Habitat Mapping and Multiple Criteria Analysis for Ecotourism Planning in Lantau Island with GIS

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ABSTRACT

Lantau Island is one of the very few remaining pieces of land stays mostly intact in Hong Kong. Supported by its diversified natural and cultural resources, Lantau has great potential in providing another form of tourism experience – ecotourism – to both local and foreign tourists. The concern is how to generate recreational opportunities and tourism satisfaction without posing serious negative impacts on and curtailing the ability of such resource in satisfying the future needs. Ecotourism planning becomes indispensable in maintaining a harmonious relationship between the conservation of environmental resources and tourism development. Studies showed that although Hong Kong has a high percentage of areas being designated for conservation purpose, many important ecological habitats tend to fall outside the boundaries. The identification of additional conservation sites has become a significant first step in planning. Through zoning, the negative impacts from tourism activities can be reduced by separating them from important ecological habitats or sites.

With the assistance of remote sensing and Geographic Information System (GIS), the study has three focuses. The first focus is on mapping the potential habitats of fifty common species in Lantau by three statistical modeling methods. The best performed model is selected and combined to form an overall species richness map. And the high species-rich sites act as a guide to select conservation areas in Lantau. The second focus is to identify potential sites suitable for three kinds of recreational activities including camping, hiking and cycling as well as for tourism development through the integration of GIS and Multiple Criteria Analysis (MCA). Finally, based on previous results, areas are allocated to four zones – (1) sanctuary; (2) nature conservation; (3) outdoor recreation; and (4) tourism development with the first two emphasizing on conservation and last two focusing on recreation and tourism development. Three scenarios are created to simulate different perspectives towards the tourism issues in Lantau. The zoning maps provide an objective base for the evaluation of the Concept Plan for Lantau.

From habitat modeling results, the Generalized Additive Model (GAM) is used to represent the distribution of the species because of its reliability and discriminatory ability outperforms the Binary Logistic Regression Model (BLRM). However, the species richness map cannot be used as a sole guide for selecting conservation areas. As for the sites for recreational activities, although the results match closely with the proposed sites in the Concept Plan, other potential sites are revealed and worthy of further assessment. The three zoning plans form a continuum, which provides a few implications on the future development of the island. When compared with the proposed extension of Lantau North Country Park with the conservation-oriented scenario, the coincidence lies immediately contiguous to the existing boundary of Lantau North Country Park without expanding to the northeastern portion. Also implied by this scenario are tourism development sites with a high priority. The equal-preference scenario provides a more balancing view. As for the recreation-and-tourism-development-oriented scenario, the conservation areas identified are of

high conservation values. The Concept Plan for Lantau falls in-between the equal-preference and recreation-and-tourism-development-oriented scenario.

論文摘要

大嶼山是香港其中一片近乎完整的土地。豐富的自然及文化資源令它擁有發展另類旅遊的潛力，尤其是生態旅遊。但在提供休閒活動以滿足遊客的同時，我們亦要考慮減低這些活動可能引起的負面影響，以避免削弱這些資源可維持未來需求的能力。生態旅遊規劃是一不可缺少的工具用以建立與維持自然資源保育與旅遊發展的和諧關係。據一些研究顯示，儘管香港擁有高比率的保育用地，很多重要的生態環境都在這些保育範圍之外。因此，界定額外的保育地點便成爲生態旅遊規劃重要的第一步。接著，通過區域劃分的方法，這些重要的生態地點便可以與旅遊的活動分割開來，籍此減低因休閒活動所導致的負面影響。

是次研究利用環境遙感及地理訊息系統以達到三個主要的目的。第一，利用三種不同的統計模型，建立在大嶼山常見五十種物種的環境棲息地模式，並藉此推估其潛在棲息地的分佈。最優的模型會用來代表物種的分佈，並會組合起來成爲一代表物種豐富度的合成圖。一些擁有豐富物種的地區會作爲以後選擇大嶼山保育區域的基礎。第二，藉著地理訊息系統及多目標分析技術的結合，點選出一些具有休閒活動發展潛力的地方，這些活動包括露營、登山、踏單車以及旅遊發展。第三，根據以上的結果，把大嶼山劃分成四個主要區域包括保育禁區，自然保護區，野外休閒活動區及旅遊發展區。前兩者以保育爲重而後兩者則以旅遊爲目標。此外，本研究會建立三個不同的方案，以模擬社會上不同的觀點。最後，那三個方案會用來對大嶼山發展概念計劃作出評價。

根據棲息地模擬的研究結果，廣義累加模型(GAM)在可賴性及區別能力上都比二元羅吉斯迴歸模型(BLRM)優勝。但是據分析顯示，物種豐富度不能作爲選擇保育區域的單一條件。另外，在界定休閒活動地點方面，雖然研究結果與概念計劃有很大程度上的吻合，但是結果亦提供了很多其他極具潛力的地點，而這些地點仍有待以後評估。那三個方案提供了幾個對大嶼山未來發展的重要含意。以保育爲前提的方案指出一些應該最先考慮的旅遊發展地區。與此同時，當比較此方案以及擬議的北大嶼郊野公園擴建部分的差別時發現，兩者重疊的地方只限於北大嶼郊野公園接壤的鄰近邊緣，而並沒有延伸至大嶼山的東北面。另外，那個對於四個目標沒有偏頗的方案提供了一以平衡自然保育與旅遊發展的規劃模式。最後，那個以休憩及旅遊發展爲主的方案則指出一些擁有最高保育價值的地方。如果把三個方面看成一連續線，大嶼山發展概念計劃則界乎沒有偏頗的方案與以休憩及旅遊發展爲主的方案之間。

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LIST OF ABBREVIATIONS

AFCD	: Agriculture, Fisheries and Conservation Department
GAM	: Generalized Additive Model
BLRM	: Binary Logistic Regression Model
ENFA	: Ecological Niche Factor Analysis
EW	: Equal Weighting Scheme
HZMB	: Hong Kong – Zhuhai – Macao Bridge
GIS	: Geographical Information System
IUCN	: The World Conservation Union
GCPs	: Ground Control Points
DEM	: Digital Elevation Model
MCA	: Multiple Criteria Analysis
MOLA	: Multi-objective Land Allocation
GLM	: Generalized Linear Model
H-L	: Hosmer and Lemeshow Goodness-of-Fit Test
IV	: Independent Variables
ROC	: Receiver Operating Characteristics
AUC	: Area Under Curve
GRASP	: Generalized Regression Analysis and Spatial Prediction
AIC	: Akaike Information Criterion
SSSIs	: Sites of Special Scientific Interest
AHP	: Analytic Hierarchy Process
AHPW	: Analytic Hierarchy Process Weighting Scheme
CR	: Consistency Ratio
SAW	: Simple Additive Weighting method
WLC	: Weighted Linear Combination
REDPA	: Regional Ecotourism Development Planning Approach

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CHAPTER 1 INTRODUCTION

1.1 Background to the Study

1.1.1 Ecotourism Opportunity in Hong Kong and Ecotourism Planning

Hong Kong depends heavily on tourism as her major source of foreign exchange income. Except in the year 2003, the total number of visitor arrival grows continuously and reaches another new record of 23.36 million in 2005. The total tourism expenditure associated with inbound tourism exceeds HK$100 billion in 2005. The latest figures show the number of visitor arrival in March 2006 is 2.1 million which increases 14.8% when compared with that of the same month in 2005 (Hong Kong Tourism Commission, 2006). Judging from these figures, tourism industry is still an important economic pillar in Hong Kong. Observing the opportunity, the Hong Kong SAR Government has been actively and enthusiastically exploring new destinations in accommodating different kinds of tourism activities. Apart from large-scale tourism projects, such as amusement park, cable car, more emphases have been put on the utilization of existing natural and cultural resources.

Hong Kong has many remarkable landforms and a variety of ecological habitats with the majority of them being protected within the Country Parks. She also possesses cultural heritages with historic, architectural and archaeological significances, which are both tangible and intangible in nature (Chu and Uebergang, 2002). With such a diversified resource base, Hong Kong has the potential to broaden her tourism resource base with a view to accommodate the continuously growing demand in the present and future tourism market. According to the "alternative tourism survey" conducted by the Citizens Party in July 1998, historical buildings, outlying islands and Chinese festivals are top attractions to the tourists after shopping markets. On the other hand, Disney theme park and casino are ranked with the lowest interest (Citizens Party, 1998). This shows that the existing natural and cultural attributes are more attractive when compared with artificially-built tourism projects in Hong Kong. Opportunities are being looked for in the northern New Territories and Lantau Island since most of the lands still remain intact.

However, a question being aroused is how to on one hand create recreational opportunities and satisfaction to tourists and; on the other hand keep the natural and cultural assets sustainably in use. Regarding the issue, tourism planning and management are fundamental before a site is opened to public and it is considered as part of the management strategies (Eagles and McCool, 2002).

1.1.2 Habitat Mapping and Conservation Areas Selection

Although Hong Kong is highly urbanized, with non-extreme temperature and plenty of rainfall gifted by the sub-tropical climate, she is still rich and diversified in both fauna and flora. Extensive systematic ecological survey has been carried out in Hong Kong in 2002 by the Department of Ecology and

Biodiversity at The University of Hong Kong (DEB). In the survey, over 95,000 point records regarding 5,201 species from different taxonomic groups have been recorded. Although the number is quite high, new species are constantly discovered throughout the territory of Hong Kong (Dudgeon and Corlett, 2004). It is necessary to identify potential sites that are diversified and rich in species. The question is where these extra conservation areas should be located or how these areas can be identified.

