NEST-SITE SELECTION AND DISTRIBUTION MODEL OF THE WHITE-BELLIED SEA-EAGLE *Haliaeetus leucogaster* USING GEOGRAPHIC INFORMATION SYSTEM

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MASTER OF SCIENCE
UNIVERSITI SAINS MALAYSIA
2012

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by

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Thesis submitted in fulfillment of the requirements
for the degree of
Master of Science

January 2012

ACKNOWLEDGEMENT

First and foremost I would like to thank Allah s.w.t for his guidance that for it, I was able to complete this thesis. For all the strength he provided me through out that period of time, I was deeply grateful for it.

I offer my sincerest gratitude to my supervisor, Prof. Madya Dr. Shahrul Anuar Md. Sah and my co-supervisor Dr. Nurul Salmi Abd. Latip. They have supported me throughout my thesis with their patience and knowledge whilst allowing me the room to work in my own way. I attribute the level of my Masters degree to their encouragement and effort and without them, this thesis, too, would not have been completed or written. One simply could not wish for a better or friendlier supervisor and trustworthy co-supervisor.

I would really like to say thanks to Encik Yusoff, Encik Faizal, Encik Hussin and many other staff of the School of Biological Sciences for all assistance in the field. They have provided me with a very good logistic and tools that much needed in order to complete the research, without which research will become invalid. For that, I would also like to say my thanks to Encik Suhaimi and Pak Din for the boat services that they have greatly provided – safe, on time and reliable.

I would like to say many thanks to my fellow student friends that I have known for so many years during my stay here in USM. For all the lab mates that had helped me so much – Najwa, Patricia, Shima, Shazana, Farhana and Azimah, thank you for your sincere support and valuable knowledge that you all shared. Well not forgotten Jamsari,

Suhail, Munira, Juliana, Liana, Asif and Akbar for all their direct and indirect contribution that made this thesis a reality.

And yes, for many more friends – Mohd Taufik, Hanafi, Fitri Ishak, Hazan, Zulkifli and colleagues that I did not managed to list, I really owed you guys some big thank you for all the help you guys gave to me, with you all, I am none, but hopeless.

With hundred of miles separating us, I can still feel the warmth of the love and care that they had provided for me during all these days; easy and hard. Haji Mohd. Zainudin Othman, you had been a terrific father – consulted me with your discipline and words of wisdom, for without them, I will not be the man that I am today. And Wan Mariam Wan Jaafar, for all the love and tenderness that you have showed, I am blessed to have you as my beloved mother who always care and always there to listen to my problems. Both of you were my strength, for every resistance that I conquered, you were the reason.

Last but not least, I would like to thank my wife – Khowilah Mohamed for all the time she had spared and the attention that she gave every time when I needed one and for being ears when I needed someone to hear.

Thank you all for the never lasting support and love that you all had shown for me. I will never forget them, as it had been an honor for me to complete this thesis with the aid that you all provided.

This study was funded by E-Science Grant, Ministry of Science and Innovation, Malaysia, (Grant No. 04-01-05-SF0362) and the author (Mohd Syafiq Masduqi bin Mohd Zainudin) was partially supported as Graduate Assistant from Institute for Graduate Studies, USM.

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ABSTRAK

Burung Lang Putih (*Haliaeetus leucogaster*) adalah spesies burung pemangsa terbesar di Pulau Pinang dan juga di Malaysia. Ia biasa dilihat terbang di kawasan pesisiran pantai Taman Negara Pulau Pinang. Taburan spesies ini tersebar di seluruh Pulau Pinang tetapi dengan bilangan yang tinggi di Taman Negara Pulau Pinang, daripada segi bilangan sarang dan kepadatan populasi. Objektif utama kajian ini adalah untuk membina model ramalan taburan dan pemetaan habitat yang berpotensi dan sesuai bagi spesies di kawasan kajian berdasarkan analisis pemilihan tapak sarang. Sejumlah 34 sarang telah ditemui dalam tinjauan yang dijalankan dari Disember 2007 hingga April 2009 di kawasan hutan pantai Taman Negara Pulau Pinang dan digunakan dalam analisis pemilihan tapak sarang dengan membandingkan habitat dipilih dengan habitat tersedia menggunakan analisis ujian-*t*. Tujuh ciri atau pembolehubah habitat dipilih untuk dianalisis, iaitu altitud, kecerunan, orientasi cerun, kepadatan kontur, jarak dari jalan, jarak dari bangunan dan jarak dari air. Pembolehubah altitud, kecerunan, jarak dari jalan dan jarak dari air memberikan keputusan yang signifikan ($P < 0.05$). Maklumat daripada analisis pemilihan tapak sarang digunakan untuk membina model ramalan taburan bagi spesies. Tiga belas sarang tambahan yang ditemui digunakan untuk menilai ketepatan model dan memberi ketepatan 30.2% dan juga memberi keputusan yang memuaskan apabila dibandingkan dengan titik rawak. Maklumat dari kajian ini adalah sangat bernilai dan penting bagi pengurusan dan konservasi spesis tersebut pada masa hadapan.

