications about the marine turtle populations on the west coast of Peninsular Malaysia. Therefore, the main aim of this study is to update the current nesting status of green and hawksbill turtles in Penang Island and Melaka. The study on the hawksbill population has been initiated by Mortimer *et al*. (1993) in 1990 and 1991, thus, it is essential to update the current nesting status after more than 20 years with the cooperation from DoF (Melaka branch) and World Wildlife Fund (WWF). Besides, it is also important to understand the nesting site preference and breeding biology of green and hawksbill turtle in Penang Island and Melaka. In addition, the influence of sand-particle size on the successful nesting and unsuccessful nesting (digging attempt) was also observed in Penang Island. Higher number of nests distribution in Penang Island in relation to temperature is hypothesized to be caused by (1) increase in the number of nests of each individual in one reproductive season or (2) increase in the number of individuals landing on the beach.

1.2. Rationale of study

The rationale of the study is to determine the seasonality of green turtle nesting in Penang Island and the spatiotemporal preferences in nesting of hawksbill turtle in Melaka. Information on the seasonality of green turtles nesting between 2010 until 2014 is important to show the nesting trend and the number of nesting per year in Penang Island. In addition, the environmental data (e.g., temperature, humidity, and precipitation) were derived from Malaysian Meteorological Department to find the effect of the environmental factors on marine turtle nesting in Penang Island. Mortimer *et al.* (1993), has shown that >350 hawksbill nesting annually in Melaka beaches from the research performed between 1990 and 1991. The current status of hawksbill turtle nesting in Melaka between 2013 and 2014 will be an important result for conservation purposes and general knowledge, as there are only a few locations in Southeast Asia that have been listed as prominent areas for hawksbill nesting. Hawksbill currently can be found in Vietnam (Stiles, 2009), Indonesia (Nasir *et al.*, 1999; Limpus, 2009), Pulau

Gulisan, Sabah (Chan *et al*., 1999), and Western and Northern territory of Australia (Limpus, 2009). Therefore, it is important to determine the current nesting status of hawksbill turtle in 2013 and 2014 by deriving the nesting data from DoF (Melaka branch) and compare the nesting result with the previous studies done by Mortimer *et al.* (1993).

1.3. Improvement of conservation effort by Kerachut Turtle Conservation Centre, KTCC (1995-2014)

Turtle landing, nesting, and clutch size were recorded by KTCC starting from 1995 (Department of Fisheries, personal communication). The tagging method was introduced from 2000, and every female turtle landed at Kerachut and Teluk Kampi was tagged to ensure the reliability of data collection. Green turtles were tagged according to the 'Standard Procedure for Turtle Management Guidelines (Peninsular Malaysia)' book published by Department of Fisheries (Wagiman & Mohd Alias, 2007). The data collection have been improvised in 2010, where the staffs of KTCC begin taking information and measure the turtle morphological characteristics as it is important to know the female turtle that performed re-migration in the next nesting season (Department of Fisheries, personal communication). Furthermore, the record on digging attempts, clutch size, eggs survivorship, and poaches nests were properly recorded. The eggs poaching in Penang Island has also been reduced due to there are staffs patrolling the beaches of Kerachut and Teluk Kampi every night. In conclusion, the efficiency of data collection and intensive nocturnal surveys by KTCC and DoF (Penang branch) has been improvised every year since 1995.

1.4. The aim of Split Clutch Design Method

According to Mortimer *et al.* (1994), the nest will enjoy a high rate of hatching success by splitting the eggs and incubate in separate nests (Split Clutch Design Method). The reason this method was performed in KTCC because it has not been conducted previously in Penang Island. Likewise, it is very important to test which nest plots, between Styrofoam box and Open Area nest that will produce a higher hatching success and better sizes of hatchling morphological characteristics (e.g., straight carapace length and weight). The aim of this method is to improvise the hatching success and to maintain the existence of green turtle population in Penang Island. *In-situ* programmes did not perform in Penang Island because nesting sites are exposed to human poacher and land predator (Department of Fisheries, personal communication). Therefore, various methods need to be performed in order to increase the hatching success of relocated nest in Penang Island. Figure 1.1 shows the research flow of this study.

1.5. Objectives

The specific objectives of the study are:

- To assess the seasonality of green turtles, *Chelonia mydas* nesting and the environmental factors affecting it on Penang Island, Peninsular Malaysia.
- To assess the spatiotemporal preferences in nesting of hawksbill turtle, *Eretmochelys imbricata* in Melaka, Peninsular Malaysia.