Based on the records from the survey, Yip *et al.* (2004) overlaid the survey points to conduct the gap analysis in order to identify high-conservation-valued sites that are possibly under-protected in current protection system. Although Hong Kong has almost 40% of areas circled and defined as Country Parks, Restricted Areas, and Special Areas, the analysis concluded that some important ecological habitats fell outside the protection boundary (Dudgeon and Corlett, 2004; Yip *et al.*, 2004).

Gap analysis is conducted by simply aggregating the point data which show the presence of a species at a particular place collected directly from local ground surveys and observations. The use of point data map in representing the presence of species has received a few concerns. First, data are only available to sites which have been visited. Sites which have not been surveyed or where a species is undetected are ignored. Second, since the data is not spatially continuous, blank areas are ambiguous in definition. They do not essentially represent the absence of species, but also can stand for no records available (Scott *et al.,* 1993). Spatial analysis, such as overlay analysis can be performed, however, these data are not comprehensive and of sufficient continuity further analysis which can aid decision making. With a view to solving this limitation, habitat models are established through describing the field data by a set of environmental attributes using statistical models. The models are then used to generate prediction over unsurveyed or blank areas (Osborne and Tigar, 1992; Buckland and Elston, 1993; Augustin *et al.*, 1996). With the aid of remotely sensed images, environmental information is available in large-scale coverage (Cowley *et al.*, 2000). The geographical information system (GIS) technique raises the efficiency in storage, manipulation and analysis of data as well as modeling processes (Miller and Allen, 1994, Rushton *et al.*, 2004). The advantage of using the results from habitat modeling over the traditional way of representation is that the distribution of species is illustrated by a continuous surface depicting the probability of occurrence of the species at each individual site within the study area (Lawton and Woodroffe, 1991; Rushton *et al.,* 2000). These species map providing a thorough coverage of the study areas can aid conservation and tourism planning studies through identification of sites with high ecological values.

1.1.3 Lantau Island and the Concept Plan

Lantau Island is not only the green lung of Hong Kong on account of its abundance in flora and fauna, but also regarded as the second oldest island of

China after Hainan (Hui, 2004). After the grand launch of the Hong Kong Chek Lap Kok Airport in 1997, the island has been under multi-stakeholders' concern. The Green Groups immediately drew up "A Conservation Strategy for Lantau" in 1998. In the same year, the Territory Development Strategy Review has also mentioned the importance of conservation in the island. In the 1999 Policy Address, Mr. Tung, then chief executive of HKSAR proposed the extension of Lantau North Country Park. In 2001, the final recommended report of South West New Territories Development Strategy Review worked out the future development plan for the island in several aspects (Noffke, 2006). One of the major issues is tourism and recreation development. Many studies concerning tourism and conservation compatibility have since been carried out, including the Study on Revitalization of Tai O in 1998; Tung Chung Cable Car Feasibility Study in 1999; and Study on the Suitability of Southwest Lantau to be established as Marine Park or Marine Reserve and Study on the Suitability of South Lamma to be established as Marine Park or Marine Reserve in 1998 (Hong Kong Planning Department, 2001a).

The Island was officially put under the agenda of discussion in November 2004 when the Concept Plan for Lantau was opened for public consultation. Lantau is one of very few remaining places of natural landscape in Hong Kong. With attractive and abundant natural and cultural assets in her possession, the island has to shoulder an important task in sustaining Hong Kong's future development. In terms of natural resources, over half of the islands' area is designated as Country Parks under the Country Parks Ordinance enacted in 1976. The cultural resources are the traditional settlements of high values on account of their historical and archeological significance. With expanding demand and pressure on local facilities, this piece of land has been urbanized gradually with major infrastructures including the Hong Kong International Airport, the newly-influx of Disney amusement park as well as housing estates or and towns such as Tung Chung, Discovery Bay, Mui Wo, etc. The Tung Chung Cable Car Project, recently renamed as Ngong Ping 360, is the latest tourist attraction expected to open in Mid-2006. With a view to utilize this piece of land with sustainable development, the Lantau Development Task Force led by the Financial Secretary was set up to monitor the developments on the island. They Task Force has finally come up with a concept plan for Lantau Island putting forward a feasible scheme of development.

The concept plan proposes a concrete planning framework to support its major objective which is "*to balance the development and conservation needs in accordance with the principle of sustainable development, with particular emphasis on turning the sub-region into a Tourism, Recreation and Leisure centre* (Lantau Development Task Force, 2004, p.1)". The plan hopes to achieve its objective by suggesting four development themes with solid proposals. The first theme concerns the transportation facility as well as tourism recreational facilities development. The second and third themes aim to utilize existing natural and cultural resources for ecotourism-related activities. And the fourth theme concerns the extension of nature conservation areas. The plan has received tremendous echoes with both appreciation and opposition from different pressure groups. Severe opposition from the green groups was received blaming particularly on the heavy development proposal in northern Lantau and satirized the plan as "Concrete plan of Lantau" (Civic Exchange, 2006). On the other hand, indigenous villages protested against the extension of North Country Park which would possibly undermine the opportunity of land development (Shamdasani, 2005). After consultation, a report was released in November 2005 within which 174 proposals and recommendations were evaluated with 65 being dropped out. The remaining 109 proposals, 83 or 76% are tourism and recreation related. Given the diversified opinions and comments on the Concept Plan, the question is how to formulate a plan which can cope with the multi-objectives. Besides, were the Concept Plan is adopted as a guide for Lantau's future, how justifiable is it?

1.2 Objectives of the Study

The study is to take advantage of remote sensing and geographic information system in achieving the seven objectives below. The first four concern habitat modeling while the last three are related to tourism planning.

i. To map out the habitats of fifty common species based on the presence data from the Biodiversity Survey and the generated pseudo-absence data.

ii. To statistically compare the results of two habitat models.

iii. To identify biodiversity hotspots based on the habitat mapping results.

iv. To identify possible conservation gaps by matching the map of biodiversity hotspots and current protection system in Lantau Island.

v. To identify sites for different kinds of tourism-related activities through multiple criteria analysis.

vi. To formulate zoning plans with several scenarios.

vii. To evaluate the Concept Plan for Lantau by comparing it with zoning plan.

1.3 Significance of the Study

There are basically three purposes for habitat mapping. First, it helps to prevent common species from becoming rare in the future. In most countries, including Hong Kong, governments have adopted the so-called reactive strategy in protecting wildlife. That is, they would save a species only when the species is in the verge of extinction. Such a strategy is not sustainable since only those rare species will receive attention. The biodiversity conservation is a significant step beyond the protection of endangered species only (Noss, 1991; Scott *et al.*, 1991). Many species that are not currently endangered will become so once their habitats are lost due to human activities (Margules, 1989). What is needed is a proactive strategy. The word proactive, according to the Cambridge online dictionary, means 'taking action by causing changes and not only reacting to change when it happens.' That is to protect the common species as well so as to minimize likely threats to their extinction.

The second purpose is to minimize disturbances to different species within the parks. Noss and Cooperrider (1994) identified four types of human influences on biodiversity; they are direct exploitation, indirect exploitation, disturbance, and indirect disturbance. The indirect exploitation and disturbance which are probably the most ubiquitous, permanent, and controllable forms since human influences are the principal causes of the modification of habitat types and structure (Ningham and Noon, 1997; Noss and Cooperrider, 1994). These habitat maps assist the identification of species' location so that the species and their habitats can be both better protected and managed (Miller and Allen, 1994).

The results of habitat mapping can aid planning, management and decision making. Manel *et al.* (1999) and Jaberg and Guisan (2001) suggested that since such maps can convey potential habitats suitable for different species, they are applicable to conservation and wildlife management. Such maps can help improve the design of country parks system with a view to ensuring the existing parks have adequate protection for those significant habitats. Possible conservation gaps can be identified through matching with existing protection system (Scott *et al.*, 2002). Besides, by integrating the habitat mapping results into project design and planning (Miller and Allen, 1994), it can help balance conservation development (Root *et al.*, 2003). The significance of spatial prediction of species distributions as a component of conservation planning is endorsed by many scholars (Franklin, 1995; Austin, 2002; Guisan and Zimmermann, 2000; Elith and Burgman, 2002; Scott *et al.*, 2002).

The integration of habitat mapping results with the other environmental and tourism attributes helps tourism planning in Lantau. The planning results provide an objective base for comparison with and evaluation of the tourism proposals listed in the Concept Plan for Lantau. Sites with high suitability for a certain type of activities calculated with the multiple criteria analysis is matched against existing and proposed sites in the Concept Plan so as to provide an unbiased evaluation to the Plan. Apart from that, the zoning plans provide a general guideline to facilitate the future conservation and development issues in Lantau. Coupled with the simulation of different scenarios, the results provide great flexibility in aiding decision making.

1.4 Scope of the Study

Ecotourism – This study treats ecotourism as a sustainable tourism practice. The boundary between ecotourism and sustainable tourism is not clearly distinguished here. Apart from considering natural resources, cultural resources are considered as second important elements in ecotourism. Conservation and Recreation are the two foci in the formulation of zoning plans. Other principles of ecotourism such as tourism satisfaction, economic benefit to local communities, educative role, etc are assumed to be intrinsic in the two aspects.

Ecotourism Planning – There are different scales of planning including site, destination and regional (Gunn, 2002). Site and destination are large scales considering the setting and design of individual site and community. Instead of working on the border scale, this planning study takes a small scale similar to the regional scale in which comprehensive plans are formulated through zoning. The plans broadly identify and suggest potential sites for different tourism activities. The planning details within each zone are out of scope of this study.