NEST-SITE SELECTION AND DISTRIBUTION MODEL OF THE WHITE-BELLIED SEA-EAGLE *Haliaeetus leucogaster* USING GEOGRAPHIC INFORMATION SYSTEM

ABSTRACT

The White-bellied Sea-Eagle (*Haliaeetus leucogaster*) is the largest raptor species in Penang as well as in Malaysia and is commonly sighted in coastal and near coastal of Penanng National Park. The species distribution is island-wide but with a high concentration in Penang National Park, in terms of nesting sites and population density. The main aim of this study is to develop the predictive distribution model and map the potential and suitable nesting habitat for the species in the study area based on nest-site selection analysis. A total of 34 nesting sites have been located during the survey on December 2007 to April 2009 in coastal forest of Penang National Park and therefore used in nest-site selection analysis by comparing the selected and available habitat using *t*-test analysis. Seven habitat features or variables were chosen for analysis; elevation, slope, aspect, ruggedness index, distance to road, distance to building and distance to water. Variables of elevation, slope, distance to road and distance to water showed significance result ($P < 0.05$). The information from the nest-site selection analysis was used to build the predictive distribution model for the species. Thirteen independent nests located at evaluation area were used for model validation and give 30.2% accuracy and showed satisfactory result when tested against random points. The information and results from this study is highly valuable and crucial for future management and conservation of the species.

Chapter 1

Introduction

1.1 Research background

As natural habitats worldwide are being destroyed or converted to other uses, species supported by those habitats are inevitably threatened (Groombridge, 2002). Habitat destruction is a main factor for a species population to decline, eventually leading to it being endangered, or even to its extinction (Kajiyamahe, 2008). According to Vanreusel & Van Dyck (2007) habitat destruction takes several forms: complete loss of areas used by species; degradation, i.e. from vegetation removal and erosion; and fragmentation, when species are constricted onto small patches of undisturbed land surrounded by areas cleared for agriculture and other purposes.

The changes in habitat can be natural or human related. Human related activities are the crucial factor in rapid habitat loss which contributing to global biodiversity losses and are among the greatest challenges that face the world.

The conservation of wildlife and biodiversity has been the major concern since decades ago. Since the United Nations Summit Conference at Rio de Janeiro in 1992 that resulted in agreement by world government leaders on a Biodiversity Convention for species and habitat protection and an agenda for sustainable development, many countries as well as Malaysia have signed and rectified the Convention on Biological Diversity (CBD) ensuring their commitment to protect the biodiversity as well as their environment.

The rapid development and advance of technologies especially in computers and associated software during the last thirty years has led to the expansion and emergence of Geographical Information Systems (GIS). Coupled with statistical analysis and ecological modelling approach, GIS can provide significantly increased opportunities for species management and show considerate promise for extensive use in ecology and nature conservation. The recent study used GIS to spatially model the potential nesting habitat and predict the distribution of the White-bellied Sea-Eagle in Penang Island in relation to environmental predictors and other factors such as human activities.

1.2 White-bellied Sea-Eagle ecology and conservation

The White-bellied Sea-Eagle (*Haliaeetus leucogaster*; Greek *hals*, the sea, *aetos*, an eagle, *leukos*, white, and *gaster*, the belly) (Mason & Jarvis, 1989) and also known as the White-bellied Fish-Eagle or White-breasted Sea-Eagle, is a large bird of prey in the family Accipitridae which also includes many other diurnal raptors such as kites, buzzards, and harriers. A traditional Malay name for the *H. leucogaster* is *Burung Hamba Siput* ('slave of the shellfish'). Its role was to scream to warn the shellfish on the shore of changes in the tide so that they knew when to take shelter or when it was safe to emerge to hunt for food (Yong, 1998). Currently, the species is commonly known as *Lang Siput* or *Lang Putih*. It is the largest raptor in Malaysia (Jeyarajasingam & Pearson, 1999).

This large eagle is very distinctive. The adult has white head, breast underwing coverts and tail. The upperparts are grey and the black underwing flight feathers contrast with the white coverts. The tail is short and wedge-shaped as in all *Haliaeetus*

species (del Hoyo *et al*., 1998). In flight the black flight feathers on the wings are easily seen when the bird is viewed from below. The large, hooked bill is grey with a darker tip, and the eye is dark brown or hazel. The bare legs and feet are cream-white and heavily scaled as armor, with long black talons (claws) (Fig. 1.1). The sexes are similar, but in body size displays reversed sexual dimorphism with female significantly larger (Shephard, 2003). Males are around 75 cm in height and are slightly smaller than females that are up to 85 cm in height. The weights of females are 2,800 g and males are about 2,475 to 2,800 g. The wingspan is about 2 m and the eagles can fly up to 50 km/h. The young White-bellied Sea-Eagles are mottled pale brown when juveniles then gradually come to resemble adults, acquiring the complete adult plumage by their fourth of fifth year (Fig. 1.2). They differ from the falcons in having generally blunter, more rounded wings and paler eyes (yellow or red) (Mackinnon, 1988).

White-bellied Sea-Eagles are not actually true eagles – they do not have feathered legs, but tend more to giant kites. The adults may be confused with smaller Osprey and the juveniles can be confused with Wedge-tailed Eagle (Fig. 1.3). Its closest relative is the little-known Sanford's Sea-eagle of the Solomon Islands. These form a species pair, and as usual in sea eagle species pairs, as opposed to the dark-headed Sanford's, the White-bellied Sea-eagle has a white head. Talons, bill, and eyes are dark as in all Gondwanan sea eagles. This species pair has at every age at least some dark coloration in its tail, though this may not always be clearly visible in this species. Although they differ much in appearance and ecology, their ancestors diverged less than one million years ago (Wink *et al*., 1996).