1.6. Research Flow

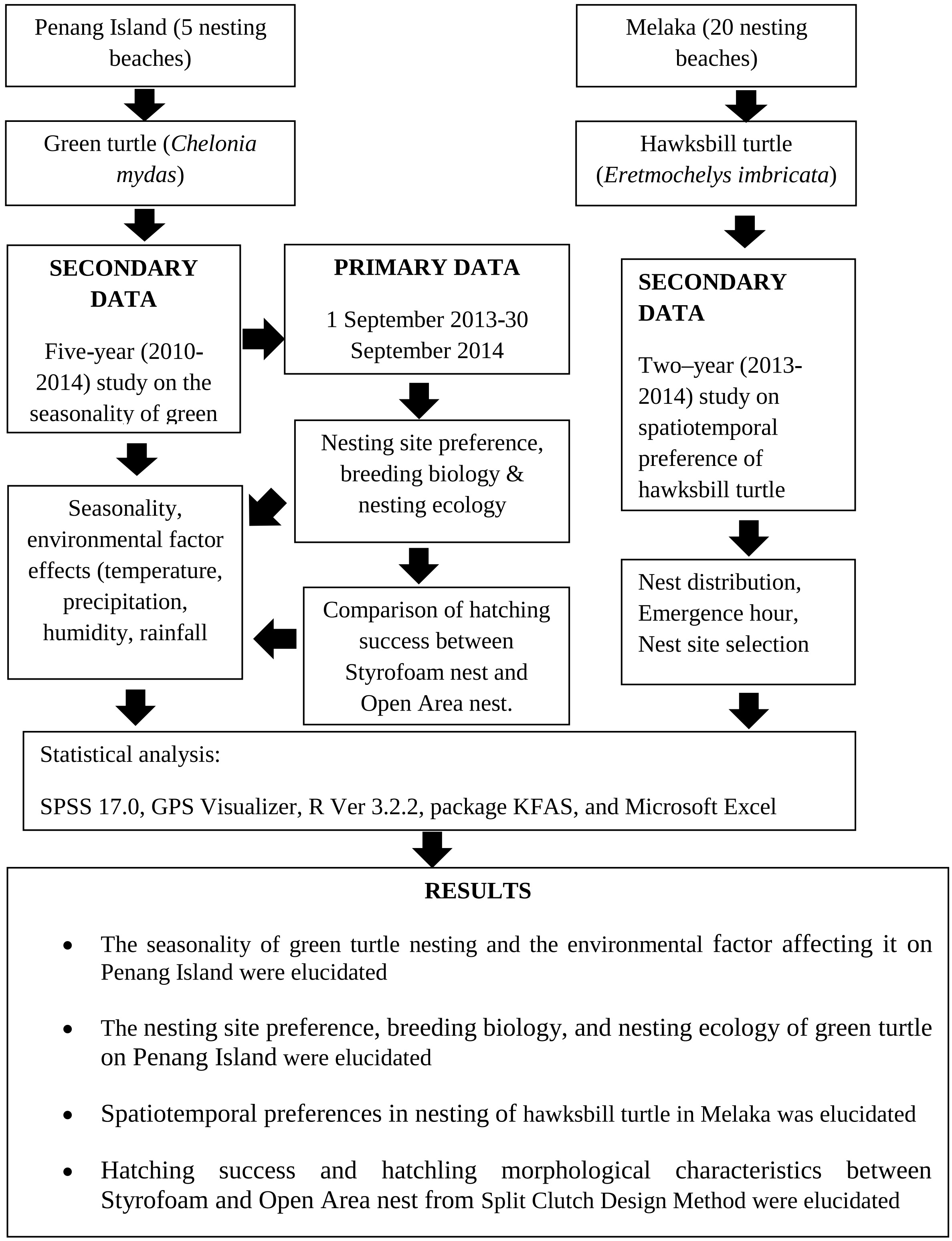

Figure 1.1. Research flow of the study for the green and hawksbill turtle.