Multiple Criteria Analysis (MCA) – MCA integrated with GIS provide a platform to assess criteria and preferences of decision makers with decision rules to identify sites suitable for different kinds of recreational activities as well as tourism development. Making use of the GIS technique, the results are displayed and visualized in the forms of maps.

1.5 Organization of the Thesis

This thesis is organized in the following ways with this chapter as an introductory chapter, followed by Chapter 2, a literature review on three major aspects of the study. The chapter begins with the identification the habitat requirements of animals and introduction of the history of habitat mapping. This is followed by the review of the techniques and frameworks of multivariate statistical habitat modeling. After that, the relationship between biodiversity, species richness and conservation planning is examined and reviewed. The chapter ends with the discussion on GIS and multiple criteria analysis as decision support tools and its association with ecotourism planning.

Chapter 3 discusses the methodological framework of this study. This chapter begins with a description of the study site and is followed by the construction of a GIS database on which subsequent analyses depend. The next section discusses the three habitat modeling techniques employed in the study, together with their evaluation and selection. This is followed by the formulation and evaluation of biodiversity hotpots map as well as identification of possible under-represented sites of an existing protection system. Afterwards, the procedures of multiple criteria analysis in determining sites suitable for recreational activities plus the process in developing zoning plans are revealed.

The results of fifty species from the three habitat modeling methods are summarized and discussed in Chapter 4. The species are categorized into five taxonomic groups including amphibian, bird, butterfly, dragonfly and mammal. Detailed statistical results of individual species are shown in Appendix 5. This is followed by the results on model selection, hotspots identification and evaluation as well as gap analysis to identify possible unprotected areas.

Chapter 5 shows and discusses the site selection results of the three selected and comparable tourism activities, including camping, hiking, cycling and picnicking as well as that for tourism development. This is followed by presenting the results of zoning plans simulating three scenarios and based on which the Concept Plan for Lantau is compared and evaluated.

This thesis ends with a concluding chapter, Chapter 6 in which the findings of the study is summarized. This is followed by a discussion on limitations of the study and recommendations are provided for further studies.

CHAPTER 2 LITERATURE REVIEW

The chapter is going to first discuss and review potential factors influencing the distribution of wildlife. This is followed by a review of traditional and recent habitat mapping and modeling techniques and the use of multivariate statistical modeling as a tool to identify possible habitats of species. Furthermore, the linkages among species richness, biodiversity and selection of conservation areas are discussed. The chapter ends with a discussion on GIS and multiple criteria analysis used as decision support tools in ecotourism planning.

2.1 Wildlife Habitat Mapping

Wildlife conservation, habitat mapping, park planning and management, have become the mostly concerned issues in the western world. National parks and reserves have been the prevailing means of wildlife conservation for centuries (Western and Gichohi, 1993). However, these parks and reserves do not essentially play the role of wildlife conservation because of a few reasons. First, negative impact on wildlife or their environment may be imposed by visitors, particularly in highly frequented areas or where sensitive species occur (Leeuw *et al.*, 2002). Second, it is suggested that some areas having high ecosystem function fall outside the boundary of these parks and reserves. Although the current system of protected areas in Hong Kong has covered almost 40% of Hong Kong, some important wildlife habitats have been excluded from the system (Hong Kong biodiversity survey, 2002). According to the Hong

Kong biodiversity survey conducted by the Department of Ecology and Biodiversity at The University of Hong Kong (DEB), "the Country Park system does provide a good coverage for vascular plants and bryophytes, but poor coverage for butterflies, amphibians, fishes and bats". This will eventually lead to the decline in both plant and animal diversity (Western and Gichohi, 1993). It seems that the sole dependence on national parks and reserves is not satisfactory in protecting the wildlife. Areas with rich wildlife resources fall outside the protected system require instant conservation. However, the deficiency of both information and knowledge in species distribution and abundance is likely to hamper such actions (Leeuw *et al.,* 2002). As a result, habitat prediction and modeling which map out the potential habitats of different species within a short time becomes a popular methodology to provide an objective and scientific base for wildlife conservation and park planning and management.

2.1.1 Habitat Requirements and Factors Influencing Wildlife Distribution

Wildlife is not distributed randomly without patterns. The basic needs of different species have certain implications on their distribution since they reflect essential environmental characteristics of the habitat. Habitats that are suitable for the species in turn aid in choosing suitable environmental parameters in later modeling process. These needs are basically related to their life support system including food, water, nesting sites, shelter, evasion of potential enemies, etc

(Leeuw *et al.*, 2002). There are many ways to categorize these parameters that control the distribution of the species.

Leeuw *et al.* (2002) classify the environmental factors determining the distribution of animal species into three broad categories namely, the resource base, physico-chemical factors and anthropogenic factors. As for the physico-chemical and human influence, they can indirectly influence the resource base which in term affect the distribution of animal species. More specifically, Austin (1980) and Guisan and Zimmermann (2000), have used different levels to distinguish and categorize the ecological factors. The factors are broadly classified into resource, direct, and indirect gradients. Resource refers to those matter and energy consumed by plants or animals such as the nutrients, water and food. Direct gradients are environmental variables which 'physiological' influence, but are not consumed such as temperature, soil, precipitation, wind, radiation. Indirect gradients are factors such as slope, aspect, elevation, topographic position, habitat type and geology, having no direct physiological relevance for species' performance. In fact, the resource and direct gradient should be used as predictors since they govern the life and death of the species. However, data availability and interpolation uncertainty are always concerned with these two types of gradients. Instead, the indirect gradients are mostly used as environmental predictors than the other two for species distribution modeling because they are easily collected especially when remote sensing and GIS data is widely available. Besides, they have sound association with observed species pattern (Guisan and Zimmermann, 2000). Moreover, Guisan *et al.* (1999) realized that the indirect variables tend to combine and represent different information from resources and direct gradients. However, one limitation of model using indirect parameters is its inapplicability over large geographical extent since the underlying direct and resource gradients with similar topographic position in different regions are not likely the same. If a more general model is needed, the use of resource and direct gradients as predictors is recommended (Guisan and Zimmermann, 2000).

2.1.2 Habitat Mapping: Past and Present

The significance and value of locating plants and animals in wild area is already recognized in the past. Historically, species distribution maps have been compiled based on reliable ground surveys and observations (Butterfield *et al.*, 1994) such as counting animals, trapping, collection of droppings, investigations of feeding sites as well as ground mapping of habitats are useful in collecting species distribution data. However, such ground-truth survey cannot encompass the whole study area (Kushwaha, 2005). Sometimes, in order to get more detailed ecological and abundance data, intensive surveys are carried out but such surveys are restrictive to only a few species and small area (Cowley *et al.*, 2000). When remoteness and the habitat range of a species are concerned, it becomes unwise and impractical to map the distribution of species through intensive survey of a large area with several hundreds of species. Scott *et al.* (1993) mentioned four types of traditional maps that are used to represent distribution from surveys including dot distribution maps, grid-based maps, range maps and hybrid dot distribution maps. The dot distribution maps are the simplest method to show the presence of a species at a particular place based on the local ground surveys and observation. Range maps are created by drawing boundaries around the location points of the dot-distribution maps. However, the dot-distribution maps fail to depict the presence of a species in areas that have not been searched or where a species is undetected. Blank areas on a dot distribution map do not necessarily mean a species is absent but merely that no records are available (Scott *et al.*, 1993). As for range maps, they cover both suitable and unsuitable habitat. They may provide incorrect conclusions (Butterfield *et al.*, 1994). To conclude, these maps are regarded as the most objective but provide least information on the distribution (Hollander *et al.,* 1994). Therefore, they can hardly satisfy advanced analytical processes.

Owing to the shortcomings inherent in the traditional maps, ecologists have tried different methods to model species' distribution. For example, Farina (1997) uses simple linear interpolation to estimate species' occurrences between sample points. However, the result is not satisfactory since habitat discontinuity occurs (Osborne *et al.*, 2001). Another alternative is to determine the relationship between various features of the environment and the distribution of each individual species. In other words, it relates species' occurrences at points to a collection of predictor variables that are available across the whole study area (Osborne and Tigar, 1992; Buckland and Elston, 1993; Augustin *et* *al.*, 1996). The information can then be used to generate models that predict species' distribution by identifying suitable habitat (Cowley *et al.*, 2000). According to Morrison *et al.* (1992), the ancients have already recognized the relationship between species and natural vegetation. Vertebrate biologists have made use of this knowledge to predict the presence or absence of animals (Scott *et al.*, 1993). Many previous studies have successfully established the species-habitat relationship to model bird distribution (Osborne and Tigar, 1992; Stillman and Brown, 1994; Austin *et al.*, 1996; Parker, 1996; Siriwardena *et al.*, 1998, 2000). Similar approach has been applied on the distribution of terrestrial vertebrates (Edwards *et al.*, 1995).

Instead of using point and range, species distribution is a continuous surface representing the probability of occurrence of species. The benefit of this approach is that it can identify apparently suitable habitat that remain unoccupied (Lawton and Woodroffe, 1991; Rushton *et al.*, 2000; Smart *et al.*, 2000). Besides, it is cost-effective and is likely to reduce biases from sampling design (Williams, 1993). Moreover, the models can also act as supplement to the traditional survey information by predicting the likely richness of species within 'occupied' areas and the presence or absence of species in poorly documented regions (Edwards *et al.*, 1995). Moreover, the results can more accurately represent the distribution of species (Maddock and Plessis, 1999) which are essential for carrying-on analysis such as conservation planning (Wilson *et al.*, 2005).