Figure 1.1 Adult morphology of the White-bellied Sea-Eagle (Image sources: Australian Birdlife Photo Library, 2009).

Figure 1.2 Juvenile morphology of the White-bellied Sea-Eagle (Image sources: Australian Birdlife Photo Library, 2009).

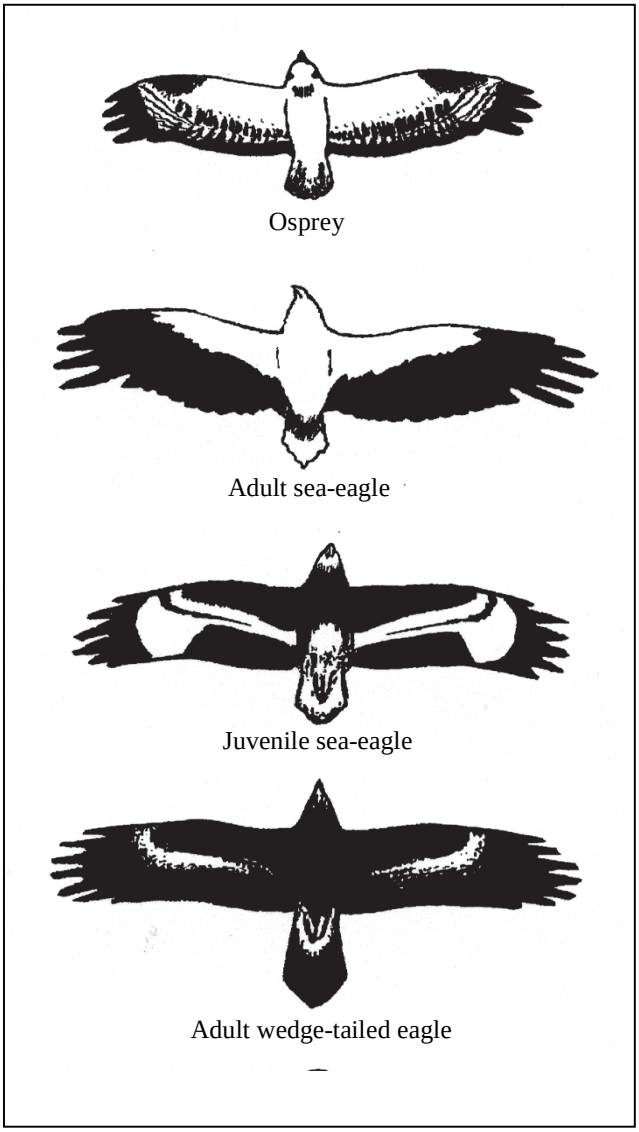

Figure 1.3 Comparisons of White-bellied Sea-Eagle with confusion species (Adapted from Parks & Wildlife Service Tasmania).

White-bellied Sea-Eagle is native in New Guinea, China, through all coastal countries of mainland Southeast Asia (Thailand, Malaysia, Singapore, Indonesia and Philippines), Australia and India. In addition, this species is also found in other island groups from Bangladesh, Sri Lanka, Burma, Andaman, Laos, Ceylon, Wallacea, Bismark Archipelago, Nicobars and Greater Sundas in west to Hainan, Taiwan, New Ireland, New Britain and Louisiades in east, south around Australia to Tasmania (Strange, 2000; Ferguson-Lees *et al.*, 2001) (Fig. 1.4).

White-bellied Sea-Eagles can be found mainly on the sea coasts, large rivers, inland freshwater swamps, settled mining pools, reservoirs, and open country (Ferguson-Lees *et al*., 2001). This magnificent eagles are a common sight in coastal and near coastal areas soaring slowly on thermals, holding their wings in a V-shape (other raptors hold them horizontally) or perched high on a tree.

The species is mostly recorded in coastal lowlands, but can occupy habitats up to 1400 m above sea level on the Northern Tablelands and up to 800 m above sea level in Tasmania and South Australia (Marchant & Higgins, 1995). Breeding has been recorded on the coast, at inland sites, and on offshore islands (Marchant & Higgins, 1995). Breeding territories are located close to water, and mainly in tall open forest or woodland (Emison & Bilney, 1982; Marchant & Higgins, 1995), although nests are also sometimes located in other habitats such as dense forest (including rainforest), closed scrub or in remnant trees on cleared land (Emison & Bilney, 1982).

White-bellied Sea-Eagles are sedentary and do not migrate, but immatures and unpaired adults may wander over a large area (Favoloro, 1944). Immatures are likely to be excluded from the core breeding territories of adults (Smales, 2005). Mated pairs