CHAPTER 2. LITERATURE REVIEW

2.1. General description of marine turtle (with emphasis on green and hawksbill turtle)

Turtles are among the oldest of all living reptiles, and they first appeared about 200 million years ago (Burnie & Wilson, 2001). A majority of the marine turtles is able to live for more than 100 years and is able to produce offspring for several decades (Davenport, 1997). According to Ernst & Lovich (2009), there are almost 320 species of turtles in the world, but there are only seven species of marine turtles living in the world's oceans today. These seven species are green turtle (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), flatback (*Natator depressa*), olive ridley (*Lepidochelys olivacea*), and kemp's ridley (*Lepidochelys kempii*) (Ernst & Lovich, 2009). Turtles today roam the ocean, lakes, rivers, inhabit swamps, grassland, forests, desserts, lowlands, and highlands (Chan, 2004). The green turtle is the world widespread marine turtle, and can be found in tropical, subtropical waters, and temperate waters across the globe (Burnie & Wilson, 2001). The hawksbill turtle is also a widespread marine turtle species, know to nest in at least 60 countries, but suspected to be in decline in many parts of its range (Grombridge & Luxmoore, 1989).

Marine turtles most distinguished features are the hard shell that encircles the soft parts of the body, and these specification has given them a protection and camouflage from the predators or the harmful elements that attack or harm them (Burnie

& Wilson, 2001). Turtle are built with shell, four limbs, and a horny, with toothless beak in their jaw (Burnie & Wilson, 2001). The shell includes of carapace and plastron (notable as the upper and lower parts respectively). Some species have soft leathery shells and lack scutes (Burnie & Wilson, 2001). An example is leatherback turtle. This shell actually serves as part of the turtle skeleton that grows around its body and serves as a protection for the internal organ and other soft turtle's body parts. Additionally, with around 40% of its total body mass consist of bone, the turtle is perhaps recognized as the most organized form of armour ever to appear in the animal kingdom (Ernst & Lovich, 2009). Hence, this remarkable armour is probably the reason the turtles had appear on the scene over 200 million years ago and had amazingly survived from the extinction of the dinosaurs and other devastation (Ernst & Lovich, 2009).

According to Burnie & Wilson (2001), some marine turtles only consume seaweed as adults while the rest feed on invertebrates including molluscs, and sea urchins. At least in some tropical regions, the green turtles know to play a key role in the dynamics of sea grass meadows (Moran & Bjorndal, 2005). Young green turtles are more carnivorous, consume sponges, molluscs, and jellyfish, but the adults graze on the sea grass, mangrove roots, and leaves (Burnie & Wilson, 2001). For hawksbill turtle, they forage most commonly over rock outcropping and coral reefs (Bjorndal, 1997). Hawksbill turtle used their narrow beaks to forage for molluscs, sponges, and other animals in the coral reefs and on the seabed (Burnie & Wilson, 2001).

With regionally important populations occurring in Southeast Asia, green turtles are the most widely distributed species in Indonesia that can totalled to around 10,000-20,000 nests per year (Halim *et al*., 2001). In Vietnam, green turtle is likely to be around

250 females per year for the record of total Vietnam nesting populations (Hamann & Chu, 2002). Over the last five years between 2004 and 2009, the average annual nesting density of green turtle in the Sabah Turtle Island Park to be an approximated collection of 6,500 nests while in Terengganu was 2,300 nests (Chan, 2009). It has been estimated that about 350 to 400 hawksbill turtle nests lay annually in Sabah Turtle Island, especially Gulisan Island (Phillipps, 1988). In Melaka, it has been estimated that there are >350 hawksbill nests that are annually laid (Mortimer *et al.*, 1993). The nesting of hawksbill turtle is considered as much as in Indonesia, with a total of 1,000-2,000 nests per year (Nasir *et al.*, 1999; Chan 2001).

In recent years, most turtle populations in Asia has decreased and some to the verge of extinction (Shanker & Pilcher, 2003). The long history of eggs poaching (Chan, 2006) and accidental turtle capture by fishermen with fish trawls are threatening the marine turtle population (Hamann *et al.*, 2006). Fishing gear such as drift net, trawl net, long lines, fish trap, purse seines, ray net (pukat pari), life net, and even beach seines have been found to affect marine turtles (Chan & Liew, 2001). In addition, interference from the unregulated eco-tourism industry also gives and impacts to the marine turtle populations (Yeo *et al.*, 2007). It was expected the development of prime beaches for tourism do affect the loss of nesting habitat in Malaysia (Chan, 2006). In addition, remaining existing nesting beaches will be threatened, effects from beachfront development (Chan, 2006). For example, multiple chalets are build nearby the shores in Melaka is to fulfil the high demand of visitors' night activities such as fishing and fire camping. It has significantly impacted the reduction of hawksbill landing due to heavy human population. Similar problems are currently occurring in Batu Feringghi, Penang

Island where the tremendous growth of hotel at the beachfront has influenced the drastic deduction of green turtle nesting and this location has even been used to be a spot of nesting rookeries recently (Department of Fisheries, personal communication).