2.1.3 Remote Sensing, GIS and Habitat Mapping

The development of remote sensing and geographical information system (GIS) has tremendously facilitated the habitat mapping of species. Remote sensing allows research to be carried out in remote areas and in habitats which are technically difficult to collect a large amount of habitat information (Jeganathan *et al.*, 2004). Especially when the current emphasis of conservation is put greater on landscape scale, remote sensing makes the collection of quality habitat information over extensive areas possible which in turn makes broad-scale species' distribution modeling becomes desirable and realistic (Cowley *et al.*, 2000). Since the early 1980s, remote sensing has been used to identify the distribution of areas suitable for wildlife (Leeuw *et al.*, 2002). However, in the early day, the studies depended solely on a vegetation map, derived from aerial photos or satellite images, as the only predictor. It is obvious and indisputable that the distribution of species tends to be affected by other environmental factors. A single vegetation map is insufficient in explaining the distribution of a species. With the assistance of GIS which acts as a tool to store, manipulate and analyze spatial data, mapping of various land attributes into separate data layers becomes feasible. Given a number of predictors, the suitable habitat of different species can be modeled and localized (Leeuw *et al.*, 2002).

Remote sensing combined with the use of GIS lead to increase in species distribution modeling worldwide (Miller and Allen, 1994; Rushton *et al.*, 2004).

Large numbers of studies have integrated remote sensing and geographical information systems to produce models which can predict the distribution of a species. Austin *et al.* (1996) have incorporated GIS and remote sensing into the prediction of distribution of buzzard Buteo butes nesting area in Scotland. Debinski *et al.* (1999) combine remote sensing and GIS to model habitat and biodiversity relationships in the Great Yellowstone Ecosystem. Osborne *et al.* (2001) have modeled habitat of great bustards with the aids of GIS and remote sensing. Luoto *et al.* (2002) have incorporated remote sensing data in modeling butterfly distribution in south-western Finland. Gibson *et al.* (2004) have applied GIS to predict the rufous bristlebird habitat.

2.1.4 Multivariate Statistical Habitat Modeling Approaches

In the last two decades, multivariate statistics such as principal components analysis, canonical correlation analysis, discriminant function analysis, classification and regression trees, generalized linear models or regression analysis and the artificial neural networks, has increased in popularity as tools for species distribution modeling. No matter what statistical models are used, all modeling studies basically contain three elements – dataset, mathematical model and model assessment. The data include the incidence or abundance of the species concerned and a set of explanatory variables. The mathematical model is employed to develop the relationship between the species data and the independent variables. The model is then evaluated and assessed for its accuracy and robustness (Rushton *et al.*, 2004). Apart from these components, assumptions behind the model are also critical. Two fundamental assumptions are applied in every model. First, it is assumed that various environmental or physiographic factors control or govern the distribution of species, communities and biodiversity (Beutel *et al.,* 1999; Guisan and Zimmermann, 2000). Second, since most of the studies use the static distribution models without considering the temporal factor, equilibrium is assumed between the environment and observed species patterns. That is the predicted probability of occurrence does not capture the existence of the species in long term (Lischke *et al.*, 1998; Guisan and Zimmermann, 2000).

Among the methods, regression models have been extensively applied on species distribution prediction (Walker, 1990; Osborne and Tigar, 1992; Mlandenoff *et al.*, 1995; Augustin *et al.*, 1996). Regression analysis establishes relationship between a response variable and a single (simple regression) or a combination (multiple regression) of environmental predictors (explanatory variables) (Hosmer and Lemeshow, 1989). Traditionally, linear regression, multiple regression and multiple discriminant analysis in which data are assumed to have normal errors, are used to predict species abundance. However, the assumption of Gaussian distribution error is sometimes difficult to satisfy (Austin and Meyers, 1996; Lek *et al.*, 1996). Therefore, new modeling paradigms are developed. Two particular models are intensively used – the generalized linear model (GLM) and the generalized additive model (GAM).

GLMs is an extension from classical regression in which dependent variables such as species richness and presence/ absence data are allowed to follow a non-Gaussian distribution (McCullagh and Nelder, 1997). It is a flexible type of regression model which can handle distribution such as the Gaussian, Poisson, Binomial or Gamma with respective link function (Guisan and Zimmermann, 2000). The resultant model or equation is the combination of the independent variables in a linear or curvilinear form as in classical regressions. Binary Logistic regression model, a category of GLMs, is the most frequently used modeling approach in species distribution modeling to predict the likely occurrence and distribution of species. The reason is simply because the outcome variable is binary or dichotomous i.e. presence or absence, which is the kind of species distribution data that is comparatively easy to collect in field. In other words, logistic regression uses a linear combination of independent variables to explain the variance in a dependent variable having only two states (Osborne and Tigar, 1992). Analogous to any other GLMs, logistic regression model has three components including the linear predictor, link function and an error structure. The link function of logistic regression is logit transformation and the error structure is assumed to be binomial (Hosmer and Lemeshow, 1989). There are several advantages of logistic regression. First, it allows the prediction to be a function of more than one environmental variable (Hosmer and Lemeshow, 1989; Peeters and Gardeniers, 1998). Second, since it restricted the outcome value to fall in between 0 and 1, it has the advantage in terms of interpretation over ordinary linear regression (Pampel, 2000) and discriminant function analysis which may also be used to discriminate binary data. Logistic regression has the further advantage with its logit link function. The logit link function assumes that the probability of species' occurrence relate to an environment gradient in a logistic rather that a linear manner. Third, Osborne and Tigar (1992) realized the shape of the logistic curve matches with ecological and biological sense because a species is likely to exhibit tolerance over part of the gradient. Once a threshold has been reached, decreasing tolerance are experienced, and then intolerance will appear over the remainder.

Examples of logistic regression being applied in environmental and ecological studies are numerous. According to Guisan and Zimmermann (2002), logistic regression has been applied by Bloomfield and Apperson to predict the habitat of mosquito in 1987 as the early application. Followed by the modeling of Kangaroos in relation to climate (Walker, 1990); Lesotho distribution in Southern Africa (Osborne and Tigar, 1992); red deer (Buckland and Elston, 1993); common gammarids in Netherlands (Peeters and Gardeniers, 1998); butterflies and day-flying moths in Wales (Cowely *et al.,* 2000); great bustards (Osborne *et al.,* 2001); threatened species of butterfly in Finland (Luoto *et al.*, 2002); different vegetation species in the Yellowstone National Park in USA (Aspinall, 2002); and Bristlebird (Gibson *et al.*, 2004). Some studies compared the performance and result between logistic regression and discriminant function analysis (Austin *et al.,* 1996); overlay analysis (Brito *et al.*, 1999); neural network/ discriminant analysis (Manel *et al.*, 1999).

As for GAM, it is a non-parametric extension of GLM that allow the independent variables to be non-linear in nature (Hastie and Tibshirani, 1990; Yee and Mitchell, 1991). This kind of model does not have predefined response shape and the shape is subject to the actual data. The spatial prediction result from regression analysis is regarded as objective (Lehmann *et al.*, 2002).

The majority of statistical models including regression models require both presence and absence of dataset. However, Hirzel *et al.* (2002) argued even though the absence data is available, their accuracy is in doubt. The points representing the absence of a species on a map depict three possibilities. First, the habitat is genuinely unsuitable for the species. Second, the target species is present but failed to be detected by the surveyors. Third, the habitat is actually suitable but due to some historical reasons, the species disappears in the site. Since the real reason behind is not know, a new algorithm, the Ecological Niche Factor Analysis (ENFA) developed by Hirzel is able to overcome the problem by using presence-only data for modeling species distribution. The basic notion is through the comparison of environmental variable or ecogeographical variable (EGV) space of those cells or areas with species presence with that of the whole study area. Suitability functions are then developed to describe the habitats of species (Hirzet *et al.*, 2002). The concept of "ecological niche" follows the definition by Hutchinson in 1957, which refers to "the subset of cells in the ecogeographical space where the focal species has a reasonable probability to occur (Hirzet *et al.*, 2002)." The term "factor analysis" is similar to the Principal

Components Analysis, which converts the predictors or EGVs into uncorrelated factors explaining the same amount of variance (information) as they are in the EGVs. And these factors are ecologically meaningful (Hirzel *et al.*, 2001). The first factor explaining the maximum amount of variance is the "marginality", which is the difference between species mean and the global mean. The directional difference between the species niche and the conditions of the study area is specified (Hirzel *et al.*, 2001). The subsequent factors are the "specialization" which is expressed as the ratio of the standard deviation/ variance of the global distribution to that of the focal species (Hirzet *et al.*, 2001; Hirzet *et al.*, 2002). These two groups of factors are used to represent and quantify the concept of ecological niche. Unlike the GLM and GAM which predict the probability of presence, ENFA generates maps indicating the habitat suitability index (HSI) for species, which is normalized to fall between 0 and 100. Zaniewski *et al.* (2002) have compared the ENFA and GAM in modelling of native New Zealand ferns. More recently, Segurado and Araújo (2004) have compared ENFA, GLM and GAM in modelling a large number of species in Portugal.