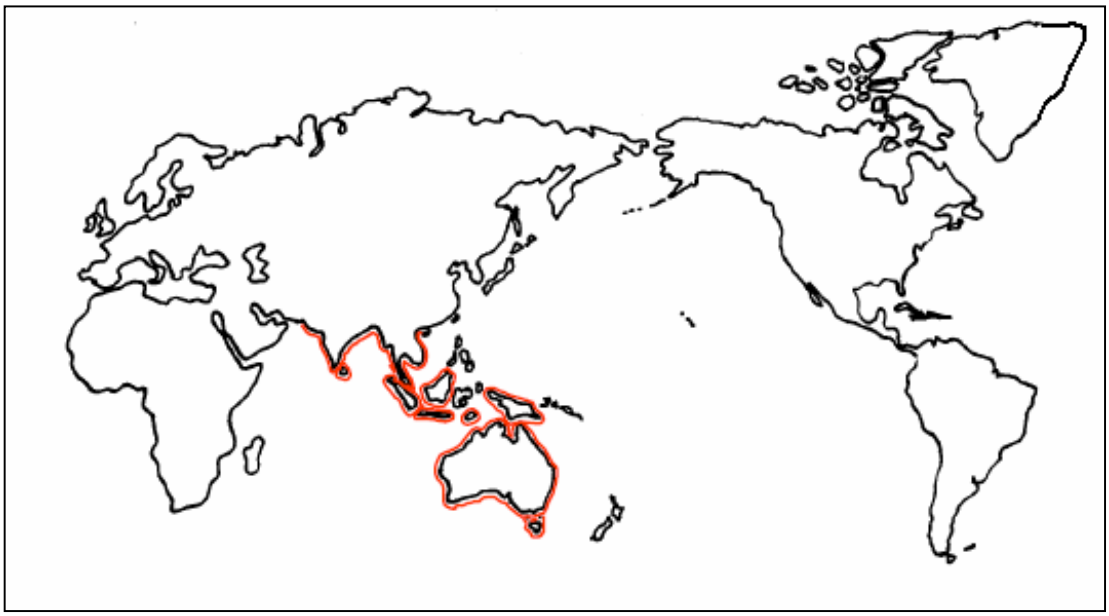

Figure 1.4 Global range distribution of the White-bellied Sea-Eagle designated as red line (Adapted from Ferguson-Lees et *al.*, 2001).

tend to stay near their nesting site (Strange, 2000). White-bellied Sea-Eagles appear to form permanent pair for life. Pairs may perform aerial displays which include locking talons and tumbling together through the air to the accompaniment of loud goose-like honking – they indulge in spectacular courtship display (Greval, 1993).

In choosing a nest site, this species go for height, choosing the tallest objects near coasts or other large bodies of water (e.g., reservoirs) (Jeyarajasingam & Pearson, 1999; Strange, 2000). These include tall emergent trees in mangroves, or along the shores or sometimes on tall telecommunication masts (pylon); when a taller pylon is built nearby, they often shift to the taller one! They may also nest on islands, sometimes on a small tree growing on a cliff face or on rocky cliff or on rocky ledges where there are less of ground predators (Marchant & Higgins, 1995).

The nests will serve as breeding, feeding, and sleeping platforms and act as territorial flags (Marchant & Higgins, 1995). The nest can be huge (1.5 m across and 2 m tall) and is made of sticks, lined with green vegetation. The nest can be located on a tree up to 30m above the ground (Strange, 2000). The same nest is reused every breeding season in succession and built up until it becomes a giant pile of sticks. If the original pair does not return, another pair soon takes over the old nest (Herklots, 1954). Usually, 2 bluish white eggs are laid in a nest lined with green leaves, mainly for hygiene. The female incubates while the male feeds her and defends the nest from other birds and intruders. Sometimes, the parents in turn swooping down and return to feed (Mason & Jarvis, 1989). The eggs take time up to 40-44 days to hatch but usually the first one that come out will kill the other eggs. The nestling will live in the nest up to 95 days (about 3 months) and the fledgling are still dependent on their parents to feed for another few months. Once independent, mortality is high but if the young eagles survive to breed they might live for 30 years (Parks and Wildlife Service Tasmania, 2003). Breeding may not occur until the eagles are 6 years old (Marchant & Higgins, 1995).

Adults are largely sedentary and defend an area of about 3 km^2 (the territory) against other adults. A larger area, up to 150 km^2 (the home range), is used for hunting but is not defended and is shared with other hunting eagles (Parks and Wildlife Service Tasmania, 2003). It becomes smaller during the breeding seasons (Shephard, 2003). White-bellied Sea-Eagles do not appear to be highly territorial towards others of their kind. They even usually build nest close to other White-bellied Sea-Eagles.

They also make loud harsh cries near important spots like a perch or nest. In the breeding seasons (May – October), although the timing of breeding appears to vary with

latitude, occurring later further from the equator (Bilney & Emison, 1983), it becomes noisy, frequently calling in a loud honking cry “ah ah ah ah”; in uttering this, the head is extended with the open beak pointing skyward (Henry, 1971). These can be heard up to 1 km away, perhaps helping to space out the birds and avoid confrontations.

The White-bellied Sea-Eagles is an opportunist feeder on wide range of mainly on aquatic animals, such as fish, turtles, and sea snakes, but it takes birds, crabs and mammals as well. Many types of fish are eaten, including porcupine fish which are deadly to human. Quite often it may be seen to swoop upon a large crab, rise to a height of about a hundred feet, and then drop its victim onto the rock in order to break its shell (Madoc, 1956; Tweedie, 1983). It is a skilled hunter, and will attack prey up to the size of a swan. They may also feed on carrion such as sheep and fish along the waterline, particularly for young, inexperienced eagles. Sea-eagles forage alone, in pairs or in family groups. Like other raptors, they have excellent eyesight. To forage, they circle on a thermal to gain height, then glide over water usually low and within 1 km from the shore. They catch their prey by skimming the water surface then snagging the prey in their talons with a backward slash with both feet, occasionally only one foot catches hold of the prey. They rely on their talons to kill – the most important piece of hunting equipment (Greval, 1993). If the food is not taken to the nest to feed the chicks, the prey is held on one foot and eaten while on the wing. Prey is also taken to a perch or rock to be eaten (Kumar, 2004).