Life history patterns of marine turtles may vary among individuals and populations in the details (Hatase *et al*., 2006). All marine turtles begin life as terrestrial hatchlings (Bovery & Wyneken, 2013). Once emerged from the nest and crawled to the sea, hatchlings immediately transitioned to live in the marine environment as they swim offshore (Carr & Ogren, 1960). The turtle hatchlings may stay in oceanic habitats for several years (Reich *et al*., 2007). After a changeable amount of time in the epipelagic zone, most of these turtles return as juveniles and sub-adults (large juveniles) to ocean's nearshore and occupy the neritic zone (Bjorndal *et al*., 2003) while others turtle may rotate between oceanic and neritic foraging grounds (McClellan & Read, 2007). As marine turtles approach the maturity, they move to waters in closer vicinity to nesting beaches (Bowen *et al*., 2005) and ready to lay eggs.

2.1.1. Behaviour

2.1.1(a). Migration

Marine turtles perform regular migrations between feeding grounds and nesting locations, and based on satellite tracking and recapture of tagged individuals, marine turtles often show faithfulness to both areas (Broderick *et al*., 2007). After migrating from the distant feeding grounds to the nesting areas, the marine turtle is responsible to adopt a relaxed behaviour and cease foraging to save energy for reproductive output and the return migration (Cheng *et al*., 2013). After the nests are being laid, the female turtle will migrate back far away from their re-productive grounds to their feeding grounds (Zanden *et al*., 2013) before returning for a new breeding season. Some researchers suggested the migratory breeding cycles to be initiated in every one to nine years depending on the species and ocean valley (Carr & Ogren, 1960; Miller, 1997). Adult females are able to migrate thousands distance of kilometres to foraging areas, once after finished depositing last nest of the season (Girard *et al.*, 2009). An example of a highly migratory species is green turtles, with nesting populations consists of individuals from multiple foraging grounds, and frequently separated by hundreds or thousands of kilometres (Harrison & Bjorndal, 2006).

Based on analyses of genetics, the preciseness of natal homing may differ considerably among different species and populations (Lohmann *et al*., 2008). Until now, it is still poorly understood how do they navigate themselves, but, it is believed that they probably used a combination of earth magnetic field, water chemistry, the direction of ocean currents, and the memory (Burnie & Wilson, 2001). Meanwhile, O'Keefe (1995) claims that it is the help of very well-developed brain area with highly magnetic substance, which might enable them to navigate or detect according to the earth's magnetic fields (O'Keefe, 1995). In addition, a special taste or odour that is unique to each area of the ocean or coastline is suggested to help navigate and search the natal homing (O'Keefe, 1995). However, scientific evidences of this belief does not exist so far (O'Keefe, 1995).

2.1.1(b). Mating

The only real social interaction amongst marine turtles is said to occur only during courtship and mating, because the fact that marine turtles are believed to be solitary reptiles (O'Keefe, 1995). The mating process may take place at the surface or in open water, under the ocean's bottom, and occurred approximately 30 days before the female turtles begin nesting (O'Keefe, 1995). According to O'Keefe (1995), the whole season's eggs are from the fertilization of early season of the mating process. This occurred probably because the female turtle has stored sperm for several weeks after the mating process occurred (Davenport, 1997).

2.1.2. Reproduction

All turtles lay eggs on land. Turtle do not care for their young (Burnie & Wilson, 2001) after they laid their nest. In a single breeding season, the female marine turtle is large reptile that is able to produce multiple numbers of clutch sizes between 50 to 150 eggs per nest (Ehrhart, 1982; Hirth, 1997; Miller, 1997; Spotila, 2004). Turtles are able to lay a maximum number of 9 nests in one season (Chen & Cheng, 1999; Ekanayake *et al*., 2010).