Before any model building can be performed, one of the fundamental steps is the determination of number of variables in the model. The number of predictors is a concern because an excessive amount of predictor variables does not guarantee a best model can be developed and it is possible to over-fit the models. Model over-fitting tends to explain the variation in the observed data very well, but no robust in the sense that they perform poorly when used elsewhere (Rushton *et al.*, 2004). Therefore, with a view to build a model with predictive power and acceptable accuracy, a reasonable number of explanatory variables should be used. Hosmer and Lemeshow (1989) suggested the comparison of the descriptive statistics (mean, standard deviation) between all the explanatory variables and the occurrence of a species using the univariate analysis can help to evaluate the role of the each predictor before model development (Pereira and Itami, 1991). Harrell *et al.* (1996) propose that in the final model, no more than *m*/10 predictors should be used, where *m* is the total number of observations or the number of observations in the least represented category in the case of binary response. The selection of predictors can be arbitrarily, automatically or followed principles and rules (Harrell *et al.*, 1996, 1998). Statistical analysis, such as the least-square regression, GLMs and CCA, can perform stepwise elimination of variables automatically (Collingham *et al.*, 2000). In some situations, other than using the original explanatory variables in the analysis, some studies (Alonso, 2002; Osborne and Tigar, 1992) input the orthogonalized components generated by principal components analysis (PCA) into the model instead. Since the process is time-consuming, it is recommended that a small number of variables should be used (Osborne and Tigar, 1992).

Modeling is 'the process of developing and providing an abstraction of reality (Wallace, 1994, p.1). Since a model cannot be perfectly true, model validation is needed (Oreskes *et al.*, 1994). Wildlife suitability maps and their underlying suitability models have been criticized because of their assumed poor accuracy (Norton and Williams, 1992). Leeuw *et al.* (2002) defined two sources of error – error in spatial database and error in the predictive model. Assessment of predictive performance therefore becomes essential and crucial (Fielding and Bell, 1997; Guisan and Zimmermann, 2000; Pearce and Ferrier, 2000). However, the evaluation of the predictive performance of habitat models often receives fairly little attention. A good prediction model should possess two important criteria – reliable and discriminatory. Reliable prediction depicts the accuracy of estimation in terms of the probability of occurrence of a species at a given site. While a model is said to be discriminatory represents the ability to correctly discriminate between the occupied and unoccupied sites, regardless of the reliability of predicted probability (Pearce and Ferrier, 2000). It is always suggested that the data used for modeling should be independent from those used for evaluation in order to obtain an unprejudiced estimation of a model's predictive performance. However, if observation is insufficient to split the available data into separate datasets, then statistical resampling techniques such as cross-validation (CV) (Manel *et al.*, 1999; Franklin *et al.*, 2000), *leave-one-out* jack-knifing (JK) (Manel *et al.*, 1999) or bootstrap (Guisan and Harrell, 2000) techniques can be used to minimize the bias in the evaluation process (Pearce and Ferrier, 2000).

Confusion matrix is often used to assess the discriminatory ability of wildlife habitat models derived by regression model. Since only binary (presence/ absence) data are modeled, a threshold probability value has to be determined, above which a species is regarded as present and below which is considered as absent. Then a 2 x 2 classification table or contingency table (Lindenmayer *et al.*, 1990; Pearce *et al.*, 1994) is built. Instead of choosing an arbitrary cut-off threshold, the Receiver Operating Characteristic (ROC) analysis comes from statistical decision theory (Green and Swets, 1966) is another method in assessing the discriminatory ability of models. The method was developed in electronic signal detection and was originally used for the analysis of problems with radar images during the Second World War. The term 'receiver operating characteristic' refers to the performance (operating characteristic) of a human or mechanical observer (receiver) employed in assigning cases into dichotomous classes (Deleo, 1993). The ROC analysis is threshold independent because it considers the compromises for all the possible decision thresholds. Besides, since the values are expressed as proportion, it is independent of the frequency occurrence of a species (Swets, 1988). The ROC analysis is extensively used in clinical chemistry but application in ecological studies is limited (Fielding and Bell, 1997) and only until recent years, the method became popular in ecological applications (Manel *et al.*, 1999, 2001; Marsden and Fielding, 1999; Pearce and Ferrier, 2000; Osborne, *et al.*, 2001; Luck, 2002b; Scott *et al.*, 2002; Schadt *et al.*, 2002; Engler *et al.*, 2004; Frair *et al.*, 2004; Gibson *et al.*, 2004; Jeganathan *et al.*, 2004).

The main problem of statistical modeling aroused from the incompatibly between the existing GIS technique and the statistical procedures. GIS is a renowned too for spatial studies, but the statistical procedures for predictive purposes can hardly be found (Guisan and Zimmermann, 2000). For example, the stepwise elimination procedure of logistic regression though is a method widely used for selecting variables is not included in any GIS software. However, on the other hand, the standard statistical packages such as SPSS and S-PLUS do not support GIS data directly and transfer of data is clumsy and inconvenient (Guisan and Zimmermann, 2000).

2.2 Biodiversity and Conservation

Biodiversity is always used as a guide for conservation area selection. Although the discrepancy between the definition of biodiversity and its actual representation is still under many debates, biodiversity hotspot is still playing a major role in conservation planning. Gap analysis is one of the systematic conservation planning methods concerning the protection of unidentified species rich sites.

2.2.1 Biological Diversity, Species Richness and Conservation Planning

There is no common, explicit and clear definition of biological diversity or biodiversity, but the basic idea is the same. Gaston (1996a) has listed out the various definitions of biodiversity and the one from US Congress Office of Technology Assessment is the mostly cited one.

> *“Biological diversity refers to the variety and variability among living organisms and the ecological complexes in which they occur. Diversity can be defined as the number of different items and their relative frequency. For biodiversity diversity, these items are organized at many levels, ranging from complete ecosystems to the chemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species, genes, and their relative abundance* (OTA, 1987 in Gaston, 1996a, p.2)”.

Judging from the definition of biodiversity, it is so board, comprehensive and multi-dimensional that makes it difficult to come up with an objective and quantifiable measure embracing every aspect of concern (Margules and Usher, 1981; OECD, 2002). Researchers try to get the essence out from such a wide-range and abstract concept by identifying major elements with a view to make it measurable, quantifiable and operational (Gaston, 1996a). For example, Noss (1990) use hierarchical approach to divide biodiversity into four levels of organizations. Williams (1993) introduces the strengths and weaknesses of three surrogates including environmental correlates, indicator groups and higher taxa. Margules and Pressey (2000) suggest using “sub-sets of species, species assemblages and habitat types (p.245)” as measures of biodiversity. Scott et al. (1993) use vegetation, butterfly and vertebrate distributions as surrogates for gap analysis which is going to be discussed in the next section. Among different methods, species richness becomes the most popular and useful surrogate of biodiversity (Williams and Humphries, 1994; Preece *et al.*, 1995; Gaston, 1996b). Species richness is defined as "count of the number of species recorded in an area (Williams, 1993, p.200)". This species-based approach identifies areas with the highest number of species and treated them as biodiversity hotspots (Lombard, 1995). Nevertheless, it is argued that species richness alone does not equal to biodiversity (Gaston, 1996b). Besides, a valid hotspot map defines based on species richness has a priori assumption that the number of species chosen can adequately represent species richness. But the number of species enumerated is of no universal consensus. Moreover, it is further argued that even if the species richness map is adequately represented, it can only embrace part of biodiversity (Maddock and Plessis, 1999). In spite of these limitations, species richness is always used as a surrogate of biodiversity for a few reasons. First, the lack of a universal definition of biodiversity obstructs the consensus on "what constitutes the greatest amount of biodiversity (Williams, 1993, p.198)". Therefore, no perfect surrogate exists for such a complex concept (Margules and Pressey, 2000). Even other elements such as ecosystem are included; they are still abstract of biodiversity. Second, species richness is the most conspicuous elements that can be quantified scientifically. In some situation, it is the only data available. Finally, species richness can retain the fundamental nature of biodiversity (Gaston, 1996b).

Biodiversity evolves from a sole scientific concept to a concept with social value when it is linked once with conservation (Gaston, 1996a). The study of relationship between biodiversity and conservation suggests that they are mutually beneficial to each other. Biological diversity always acts as a tool to identify conservation priority (Maddock and Plessis, 1999). The selected conservation areas play an important role in protecting and separating components of biological diversity from possible menaces of extinction (Margules and Pressey, 2000; Wilson *et al.*, 2005). However, studies showed that biodiversity based on hotspots of high species richness alone should not be used as the only criterion for the selection of areas for conservation (Prendergast *et al.*, 1993; Williams, 1993; Curnutt *et al.*, 1994). Margules and Usher (1981) reveal that diversity and rarity are two most frequently used criteria in guiding the selection of conservation areas. The first criterion, diversity embraces the concepts of species richness and habitat diversity while the second one tends to indicate peculiar ecological environment (Margules and Usher, 1981). Margules and Pressey (2000) further suggest conservation areas should be representative and persistent. Judging from this point of view, species richness can only satisfy a portion of representation, owing to its incapability of in capturing other aspects such as "levels of endemism, numbers of rare or threatened species, and intensity of threat (Reid, 1998, p.275)". Besides, species richness concerns the richness at a particular point in time. The long-term endurance of the species is not considered.

Regardless of these deficiencies, many studies still select conservation areas based on species-based approaches (Vane-Wright *et al.*, 1991; Lombard, 1995). Researches relating species richness and definition of conservation areas are overwhelming. For instances, Williams *et al.* (1996) use and compare three methods including species richness, rarity and complementary areas for the selection of biodiversity hotspots to conserve birds in Britain. Ortega-Huerta and Peterson (2004) match the distribution of species richness modeled from birds and mammals species with the existing and proposed biosphere reserves and priority areas in order to identify any discrepancy and coincide in the reserve network. Besides, various methodologies used in defining species richness for the selection of conservation network are tested. For instance, Wilson *et al.* (2005) have tested the use of different thresholds to convert the probabilities of occurrence in presence-absence data as well as the direct use of the probabilities of occurrence in formulation of conservation plan. It is argued that the use of low threshold or summed probabilities without using a threshold in designing conservation areas is likely to select false-positive areas which are actually low in probability of occurrence. However, the two methods provide great flexibility and efficiency in the design of conservation network (Wilson *et al.*, 2005).