The White-bellied Sea-Eagles is not so skillful a fisher as the Osprey - they do not plunge into the water like Osprey can do. Frequently, however it makes up for its own lack of skill by robbing a more successful osprey of a fish – chasing in until it

drops its prey (Henry, 1971). For the osprey, if a sea eagle encroaches on its territory, the smaller osprey will put up a fight to chase it away, such aerial battles will at times least some 15 minutes, being staged up to a km in the sky (Chew, 1989).

Globally, this species has a large range, with an estimated global extent of occurrence of 1,000,000–10,000,000 km². It has a large global population estimated to be 10,000–100,000 individuals (Ferguson-Lees *et al.*, 2001). Because of this vast range, sea eagle is presumably not at risk of extinction in the near future. Global population trends have not been quantified; there is evidence of a population decline, but the species is not believed to approach the thresholds for the population decline criterion of the International Union for Conservation of Nature (IUCN) Red List (i.e., declining more than 30% in ten years or three generations) (Birdlife International, 2002). For these reasons, the species is evaluated as “Least Concern”.

Although White-bellied Sea-Eagles appear quite tolerant of humans and are conspicuous, they are not present in large numbers in their range, and their numbers appear to be declining (Mohd Hifni *et al*., 2006). They are threatened by habitat loss which removes suitable nesting sites and prey, particularly by land use development and recreational activities, water pollution (the toxic matter that eaten by the aquatic animals will affect the eagles), local threats of shooting and poisoning, tree felling and accidents at fish farms (Bryant & Jackson, 1999). A number of studies have suggested that habitat modification and destruction pose a significant threat to the White-bellied Sea-Eagles through the removal of suitable nest trees (Emison & Bilney, 1982; Bilney & Emison, 1983; Clunie, 1994). According to Herklots (1954) the eagle’s eggs are valuable having in the eyes of the Chinese remarkable medicinal properties. This result in a regional

population decline which may lead to a reduction in the species overall genetic diversity (Mohd Hifni *et al*., 2006).

1.2.1 White-bellied Sea-Eagle in Malaysia

The current status of White-bellied Sea-Eagle in Malaysia in term of numbers and populations is still unknown. To date, there have been no specific studies on the species in Malaysia. The distribution of the species in Malaysia is spread along the coastal region of the Peninsular, Sabah and Sarawak with high population in Penang, Pangkor Island and Pulau Langkawi (Kumar, pers. comm., 2008).

However, this species is listed in Appendix II CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) Checklist, 1992 [10] (Appendix II includes species not necessarily threatened with extinction, but in which trade must be controlled in order to avoid utilization incompatible with their survival). In Malaysia, this species is categorized as “Totally Protected Wildbird” (Schedule III; Wildlife Conservation Act, 2010). Mohd Hifni *et al.* (2006) reported that habitat clearances driven by expanding human population have reduced the population numbers of this species in Malaysia. Although this species is not considered as threatened, but if no early actions are taken to conserve their population, they could soon be labeled as “Nationally Endangered”.

1.3 Problem statement and rationale

In order to address management and conservation priorities in any species it is essential to have a better understanding of the fundamental aspects of its biology and ecology. For the White-bellied Sea-Eagles, regionalized monitoring and surveys programmes could have address some aspects of local concern. However, a broader approach is needed to gain an understanding of large scale processes affecting occurrence of White-bellied Sea-Eagles in the study area.

Bird populations, including raptors, can be limited by natural factors and human impacts (Newton, 1979). Although the White-bellied Sea-Eagle has large global population with large geographic range sizes, they have been subject to loss of habitat which constrained them in sub-optimal habitat with dense human population. This loss of habitat could contribute more to the decline of their population.

Rare species present characteristics of vulnerability to extinction and are more susceptible to habitat change (Santos *et al*., 2006). The survival of this species depends on the conservation of the integrity of their habitat and any other changes on their habitat could lead to their extinction. In addition it is not known to what extent human activities in the study area can influence the habitat of the species. Hence, there is need in mapping and regularly monitoring the White-bellied Sea-Eagle habitat suitability.

Maps displaying the spatial configuration of potential suitable habitat of the White-bellied Sea-Eagle can be an aid to define the actions required to manage their habitat appropriately. The development of Geographic Information Systems and modelling approach can be more practical in these exercises, in terms of time as well as

cost, as they offer the possibilities of minimizing field work and are easily updated as new information becomes available.

Raptors as well as the White-bellied Sea-Eagle are considered by some as important biomonitors and hence, may provide an understanding of effects to other wildlife species (Smith, 2003). Conversely, if avian predator populations fluctuate widely, then they may have an impact on prey species populations. In addition to, the management and conservation on the habitat of the raptor species can also give significant advantages to other flora and fauna species that live inside it.