2.1.2(a). Nesting process

The female and male turtle will mate in the ocean waters, and only the female turtles will land to the ground. The nesting process begins from when the female turtle emerged from the beach, excavate the body pit, scoop out the eggs chamber, oviposit the eggs, refill the eggs chamber, smoothen the nest, and return to the sea (Miller, 1997). Under the darkness ambiance, the female turtle begins crawling to search a nesting site once landing from the sea. The process of excavating nest begins once the female turtle finds a suitable nesting site. Nesting activity hours depends on the species, but usually the times are between 1-3 hours (Department of Fisheries, 2015).

Marine turtle is a sensitive reptile. During the nest excavation, any disturbances such as obstacles of roots and rock could stop the nesting process, and digging attempts may impede. In addition, turtles may perform false crawls at any point of nesting even from a minimal disturbance. Once the female starts depositing eggs inside the eggs chamber, she will become almost ignorant with the surroundings (Miller, 1997). The clear watery-mucous will secrete together during the eggs dropping, which act as lubricant (Miller, 1997). The eggs do not break when they are dropped to the bottom of eggs chamber due to the leathery properties of the eggshells as the eggshells are able to endure the impact of being dropped (Miller, 1997). At this stage, female turtles will also shed tears to secrete the excessive salt that accumulates in the body (Miller, 1997). Once the process is finished and all eggs are inside the chamber, the female turtle will used the flippers to push the sand, cover the eggs, and pack the whole nest down. The female will then crawls back slowly and returned to the sea. The female turtle never return to look after the eggs once she left her nest (Miller, 1997).

2.1.2(b). Hatchling

Hatchling has to find their way to the sea by themselves or ‘seafinding’, right after hatching from the eggs. Terminology ‘seafinding’ refers to how the hatchlings find their way to the sea. This 'seafinding' is directed by light intensity and horizon elevation, which are the two visual cues (Tuxbury & Salmon, 2005). The first cue is light intensity which refers to an orientation cue intervene by a positive phototaxis (Verheijen & Wildschut, 1973). During light intensity, reflected light from the ocean was absorbed by vegetation behind the beach (Tuxbury & Salmon, 2005). The hatchlings then crawl away from the dimmer landward horizon and crawl by using both flippers toward the brighter seaward horizon (Van Rhijn & Van Gorkom, 1983). The second cue was horizon elevation, where turtles tend to crawl away from a higher dune, and it's related to shrubbery, and toward the lower, and oceanic horizon (Van Rhijn & Van Gorkom, 1983).

Usually at night, hatchlings generally crawl from the nest to the sea after surface sands cool (Salmon *et al*., 2009), probably because they prefer a cooling effect during the non-daylight hours. Marine turtle hatchlings crawl to the ocean and typically enter a 'swimming frenzy', which quickly brings them into offshore oceanic currents (Hays *et al*., 2010). During the 'swimming frenzy' time, hatchlings usually swim continuously for roughly 24 hours (Salmon *et al*., 2009), living entirely on their yolk reserves (Wyneken, 1997) that act as nutrient supply and they can live up to seven days without feeding in the oceans.

During many nesting episodes, marine turtles are characterized by the fact that they have few enemies and high fecundity (Heppell *et al*., 2003). From eggs, hatchlings and juvenile stages, they typically suffer high levels of mortality from predators of aquatic, array of terrestrial, and aerial (Wyneken, 2000). In fact, hatchlings are vulnerable to predators within minutes after they begin swimming, because they are undoubtedly detected in shallow water, have practically no defense against an attack, and incapable of swimming faster than their predators (Whelan & Wyneken, 2007).

2.1.3. Breeding ecology

In order for marine turtle to choose the nesting site to lay eggs, there are a few general conditions required as nesting site affects the reproduction of all marine turtle species. The smooth-sloped sandy beaches, elevation, temperature, and humidity levels of sand are affecting the nesting site preference and reproduction of marine turtle eggs. Sometimes, unsuitable other characteristics such as grain size, salinity, and water tables may force females to change the nesting behaviour (Ehrenfeld, 1979).