2.2.2 Gap Analysis Program (GAP) and Conservation Planning

The Gap Analysis Program (GAP), a program of the National Biological Service, was launched in 1987 with a view to deal with the serious habitat loss in the United States. It is a conservation planning tool defined by the U.S. Geology Survey as "a scientific method for identifying the degree to which native animal species and natural plant communities are represented in our present-day network of conservation lands. Those species and communities not adequately represented constitute 'gaps' in conservation lands and efforts (U.S. Geological Survey, 2004)". It relies on the use of satellite remote sensing and GIS to categorize habitat, based on which the prediction of different species assemblages expected to be found in those habitat are made. GAP is said to be a 'coarse filter' with the goal of identifying potential reserves (geographical gaps in habitat and species protection) or priority areas for conservation by comparing predicted locations of plant and animal habitats (species-rich areas) to those of existing natural protected areas (Scott *et al.*, 1987, 1988, 1993). Since the endangered species are well-protected in the U.S., the target of GAP are not those in the brink of extinction or naturally rare, but the ordinary species. Provided with the geographic information of habitats and status of these ordinary species, the purpose of GAP is to provide different decisions makers such as land managers, planners, scientists and policy makers with the information they need to make better-informed decisions (Scott and Jennings, 1997). Apart from the United States, gap analysis as a conservation planning and evaluation method has been widely used in Australia (Scott *et al.,* 1993). Recently, it is also used in Hong Kong (Yip *et al.*, 2004) to identify possible under-protected areas.

Although the suitability of a site for a species is determined by the complex interaction among microhabitat features and other abiotic and biotic factors, gap analysis regards vegetation, butterfly and vertebrate distributions as surrogates for ecosystem and overall biodiversity (Scott *et al.,* 1993). In other words, they are indicators of biodiversity (Noss, 1990). In terms of vegetation, gap analysis assumes that plant communities assimilate physical factors, such as type of soil, moisture, aspect, elevation, temperature that interact within a site (Scott and Csuti, 1997). Since vegetation is the most visible component of the ecosystem as well as the easily-collected factor, it is most often used as an indirect indicator of the distribution of terrestrial plant and animal species (Austin, 1991; Austin and Margules, 1986). Butterflies have been highly recommended as indicators of overall biodiversity. Scott *et al.* (1993) realized that butterflies are likely to integrate huge amount of ecological information that is presented in plant. Besides, Pyle (1982) identifies several uniqueness including moderate vagility, host specificity, an ability to resist the impact of human activities through a high reproductive potential. Finally, the vertebrates play a major role in community interactions. It is suggested that the richness of vertebrate species is highly associated with the overall biodiversity because they act as protective umbrella for the invertebrate species (Terborgh, 1988; Murphy and Wilcox, 1986).

Although Gap analysis has a sound framework, it is criticized for a few aspects. First, it is criticized on its heavy dependence on qualitative, subjective expert opinions rather than objective quantitative data. Second, it can only work best with the species that are habitat specialists but for those with high spatial and temporal variation, the prediction tends to be less accurate. Third, unlike statistical measures, there is an absence of measures to determine the accuracy of its predictions (Flather *et al.*, 1995). It is therefore recommended that field verification should be carried out before any conservation of biodiversity management action is taken (Scott *et al.*, 1993).

2.3 Ecotourism Planning and Multiple Criteria Analysis (MCA)

Ecotourism grounded on the principle of sustainable development is becoming a popular form of tourism activity around the world. However, the possible negative impacts urge for comprehensive planning. Geographical Information System (GIS) and Multiple Criteria Analysis (MCA) are regarded as useful decision support tools for the planning activity of this kind.

2.3.1 Ecotourism and Planning Model

Ecotourism is defined as the *"Purposeful travel to natural areas to understand the cultural and natural history of the environment, taking care not to alter the integrity of the ecosystem while producing economic opportunities that make the conservation of natural resources financially beneficial to local citizens (TES, 1993)."* Although there is no single definition of ecotourism, it is agreed that ecotourism is a form of sustainable tourism development with conservation and sustainability being two important principles. It distinguishes itself from traditional mass tourism which tends to exploit environmental resources and causes tremendous negative impacts (Fennel, 1999; Wearing and Neil, 1999; Page and Dowling, 2002). It is through ecotourism that symbiosis which promotes the inter-dependence of tourism and environment is achieved (Budowki, 1976; Page and Dowling, 2002, Holtz and Edwards, 2003). The idea is further elaborated by Gunn (1987) as "resource assets are so intimately intertwined with tourism that anything erosive to them is detrimental to tourism (p. 245)". The continuous conservation of environmental resources is therefore equal to sustaining tourism activities. Eagles and McCool (2002) promote the "tourism and conservation cycle" in which conservation is further reinforced owing to the promotion of tourism in the natural areas.

Although ecotourism is regarded as a sustainable form of tourism activity, it is not free from impacts. While positive impacts exist, negative impacts are under more intensive researches. Knight and Cole (1995) identified four kinds of impacts resultant from recreational activities that will pose on wildlife – exploitation, disturbance, habitat modification, and pollution (p.51). They also examine the responses of wildlife towards different kinds of recreational activities. While these are direct impacts, the indirect effects of recreational activities are also studied (Cole and Landres, 1995). More specifically, Bowles (1995) studies the influence of noise to animals. Cole (2004) reviews the impacts of hiking and camping specifically on soils and vegetation. He also identifies the factors affecting the magnitude of impacts. Buckley (2004a, 2004b) examines the behavioral change of terrestrial wildlife owing to habitat modification, lights, noise, etc. resultant from ecotourism. Page and Dowling (2002) argue that the environmental impacts from ecotourism tend to be more serious than general tourism because it depends on natural resources. The visitation of originally unexplored sites will probably disturb the ecological sensitive areas. It seems that negative impacts are unavoidable. Therefore, researches on the impacts of recreation on wildlife also include finding ways by which impacts can be mitigated without curtailing recreation use (Knight and Temple, 1995). Gunn (1988b) regards "planning as a concept of viewing the future and dealing with anticipated consequences is the only way that tourism's advantages can be obtained (p.22)". In order to maintain the harmonious relationship between conservation of environmental resources and tourism, planning is an indispensable tool in minimizing these adverse impacts and maximizing recreational and tourism opportunities (Inskeep, 1991; Gunn, 2002; Page and Dowling, 2002; Dowling and Fennell, 2003) as well as in achieving sustainability (Priskin, 2003).

"Planning is a multidimensional activity and seeks to be integrative. It embraces social, economic, political, psychological, anthropological, and technological factors. It is concerned with the past, present and future (Rose, 1984, p. 45)". In terms of ecotourism planning, it takes environmental planning and tourism planning into account with the former component concerns natural and cultural resource conservation, environmental protection while the latter identify areas of development (Dowling and Fennell, 2003). Environmental planning models and tourism planning approaches are widely available; however, there are a few frameworks cater for ecotourism planning (Dowling and Fennell, 2003). Dowling and Fennel (2003) mentioned the advancement of tourism planning through incorporation the concept of sustainability. Gunn (1988) indicates the integration of tourism functions into ecotourism and reserve planning. Among the various planning practices, zoning is regarded as a widely used planning and management technique in tourism environments. Zones are set up based on site characteristics which primarily include "natural resources and their need for protection, and capacity to absorb recreational involvement (Fennell, 2003, p.48)". Countries like Canada place park zoning into their national policy as a way to maintain ecological integrity and protect nature resources (Fennell, 2003). The practice is also supported by the International Union for Conservation of Nature and Natural Resources (Gunn, 2002). Haas *et al.* (1987) suggest that "zoning is not only a method of providing appropriate locations for desired or preferred recreation opportunity settings, but also a tool to direct and control the spread of visitor-induced impacts to previously determined levels (p.17)". Besides, zoning is also viewed as a tool in controlling and balancing the possible conflict between preservation and use and in the meantime, looks for tourism opportunities in the natural areas (Page and Dowling, 2002). The idea of zoning matches with basic principle of ecotourism which suggests the sustainable use of resources.

In terms of tourism planning or zoning, the first step is the complete search of current tourism resources and attractions with future potential. Gunn (2002) related the tourism development to five natural resources including water, topography, vegetation, wildlife and climate. The nature of these resources can accommodate diversified form of tourism activities ranging from active to passive. Gunn (2002) regards cultural resources prehistoric sites; historic sites; place of ethnicity, lore, education; industries, trade centers, professional centers; places for performing arts, museums, galleries; and sites important for entertainment, health, sports and religions (p.62-63). Both natural and cultural resources are important base for tourism since they create distinctiveness to a place (Gunn, 2002). Afterwards, the selection of suitable planning and management frameworks is needed. There are many frameworks such as the Limits of Acceptable Change (LAC), the Recreational Opportunity Spectrum (ROS), and the Visitor Impact Management (VIM) which aim at managing visitors from recreational perspective (Fennell, 2003). The Regional ecotourism development planning approach (REDPA), initially named the environmentally based tourism development planning model is one of the models used to formulate zoning plan for ecotourism purpose. It is the planning framework seeks to foster environmental protection and tourism development through a sustainable resource and development planning framework (Dowling, 1993). "It determines opportunities for ecotourism development through the identification of significant features, critical areas and compatible activities (Page and Dowling, 2002, p.212)." The rationale is to promote sustainable tourism planning through a strong connection between tourism developments, recreational activities and environmental conservation (Fennell, 2003). The merits of this model includes its grounding in the sustainable development approach, that is, being based on environmental protection, community well-being, tourist satisfaction and economic integration in order to achieve environment-tourism compatibility. Other merits include its being strategic and iterative, regionally based, incorporating land-use zoning, and environmentally educative, that is fostering the environmental ethic (Page and Dowling, 2002).