1.4 Research objectives

The present study applies a simple model through the use of Geographic Information System techniques based on nest-site selection analysis of the species in the study area to identify and predict potential suitable habitat for nesting and breeding of the White-bellied Sea-Eagles. Broadly, the objectives of this study are:

i. to determine the distribution of nesting White-bellied Sea-Eagles in the coastal dipterocarp forest of Penang National Park,
ii. to determine the nest-site selection of the eagle species by calculating the nest-site preferences,
iii. to predict the distribution of suitable nesting habitat for the White-bellied Sea-Eagles through the use of environmental and topographical data,
iv. to develop a prediction model of species habitat distribution using GIS for species conservation and management.

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1.5 Thesis overview

This study consists of a series of methodology to produce a model to predict the distribution of suitable habitat of nesting sites for the species in question starting from preliminary survey of distribution of nesting sea eagles in Penang National Park to collect presence nest data, then assess the nest-site selection analysis of the species using predictor variables significant to the species to built prediction model and final output map showing the distribution of potential suitable nesting sites in larger areas. This modelling approach is appropriate for use over large spatial scales, and could provide a means to quickly and efficiently assess the extent, distribution and status of potential breeding habitat for the White-bellied Sea-Eagles. Later, it will help the protection, conservation and management of the species.

While in this chapter the author talks about the general background of the study and some introduction on species in questions and also gives the research rationale and objectives, Chapter 2 discuss the broader aspect of this research surveyed from previous study and review from the existing literature.

Chapter 3 considers the distribution and abundance of nesting White-bellied Sea-Eagles in Penang National Park from preliminary survey conducted in early stage of study. This chapter also describes the Penang National Park as the main study area. The data from this chapter could provide a baseline and insight into the species population and abundance in Penang National Park and also may assist with future conservation management of the species. Specifically the nest data are used as presence data in chapter 4 in nest-site selection analysis.

Chapter 4 assesses the nest-site selection of the White-bellied Sea-Eagles using variables or habitat features which are believed to affect the selection by the species during their nest placement. The nest-site selection analysis was carried out to determine the range of habitat requirements by the species by comparing the selected habitats with available habitats. To date there is no attempt to analyse nest-site selection of White-bellied Sea-Eagles in relation to their environment in the Penang National Park. This analysis also identifies important habitat requirement by the species for nesting sites which affect occupancy and abundance of the species in the study area.

Chapter 5 develops a model predicting the potential suitable nesting site for the White-bellied Sea-Eagles using data from nest-site selection analysis in the previous chapter. A large number of questions in ecology and conservation modelling depend on the ability and accuracy of the model. Thus, the model built in this chapter was evaluated using independent nest data from the evaluation area (Penang Island and Teluk Rubiah, Perak) to test the accuracy and robustness of the model.

In the final Chapter 6, the author gives general discussions and conclusions of the study and also some management implications from the modelling.

Chapter 2

Literature Review

2.1 Raptors conservation and habitat destruction

There are ten different families of raptors. They are: buteos, accipiters, eagles, falcons, vultures, osprey, harriers, kites and two families of owl. The bald eagle is the most well-known of raptors, while kites and harriers are probably the least known. Raptors have large, powerful feet with sharp curved talons, hooked upper beaks and sharp eyesight.

Raptors such as the White-bellied Sea-Eagles are important because they help control animal populations and are an integral part of keeping natural systems in balance. If raptor prey such as mice, rabbits, rats and prairie dogs become too abundant, they can damage crops and lands and transmit diseases to humans, domestic livestock and pets. Raptors help to prevent prey population explosions that can lead to habitat problems.

Raptors are also important environmental bio-indicators. Since raptors feed at the top of nature's food pyramid, their population provides a good indicator of the underlying health of natural ecosystems. For examples, eagles and other raptor populations provided the first indication that pesticides were entering food and reproductive cycles in damaging ways (Chase, 1995).

There are numerous studies on raptors, especially for vulnerable or declining species, which have been done discussing mainly on their ecology and conservation

issues. An improved understanding of the species ecology and behavior is therefore essential for the proper design of conservation strategies. Bonelli's eagle (*Hieraatus fasciatus*) is one of the raptor's species that has been studied extensively especially in Europe due to their serious population decline and considered as one of the most endangered species (Rocamora, 1994). Ontiveros & Pleguezuelos (2000), Gil-Sánchez *et al.* (2004) and Ontiveroz *et al*. (2005) studied on various factors that influence the species breeding success in southeast Spain. Other studies include Balbontin (2005) identified suitable habitat for the Bonelli's eagle species for management purpose and Carrascal & Seoane (2009) analyzed the interrelationships of various parameters with recent population trends of the species.

In recent years, predictive habitat distribution model have been recognized for their utility in conservation and management planning by combining multivariate statistical analysis with Geographic Information Systems (GIS) technology (Guisan & Zimmermann, 2000). Therefore, modelling species habitat distribution has been extensively applied in wildlife conservation as well as raptors e.g. Eurasian black vulture (*Aegypius monachus*) (see Poirazidis *et al*., 2004), Bonelli's eagle (*Hieraaetus fasciatus*) (see López-López *et al*., 2005), Golden eagles (*Aquila chrysaetos*) (see Tapia *et al.,* 2007). Studies on other raptors also focusing on their ecology and habitat selection e.g. goshawk (*Accipiter gentilis*) (see Krüger & Lindström, 2001), Forest-Falcon (*Micrastur ruficollis*) (see Thorstrom, 2001).