The nest environment of marine turtles plays a key role in turtle biology because it determines the incubation period, and influences hatching success and phenotype (Booth, 2006). Nest temperature also able to influence the hatching sexes (Booth, 2006), yolk amount converted to hatchling tissue, post-hatch growth rate of hatchlings, and hatchlings locomotors performance (Booth, 2006). All of these ‘nest’ effects on hatchling phenotype and hatchling success are able to influence the hatchling fitness and therefore, play an important role in the evolution of life history strategy of marine turtle (Booth & Evans, 2011). Marine turtle sex (male or female) is determined based on the incubation temperature, through a mechanism known as temperature-dependent sex determination (TDS) (Pieau *et al*., 1999; Hawkes *et al*., 2013). All marine turtles exhibit temperature-dependent sex determination where incubation at high temperatures (>30ºC) results in females, incubation at low temperatures (<28ºC) results in males (Mrosovsky & Yntema, 1980), and incubation at intermediate temperatures results in a mixture of males and females (Booth & Evans, 2011). The prediction increases in temperatures will have a significant impact on marine turtle biology and conservation since temperature plays a vital role in marine turtle reproductive biology (Booth & Evans, 2011).

2.2. Management of marine turtles in Malaysia

2.2.1. Law

Various laws have been implemented in Malaysia to protect the marine turtles. Among them, the Turtles Enactment 1951 (Amendment 1989) which banned the utility of large mesh that exceeded 24/5 cm sunken gill nets for rays capture (Chan, 2006). Based on the survey conducted in Terengganu oceans in 1988 the drift nets with mesh sizes greater than 17.8 cm were capable of catching 16 turtles in one operation (Sukarno & Omar, 1989). The study resulted in a nationwide ban in 1989 on the use of drift nets with mesh sizes greater than 25.4 cm (Yeo *et al*., 2007). Other relevant efforts to address sea turtle-fishery interactions in Malaysia include the creation of areas barred to fishing such as the Fisheries (Prohibited Areas) (Rantau Abang) Regulations 1991 that provides offshore protection to leatherback turtles during nesting season every year (Chan, 1993), therefore, fishing activities are controlled. Fisheries Act 1985 and Fisheries Methods (Turtle and Eggs) 1989 (Table 2.1) were enforced to control illegal smuggling of turtle eggs and banned the sale of eggs openly in the market (Abd Rahim, 2016). According to this law, turtle cannot be disturbed from the inception of nesting until the completion of the nesting process, and the licenced eggs collector need to return the eggs to Department of Fisheries for incubation purpose (Department of Fisheries, personal communication). The standardisation of turtle laws and acts for all states is recommended to strengthen the enforcement in prohibiting the sale of eggs openly in public, in order to protect marine turtle from extinction (Abd Rahim, 2016). The list of laws and ordinances of marine turtles in Malaysia (Department of Fisheries, 2014) are presented in Table 2.1. In addition, the gazettement of Penang National Park (PNP) on 10 April 2013 (Taman Negara Pulau Pinang, 2016) has strengthened the collaboration with Department of Fisheries (DoF) that helps preserve and protect the vegetation habitat of green turtle.

2.2.2. Turtle conservation centre

Turtle Conservation Centre in Malaysia is managed by the DoF. This turtle conservation centre has become important as a centre for tourist attraction in Peninsular Malaysia. The establishment of Turtle Conservation Centre with assistance from the State Government has fully protected the marine turtle as well as the habitat and nests. It became the centre of reference for scientists and visitors and freely educates people to increase the knowledge of marine turtle. Table 2.2 shows the list of turtle conservation centre in Malaysia, including the information of marine turtle prime nesting beaches, and marine turtle species resides according to state.

Table 2.1. List of laws and ordinances related to the protection of marine turtles in Malaysia.

No	State/Federal	Law and Ordinances
1	Federal	Fisheries Act 1985 (Amendment 1993) Fisheries Regulations (Prohibition of Fishing Methods) 1980
2	Terengganu	Turtles Enactment 1951 (Amendment 1989) The Fisheries (Prohibited Areas) (Rantau Abang) Regulations 1991
3	Kelantan	Fisheries Methods (Turtle and Eggs) 1978
4	Pahang	Fisheries Enactment 1937 Fisheries Methods (Turtle and Eggs) 1996 - New law being drafted.
5	Johor	Fisheries Methods (Turtle and Eggs) 1984
6	Melaka	Fisheries Methods (Turtle and Eggs) 1989
7	Negeri Sembilan	Fisheries Methods (Turtle and Eggs) 1976
8	Perak	Fisheries Methods (Turtle and Eggs) 1998
9	Kedah	Turtles Enactment 1972 Turtles Methods 1975
10	Penang Island	Fisheries Methods (Turtle and Eggs) 1999
11	Sabah	Wildlife Ordinances 1997 Wildlife Regulations 1998
12	Sarawak	Wildlife Protection Ordinances 1990 Ordinances Turtle Responsibility 1957

Table 2.2. List of turtle conservation centre in Malaysia.