2.3.2 GIS and Multiple Criteria Analysis as decision support tools

Planning is viewed as a decision making process. Simon proposed the term "bounded rationality" to suggest that decision-making is constrained by capability of individual to collect and process information (Bogetoft and Pruzan, 1997). Simon (1978, 1979) further proposed the concept of "procedural rationality" which means the "effectiveness of decision support procedures in search of the relevant decision alternatives (Jankowski, 1995, p.253)." The emphasis is on the quality of the decision process rather than the outcome of decision making (Janssen, 1994; Bogetoft and Pruzan, 1997). "A decision process is procedural rational if the procedure to attain the best solution is optimal (Janssen, 1994, p.6)". Relevant decision support tools become more and more important in facilitating decision makers to make rational decisions. The availability of GIS and other computer techniques has greatly facilitated the description and analysis of geographical attributes which in turn aids policy makers and planners in tourism planning by supplying valued information (Gunn, 2002).

GIS provides decision makers with tools specialized in inputting, storing, transforming, manipulating and analyzing spatial information relevant to a decision problem (Carver, 1991). It is regarded as an important tool in transforming data into significant information to support decision making (Millar *et al.*, 1994; Farsari, 2006). By examining the decision-making process introduced by Simon (1977), the three phases including intelligence, design and choice, reveal notable relationship with GIS functions (Malczewski, 1999). Besides, when it is integrated with other technologies such as remote sensing and Global Positioning System (Malczewski, 1999) makes it a valuable tool in environmental and resource planning and management tool (Berry, 1991; Culbertson *et al.*, 1994; Beinat and Nijkamp, 1998). Moreover, the graphical display ability enables visual examination of data and results (Carver, 1991). When coupled with the digital elevation data, 3D-visualization and simulation are allowed (Farsari, 2006). Issues in tourism planning are essentially a geographical phenomenon in which decision-makings are related to the spatial analysis and allocation of tourism resources. GIS is therefore beneficial to many aspects of tourism studies. Bahaire and Elliott-White (1999) list the relationship between the functional abilities of GIS and its application in tourism analysis, from storing tourism resources inventories to evaluating the possible impacts of tourism development. They also identify the application of GIS in addressing the problems of tourism mentioned by Butler (1993). Farsari (2006) reviews and discusses ten applications of GIS related to tourism and recreation. She also notices the close linkage of tourism with inventory, analysis and management phases of GIS applications. There are plentiful applications of GIS in tourism resource planning and management depending on simple GIS analytical functions such as overlay analysis, proximity measures and buffer analysis. For instances, GIS is used for documentation and evaluation of tourism resource information (William *et al.*, 1996); identification of suitable areas for conservation, recreation and development based on tourism resource database (Berry, 1991; Gunn, 1994; Boyd and Butler, 1996; Bahaire and Elliott-White, 1999); trail, tourism center and facilities planning (Millar *et al.*, 1994); evaluation of tourism proposals and alternatives (Butler, 1993; Bahaire and Elliott-White, 1999) and assessment of possible impacts from tourism activities (Bahaire and Elliott-White, 1999).

However, researchers argue for the deficiency in function of GIS in supporting decision making (Jankowski, 1995) when the level of complexity and controversy of spatial problems are becoming more prominent. Conflicts which are becoming common phenomenon and happen in most of the cases are inevitable. Compromise has always to be sought between different interests in order to come up with a (set of) feasible solution (Bogetoft and Pruzan, 1997). The ability of GIS is questioned in dealing with problems involving lots of criteria and objectives and extremely conflicting preferences and opinions from different stakeholders or interest groups (Carver, 1991; Jankowski and Richard, 1994; Jankowski, 1995). Carver (1991) points out specifically the drawbacks of the deterministic nature of overlay analysis which are frequently used in site selection or facility location problems and suggested that GIS can act only as a site screening tool. Jankowski (1995) also reveal the incapability of GIS in minimizing the amount of feasible alternatives efficiently as well as in coping with the variation of importance and tradeoff between factors when the preference of decision makers is taken into consideration. Besides, it is also criticized for its lack of "optimization, iterative equation solving, and simulation capability" which are all considered essential in planning (Jankowski and Richard, 1994, p.339). Besides, when semi-structured decision problems in which the border between decision phases is ambiguous is considered, GIS is likely to fail (Malczewski, 1999; Feick and Hall, 2002). Nevertheless, the inherent shortcomings can be overcome by integrating GIS with specialized analytical models. Multiple Criteria Analysis (MCA) is conceived as such an example of potential tool (Carver, 1991; Jankowski, 1995).

MCA began to come into sight during the early 1970s when a more thorough planning process is demanded for facility location due to failure of sole neoclassical economic view in tackling the side-effects from projects on environment and society (Carver, 1991; Pomerol and Barba-Romero, 2000). Multi-criteria decision is divided into two types since the word "criteria" is regarded as a generic term referring to both the concepts of attribute and objective (Hwang and Yoon, 1981; Massam, 1988; Jankowski, 1995; Malczewski, 1999). By definition, "an attribute is a measurable quantity or quality of a geographical entity or a relationship between geographical entities" while “an objective is a statement about the desired state of the system under consideration (Malczewski, 1999, p.85)”. More specifically, Hwang and Yoon (1981) have divided them into two separate functions – multi-attribute decision making (MADM) is for selection and evaluation while multi-objective decision making (MODM) is for design. MADM, usually referred to multi-criteria analysis or multi-criteria evaluation, concerned with the choice from a limited number of predetermined feasible alternatives. However, in MODM, the aim is to design the best or Pareto-optimal alternative from a decision space bounded by constraints without predetermined alternatives. No matter what difference falls between the two concepts, the general objective of MCA is to “assist the decision-maker in selecting the ‘best’ alternative from the number of feasible choice-alternatives under the presence of multiple choice criteria and diverse criterion priorities (Jankowski, 1995, p.252)”. The procedures include “methods effectively decompose choice decisions by indicating the performance of alternatives across different aspects of the decision problem through a series of criteria scores and capturing the relative importance of each criterion to a given decision maker through assignment of a criterion weight factor (Feick and Hall, 2002, p.394)”. Jankowski (1995) regards it as a vital decision support tool because the general MCA process match with the four steps of “procedurally rational model of decision making” including problem definition; search for alternatives and selection criteria; evaluation of alternatives; and selection of alternatives.

With a view to expand the applications of GIS in decision making, the integration of GIS and MCA forms the so-called spatial multi-criteria decision analysis (SMCDA). MCA can supplement the deficiencies of GIS by strengthening the decision support ability through allowing consensus-building and conflict-compromising (Janssen, 2001). Besides, criteria are not required to be deterministic in nature (Carver, 1991) and they can be standardized using algorithms such as fuzzy membership function (Eastman, 2001b) when uncertainty due to imprecision exists (Leung, 1988). Moreover, it can aid decision makers in the process of dealing with semi-structured spatial problems (Malczewski, 1999; Ascough II *et al.*, 2004). It is also regarded as a systematic, transparent, objective and replicate planning and assessment tool (Janssen, 2001). Opportunities have been explored to integrate GIS technology with Multiple Criteria Analysis (MCA) techniques (Jankowski *et al.*, 1997; Bojórquez-Tapia *et al.*, 2001; Feick and Hall, 2002; Farsari, 2006). A number of papers have discussed the integration of GIS and MCDM techniques (Carver, 1991; Jankowski and Richard, 1994; Jankowski, 1995; Malczewski, 1996). As far as the data model used in GIS is concerned, the vector-based GIS provides much less alternatives than the raster-based GIS. In raster-based GIS, every single pixel is considered as an alternative subject to evaluation. The huge number of alternative restricts the choice of MCA techniques since many become unfeasible when computational efficiency is considered. Eastman (2001b) integrates MCDM into GIS environment to provide suitability assessment in the form of raster.

Current *et al.* (1990) review the extensive use of MCA to facility location decisions. Its application on planning and management are also numerous. For instances, they are extensively applied to water resource control and management (Raju and Kumar, 1999; Malczewski *et al.*, 2003; Bana-e-Costa *et al.*, 2004; Ellis *et al.*, 2004; Martinez-Cordero and Leung, 2004; Srdjevic *et al.*, 2004; Abrishamchi *et al.*, 2005; Durga-Rao, 2005; Levy, 2005; Rossi *et al.*, 2005); forest planning and management (Leskinen *et al.*, 2003; Mendoza and Prabhu, 2005; Phua and Minowa, 2005; Sheppard and Meitner, 2005; Wolfslehner *et al.*, 2005); site assessment (Noss *et al.* 2002); setting conservation priority (Geneletti, 2004; Moffett and Sarkar, 2006); locating park boundary (Keisler and Sundell, 1997; Sharifi *et al.*, 2002) and ecotourism planning (Boyd *et al.*, 1994; Villa *et al.*, 2002).