As with all wildlife, loss of habitat is the most significant problem of raptors endangerment. High deforestation rate remains the greatest overall threats to raptors, particularly in tropics (Bildstein *et al.,* 2000; Thiollay & Rahman, 2002). While raptors

are able to migrate and some can adapt in certain urban environments, the continued loss of areas to human use is keep putting pressure on many species as such area are developed (Chase, 1995). According to Bildstein (2006), there are three general categories of human threats to all wild birds including raptors, and their effects are often additive; (1) habitat degradation and habitat loss, (2) environmental contaminants, including pesticides and other agricultural chemicals from agriculture developments, and (3) direct assault, including persecution and trapping for captive use. Besides, thousands of raptors die each year because of illegal shooting, trapping and poisoning (Chase, 1995).

2.2 The influence of habitat selection on species distribution

Habitat selection behavior is of great importance in both ecological theory and individual-based modeling because this behavior is a primary way that mobile organisms adapt to changing conditions (Railsback & Harvey, 2002). Habitat selection studies have recently assumed a new urgency, partially as a result of the importance of incorporating both habitat and demographic information into conservation planning. Understanding the habitat requirements is one of the most crucial questions in conservation and management of animals (Kneib *et al*., 2007). Various studies of habitat selection on different animals have been carried out e.g. bird (Olivier, 2006); fish (Railsback & Harvey, 2002); deer (Lamberti *et al*., 2006; Licoppe, 2006); toad (Bull, 2006); bear (Kneib *et al*., 2007); raccoon (Bozek *et al*., 2007).

Habitat selection of animals is proximately determined by necessary resources, such as food and safe roosting sites, which they require for daily activities. Ultimately,

habitat selection aims at improving the survival of individuals and enhancing their reproductive success by providing food, mates and potential nesting sites. Interactions between conspesifics and other species or predation risk influence the behaviour of individuals and contribute to the habitat selection process. According to Railsback & Harvey (2002) net energy intake (growth) and mortality risks also can influence habitat selection. More recently, habitat selection studies have shown that many factors, such as landscape structure, can influence exactly how animals select habitats while moving through a landscape (Balbontin, 2005; López-López *et al*., 2006).

The actual distribution of animal species may be determined by their habitat selections related to a variety of environmental factors (Morrison *et al*., 1998). According to de Leeuw *et al*. (2002), it can be categorized into three broad classes; those describing the resource base, physio-chemical factors and factors related to human activities.

The definition and empirical distinctions between the terms habitat use and habitat selection are often unclear (Hall *et al*., 1997). Habitat refers to a distinctive set of physical environmental factors that a species uses for its survival and reproduction (Block & Brennan, 1993). Habitat implies more than vegetation or vegetation structure; it is the sum of the specific resources that are needed by organisms (Hall *et al*., 1997). Habitat use refers to the way in which an individual or species uses components in habitats to meet its needs in life (Block & Brennan, 1993; Hall *et al*., 1997). The study of habitat use patterns describes the actual distribution of individuals across habitat types (Hutto, 1985). Meanwhile, habitat selection refers to a hierarchical process of

behavioral responses that may result in the disproportionate use of habitats to influence survival and fitness of individuals (Hutto, 1985; Block & Brennan, 1993).

Habitat selection can be considered as a hierarchical and scale-dependent process (Hutto, 1985). In terms of individual fitness, habitat selection at home range scale is likely to be more important than local or regional scale decisions because the survival of individuals and their reproductive success is obviously dependent on resources in the vicinity of the nesting site (Cody, 1981; Hutto, 1985).

According to Rice & Owsley (2005) 'rich' habitats give higher fitness to the organisms living there where 'poor' habitats give lower fitness. The quality of the habitat has many variables such as food availability, predator occurrence, defense strategy, breeding success, microclimate changes, distance to human settlements, topography and many others. Prediction of the potential impact of habitat changes needs to be based on detailed understanding of the habitat requirements of the animals, or on quantification of distribution or extent of suitable habitat.

2.2.1 Habitat selection in birds

Birds as well as raptors are nearly ideal subjects for studies of habitat selection, because they are highly mobile, often migrating thousands of miles (pass over an enormous range of environments), and yet ordinarily forage, breed, and winter in very specific habitats (Ehrlich *et al*., 1988). Ornithologists are interested in answering what determines the range of habitats in which a species occurs and how does each individual determine when it's in an appropriate habitat.

Indeed, some ecologists employ the term "habitat use" rather than "habitat selection" to avoid the connotation of birds making deliberate decisions among habitat alternatives (Ehrlich *et al*., 1988). Habitat use describes the relative proportions of different habitats utilised by animals, and provides information on where animals find and use resources. However, it can be difficult to understand the significance of results of habitat use, for example, in isolation of landscape composition (Hall *et al*., 1997). For example, results may show that an animal feeds in a certain habitat, but it cannot be determined whether this is because food is particularly abundant within that habitat, or because the animal has little alternative.

In addition, habitat selection carries a connotation of understanding complex behavioral and environmental processes that habitat use does not, by which habitat use patterns are the end result of habitat selection processes (Jones, 2001). According to Jones (2001) nest-site selection is a subset of habitat selection focusing solely on nest sites and it can be highly influence by two main factors; access to food and anti predator strategies (Johansson, 2001). Hence, the author uses the term of nest-site selection in the rest of this thesis, as distinct from simply habitat use, or broader term habitat selection to try to understand the relative importance of nest-site components.