No	Malaysian state	Management	Collaborator	Species	Prime nesting beaches
1	Penang Island	Department of Fisheries (Kerachut Turtle Conservation Centre)	-	Green, Olive Ridley	Kerachut, Penang Island (Department of Fisheries, 2014)
2	Perak	Department of Fisheries (Segari Turtle Conservation and Information Center).	-	Green	Pasir Panjang, Segari, Perak. (Department of Fisheries, 2014)
3	Melaka	Department of Fisheries (Padang Kemunting Turtle Conservation Centre)	World Wildlife Fund (WWF)	Hawksbill	Padang Kemunting, Melaka (Mortimer *et al*., 1993)
4	Pahang	Department of Fisheries (Cherating Turtle Conservation and Information Centre)	-	Green	Cherating, Pahang (Ikonomopoulou *et al*., 2013)
5	Terengganu	1.Department of Fisheries (Ma'daerah Turtle Sanctuary) 2.Turtle and Marine Ecosystem Centre (TUMEC) 3.Sea Turtle Research Unit (SEATRU, Universiti Malaysia Terengganu)	World Wildlife Fund (WWF)	Green	Setiu (Aini Hasanah *et al*., 2014) Rantau Abang (Department of Fisheries, 2014) Redang Island (SEATRU, 2016)
6	Johore	Department of Fisheries (Mersing Turtle Sanctuary)	-	Green	Mersing (Wagiman & Mohd Alias, 2007).
7	Sabah	State Park (Turtle Islands Park)	-	Green, Hawksbill	Turtle Islands Park, Sabah (Chan *et al*., 1999).
8	Sarawak	Sarawak Forestry (Talang-Satang National Park)		Green	Sarawak Turtle Islands (Leh, 1994; Chan, 2006).

2.3. Previous studies on green turtle

Table 2.3 shows the important previous studies that are related to nest site selection, breeding biology, and breeding ecology of green turtle in various counties.

2.3.1. Nest site selection

One of the significant topics in this thesis is to reveal the factors influencing nest site selection of marine turtle. Factor suggested related to nest site selection are vegetation distribution (Wang & Cheng, 1999; Aini Hasanah *et al*., 2014), sand particle, wave action, and beach slope (Madden *et al*., 2008).

2.3.1(a). Vegetation areas

The vegetation areas are defined as the supra-littoral vegetation area that backed onto the beach (Wang & Cheng, 1999). The vegetation of nesting site in Malaysia may disperse with varies species. For example, vegetation of nesting site in Terengganu was populated with Catappa trees (*Terminalia catappa*), coconut trees (*Cocos nucifera*), shrubs, and other plants (Aini Hasanah *et al*., 2014). In Melaka, the hawksbill also tends to nest under the vegetation (Mortimer *et al*., 1993). Merambong or *Scaevola taccada* (family: Goodeniaceae) dispersed on sandy beaches, natural shores, and sand dunes, and it is evaluated among the most ordinary seashore shrubs in many parts of the world (Chan, 2003). This bushy tree has been observed distributed in many nesting sites in Malaysia, e.g., Melaka, Penang Island (DoF, personal communication). It is explained as a shrub tree that is able to grow into a small tree with a height up to 3 m tall, with thick and luscious leaves and the position of the leaves in a spiral shape (Chan, 2003).

2.3.1(b). Open sand

Open sand or open beach zone is defined as an area where there is no vegetation coverage (Wang & Cheng, 1999). Turtle nest was also found at open sand (Hays & Speakman, 1993; Wang & Cheng, 1999) depends on the species. In Terengganu, a majority of nesting sites is in dunes and open sand because they provide less hindrance from the vegetation and grassy zone and could be convenient for nesting turtles to land (Aini Hasanah *et al*., 2014). The risk of nest locate at open beach is female turtle will be easily disturbed by animal and human disturbances (Donlan *et al*., 2004; Maros *et al*., 2003).