Avian habitat selection is a vast topic in animal ecology because both amateur and professional students of birds have accumulated an enormous body of information on which birds live where, and how they live in their environments. However detailed observations can still add to more understanding of the habitat selection of birds - especially observations of bird behavior made when habitats are being altered either by

"natural experiments" such as droughts and insect outbreaks or by human activities (Ehrlich *et al.*, 1988).

Many studies have demonstrated the special habitat requirements of different species. The reasons why individuals in an ecosystem or bird population establish territories in particular locations depending upon an interplay between the niche of individual bird species and a number of site-specific, as well as non-habitat factors (Fretwell & Lucas 1970). A few studies have been done showing the influences of these factors on habitat selection and habitat distribution of birds, e.g. geographical location, altitude, land productivity, edge effects and food limitation (McCollin, 1998); sex ratio (Fretwell & Calver, 1969); stand structure and floristic composition, social and demographic considerations (Arlt, 2007); nest predation (Johansson, 2001); vegetation structure, competitors and productivity (Cody, 1981).

The contribution of a habitat to the fitness of individual, commonly termed habitat suitability will vary in time and space (Block & Brennan, 1993). Suitability can be regarded as a continuous variable corresponding to spatial and temporal variations of environmental conditions. The assumptions of *ideal-free* habitat distribution for birds by Fretwell & Lucas (1970) defined that in an ideal situation, birds will select the best or greatest habitat for their fitness and birds are free to enter any habitat. Although, territorial behavior can influences and affect habitat suitability by reducing the amount of suitable habitat available (Block & Brennan, 1993).

There are two main ways in which nest-site selection is tested for breeding birds with territorial systems such as White-bellied Sea-Eagle: comparing used habitats with unused habitat or comparing used habitats with available habitats (Jones, 2001). Used

habitat is habitat that is currently occupied by the focal individual or species while unused habitat is habitat not currently occupied. Available habitat refers to all habitat types in a prescribed area and includes habitats currently in use. The used-versus-unused comparison is considered the less informative of the two methods (Johnson, 1980). Information on the quality of used-versus-unused space is only informative about habitat selection if the unused habitat is actually available to the birds of interest (Jones, 2001). Further, absence from a particular habitat does not mean that the habitat is being avoided.

Used-versus-available tests involve comparisons of habitats currently used by individuals to habitats available to be used. Those comparisons are preferable to used-versus-unused comparisons because they allow researchers to make inferences about choice. However, the used-versus-available comparisons are also problematic because it is very difficult to measure the habitat availability (Aebischer *et al*., 1993; Jones, 2001).

Availability refers to both the accessibility and attainability of resources in the habitat, not just their abundance (Johnson, 1980; Hall *et al*. 1997). The definition of availability based solely on the proportional area of habitat types makes a rarely tested assumption that all parts of the study area are equally available. In addition, there are assumptions that a random sampling of habitats estimates habitat availability, although that assumption is seldom tested in the field (Jones, 2001).

Both the spatial and temporal scales of the study influence the perception of habitat availability. This is likely to affect individual choices at several levels. Johnson (1980) defined four levels or orders of habitat selection that acknowledge its hierarchical ordering of selection process in nature and provide a useful empirical

framework for habitat studies. Johnson's framework ranges from the macroscale selection at the geographical or physical range of a species (*first-order selection*) to microscale descriptions of the actual attainment of food items or selection of nest sites from those available (*fourth-order selection*), which *second-order selection* refers to home range of an individual or social group and *third-order selection* considering the selection of habitat component from within territories or home ranges.

When examining habitat selection within territories, the individual has likely already made a crucial selection by choosing a territory. Hereby, measurement of habitat availability is depend on the spatial scale of study and constraints to that prior decisions made by the animal place on its current options (Johnson, 1980).

2.3 Geographic Information Systems and wildlife conservation

Geographically-explicit models are represented graphically as maps showing the distribution of areas associated with different intensities of the relationship being modelled. A map can be considered as an analogue depiction of the Earth’s surface that links features in a spatial context. The mapping sciences have developed highly sophisticated tools for accurately recording and representing the location of physical, natural and anthropogenic features and processes, and the rapid development of computing tools has enabled the handling of vast amounts of information coming from remote sensors and topographical maps. One of them is represented by the software that enables the development of Geographical Information Systems.

2.3.1 Geographic Information Systems

A geographic information system (GIS), also known as a geographical information system or geospatial information system, is any system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to Earth.

Nowadays, in the strictest sense, it is any information system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically referenced information (Mattikali & Engman, 2000). In a more generic sense, GIS is a tool that allows users to create interactive queries (user created searches), analyze the spatial information, edit data, maps, and present the results of all these operations (Salvatori, 2004).

GIS provides appropriate methods for efficient storage, retrieval, manipulation, analysis and display of large volumes of spatially referenced data with quantitative and qualitative approaches. Accordingly, GIS consists of four basic components: data input and editing, storage of geographic databases, data analysis and spatial modeling, and data visualization and presentation (Mattikali & Engman, 2000).

These particular attributes of GIS, together with the possibility of combining information coming from diverse sources using the spatial component as relational element, makes it a suitable tool for developing models and simulating processes in diverse contexts (Salvatori, 2004).