2.3.1(c). Grassy areas

Grassy area is an area distributed with grasses species and belongs to the family of Gramineae (Wang & Cheng, 1999). At Kerachut and Teluk Kampi, the locations of the grassy areas are the farthest from water's edge, after open sand and vegetation area zones. The grassy areas also provide protection to nests that are located within it, but the protection is comparatively lower to the vegetation zone that is comprised of fringed and bushy shrubs. There are two common grasses found on the nesting beaches: *Cynodon dectylon* (L.) Beauv. and *Pennisetum setosum* (Sw.) L.C. Rich (Wang & Cheng, 1999).

Table 2.3. Previous publications of green turtle related to nest site selection, breeding biology, nesting ecology, conservation efforts, and hatchery management.

No	Author	Topic	Article type	Country
1	Aini Hasanah *et al*. (2013)	Conservation efforts	Journal Article	Terengganu, Malaysia
2	Aini Hasanah *et al*. (2014)	Nesting ecology	Journal article	Terengganu, Malaysia
3	Aini Hasanah & Fadzly (2015)	Hatchery management	Journal Article	Terengganu, Malaysia
4	Burnie & Wilson (2001)	Distribution and Breeding biology	Book	Southeast Asia
5	Chen & Cheng (1995)	Breeding biology	Journal Article	Taiwan
6	Cheng *et al*. (2009)	Nesting ecology	Journal article	Taiwan
7	Cheng *et al*. (2013)	Behaviour	Journal article	Taiwan
8	Ekanayake *et al*. (2010)	Nesting behaviour	Journal article	Sri Lanka
9	Limpus *et al*. (2003)	Population	Journal article	Australia
10	Miller (1997)	Breeding behaviours	Books	General
11	Wang & Cheng (1999)	Breeding biology, nest site selection	Journal article	Taiwan

2.4. Previous studies on hawksbill turtle

Hawksbill turtles are among the least well understood out of the 7 species of marine turtles (Hawkes *et al*., 2013). This species has been exploited historically for its shell, eggs, and meat (Fleming, 2001) leading to an obvious declining in nesting populations in the region (McClenachan *et al*., 2006). The hawksbill turtles are killed, for use largely in the decorative curios (e.g. stuffed turtles), production of jewellery, and for traditional medicine ingredients (CRES, 1994). From the problem mentioned above, it is possible the hawksbill nesting has declined significantly over the last 30 years in Viet Nam each year (Stiles, 2009). In this study, the focus is to reveal the current hawksbill nesting status in Melaka in comparing with the previous hawksbill nesting population in 1990 and 1991 by Mortimer *et al.*, (1993). Table 2.4 shows the list of important publications related to hawksbill nesting status, conservation, threaten, and breeding biology in various counties.

2.5. *In-situ* and egg relocations programme in Malaysia

Eggs relocation programme has been performed in Penang Island since 1995, due to *In-situ* nest is impossible to perform at Kerachut. Below are the problems listed as the reason *In-situ* nest programme is not performed in Penang Island.

Table 2.4. Previous studies on hawksbill turtle, *Eretmochelys imbricata.*

No	Author	Topic	Article type	Country
1	Beggs *et al*. (2007)	Nest density	Journal article	Barbados
2	Chan *et al*. (1999)	Breeding biology	Journal article	Malaysia
3	Hirth (1980)	Morphological characteristics, breeding biology	Journal article	Malaysia, Europe, South America
4	Hamann *et al.* (2006)	Nest distribution	Journal article	Viet Nam
5	Hensi *et al.* (in press)	Nesting ecology, Reproductive biology	Journal article	Persian Gulf
6	Leite *et al*. (2013)	morphological characteristics	Journal article	Brazil
7	Limpus (2009)	Nest distribution, breeding biology	Report	Australia
8	Mortimer *et al.* (1993)	Nest distribution	Journal article	Malaysia
9	Moncada *et al*. (2010)	Nest distribution	Journal article	Cuba
10	Nishizawa *et al.* (2016)	DNA variation	Journal article	Southeast Asia
11	Thuoc (2003)	Conservation	Report	Viet Nam
12	Revuelta *et al*. (2012)	Nest distribution	Journal article	Dominican Republic
13	Revuelta *et al*. (2013)	Nest density, nest site selection	Journal article	Dominican Republic
14	Stiles (2009)	Nest distribution, Threaten	Report	Viet Nam
15	Zare *et al*. (2012)	Breeding ecology	Journal	Iran