Ecotourism planning falls within the scope of natural resources management (Cohon, 1997). It is also regarded as a land-suitability analysis (Malczewski, 2003) in which decision has to be made to assign lands suitable for different kinds of tourism activities as well as to conservation initiative. Especially when sustainability being one of the prominent elements, the planning activity in which different aspects such as economic viability, political influence, social recognition, and environmental sustainability has to be taken into account in order to formulate holistic and integrative plans (Cohon, 1997; Feick and Hall, 2002; Priskin, 2003; Farsari, 2006). From this perspective, it is essentially a multi-criteria problem with different objectives. The SMCDA supports the decision making process in assessing land suitability under different objectives. With strong spatial characteristics, the criteria are represented, displayed and visualized in the form of maps. Preliminary examination of spatial data, computation of extra criteria can be performed in the GIS environment. MCA provides a platform for evaluating the alternatives through combining the preferences from different stakeholders and criteria by chosen decision rule to come up with a (set of) compromise solution(s). Scenarios can be generated to facilitate planning activities. The zoning results are represented in the form of map graphically showing the zone designation of each area with the aid of GIS capability in visualization (Chen *et al.*, 1994).

2.4 Summary

Through understanding of the habitat requirements of species, together with the use of various habitat modeling techniques, the distribution of species can be represented and expressed in a more representative way when compared with the dot and range distribution maps. Regression modeling which requires both presence and absence dataset is one of the most popular habitat mapping methods. Algorithm such as ENFA which requires presence-only data can be a viable alternative technique. The modeled species distribution maps can act as a base for other analyses such as conservation planning and tourism planning.

In many studies, species-rich sites identify based on the summation of distribution of a number of species is used to represent biodiversity hotspots which in turn act as a guide for conservation area selection. Although this approach subjects to criticisms, it is still regarded as the most popular methods because of simplicity as well as its retention of the nature of biodiversity.

Ecotourism is becoming a more popular form of tourism with emphasis on conservation and sustainability. Although it is regarded as a sustainable form of tourism, like other form of tourism, ecotourism tends to pose negative impacts on both the natural and cultural resources. It is only through planning that can create a harmonious relationship between tourism and environment and promote the concept of symbiosis. With the availability of GIS and MCA, the procedures of tourism planning are significantly facilitated. GIS acts a tool to store, manipulate and analyze spatial data. Besides, it presents data and results graphically through its visualization technique. MCA supplements the deficiency in GIS through its capability in combining stakeholders' preferences in order to come up with a compromise solution. The integration of GIS and MCA forms spatial decision support system through which more comprehensive plans can be formulated.

CHAPTER 3 METHODOLOGY

3.1 Introduction

The people and government in Hong Kong, on the one hand have been aware of the significance of protecting natural and cultural assets. On the other hand, as one of the world's famous cities, she has to continuously look for potential economic benefits by surfing through various development opportunities. In reality, the two hands always fight and compete with each other. The HKSAR government is responsive to seek compromise by emphasizing sustainable development as the path of success for Hong Kong's future. Efforts has been put on balancing conservation and development needs through public consultations on environmental policy and major development projects (e.g. the New Nature Conservation Policy in 2003, the Concept Plan for Lantau in 2005). This phenomenon is apparent as far as tourism development is concerned. Dated back to 1999, the ex-chief executive, Mr. Tung, addressed in his policy concerning tourism development in natural areas by stressing on the concept sustainability, "*...Taking advantage of the beautiful natural landscape of Lantau Island and Sai Kung District, we intend to develop these two areas into centers of recreational and leisure activities compatible with the principle of nature conservation. In 2001, we will also substantially extend managed country park areas on Lantau Island...* (HKSAR government, 1999, p.134)". Besides, studies on the potential of tourism development have also been performed such as exploring tourism potential of the Northern New Territories (School of Hotel and

Tourism Management, 2003) and study of Tai O (Hong Kong Planning Department, 2001b). All these aim to broaden and diversify Hong Kong's tourism resource base from an original reputation on cityscape, shopping paradise to a city with natural and cultural character.

In order to achieve the objective of sustainable tourism development, it relies on prudent and far-sighted planning. The importance has been emphasized by Krippendorf (1977). Zoning as a form of planning methods has been adopted in country parks and protected areas around the globe such as Australia, USA and Canada. The advantages have been highlighted in many literatures (Hass *et al.*, 1987; Luck and Kirstges, 2002; Eagles and McCool, 2002). Among different zones, boundary for conservation areas is defined through the identification of ecological sensitive areas. One of the methods to determine these sensitive areas are based on species richness though they are not necessarily suitable to guide conservation area selection for some reasons (Reid, 1998). With the aids of remote sensing and GIS techniques, the procedure of identification of species-rich sites and subsequent planning issue is greatly facilitated.

This chapter begins with the brief description of the study area. Then, the overview of research methodology is illustrated. After that, the construction of GIS database is discussed. This is followed by the three main stages of the study which aims to develop a zoning plan for the study area. The three main stages are 1) wildlife habitat mapping; 2) Sites identification for ecotourism activities and 3) Zonation.

3.2 Study Site Description

The site chosen for the study is Lantau Island situated at the south-western part of Hong Kong (22°16′14″N, 113°57′10″E). She is the biggest island in Hong Kong with an area of approximately 142km^2. Being regarded as "the lungs of Hong Kong", the island has tremendous nature conservation and recreation values. Recognizing the conservation importance, the HKSAR government has designated over half of the land areas (78.4km^2) as Country Parks – The Lantau North and South Country Parks. Besides, the Concept Plan for Lantau released in Nov 2004 has planned the extension of boundary of the Lantau North Country Park as well as proposed the waters around Southwest as Marine Park (Lantau Development Task Force, 2004). Lantau possesses many rare plants and wild animals some of which are protected by laws. For instances, Lantau has over 120 butterfly species and 63 dragonfly species which represents 50% and 60% of total butterfly and dragonfly species in Hong Kong. Birds, mammals, reptiles and amphibians are abundant with some can only be found in Hong Kong (Hong Kong Agriculture, Fisheries and Conservation Department, 2003). Fauna and flora with special scientific value are identified and designated as Sites of Special Scientific Interests (SSSI). The eight SSSIs arranged in ascending order of approval are Sunset Peak (No. 9), Man Cheung Po (No. 32), Lantau Peak (No. 33), Pok To Yan and Por Kai Shan (No. 57), Sau

Tau Beach (No. 58), San Chau (No. 61), Ngong Ping (No. 62) and Tai Ho Stream (No. 63). According to the strategic environmental assessment in justifying the ecological value of SSSIs from the Environmental Protection Department of Hong Kong, the eight SSSIs have the following importance (Hong Kong Environmental Protection Department, 2006). The Sunset Peak has forest relict consisting of interesting species. Rare species are found in both the ravine of Man Cheung Po and Lantau Peak. Pok To Yan and Por Kai Shan are montane forests with over 200 species of indigenous plants in which numerous of them are listed as rare and protected. The ecological value of the diverse forests is high with great botanical importance. The San Tau Beach is also with high ecological value due to the presence of rare species of mangroves as well as seagrass bed. San Chan has the known population of one of the rarest native rhododendrons in Hong Kong. The Ngong Ping valley sustains the largest population of Romer's Tree Frog, which is regarded as high in ecological value. Finally, Tai Ho Stream consists of both the greatest diversity of fresh water, brackish-water fish in Hong Kong as well as mangroves and seagrass, which is also classified as high ecological importance. These all suggests the existence of valuable ecological resources in Lantau.

Apart from the natural resources, some of the villages in Lantau are traditional settlements with historical, cultural and archaeological significance and are regarded as valuable heritages. Five historical sites are defined as declared monuments in accordance with the Antiquities and Monument Offices under the Leisure and Cultural Services Department of Hong Kong. They are all listed as protected monuments for more than 20 yeas with the earliest one in 1979 – the Rock Carving at Shek Pik. Followed by Tung Chung Fort (1979); Fan Lau Fort (1981); Stone Circle at Fan Lau (1983); and Tung Chung Battery (1983) (Hong Kong Antiquities and Monuments Office, 2006). Some that are not protected also has distinctive characteristics. For instance, Tai O is the largest traditional settlement with distinctive local character and known as "The Venice of the Orient". All in all, these heritages offer a unique local character for Lantau.

Given Lantau's local characteristics and location as well as the unsatisfied demand for new land in Hong Kong, Lantau is also regarded as the center for future economic development. The proposed developments are diversified but can be summarized into three categories including population accommodation; tourism and related facilities development; transportation hub and logistics development (Lantau Development Task Force, 2004). Tung Chung, the largest new town in Lantau, having a population of 61,300 in mid-2004 is planned to accommodate more than three-fold of its present population. Adequate regional and community facilities are essential to support the projected swelling population. The second concern is tourism development which focuses on compatible recreational activities with the maximized aids of indigenous resources. Facilities such as hotels and resort amenities are supplemented. Finally, Logistics Park as well as cross boundary transport such as the Hong Kong – Zhuhai – Macao Bridge (HZMB), are proposed. With plentiful natural and cultural resources, sustainable plans have to be formulated with the aim of balancing development and conservation needs before any development can be initiated. The study identifies conservational areas through modeling the possible habitat of a number of different species with which the result were compared with the Concept Plan.

3.3 Methodology Overview

Figure 3.1 shows the summary of research methodology and provides an overview of the methods used in order to achieve the objectives stated in Chapter 1. Firstly, the species data as well as the environmental and landscape data are collected from various secondary sources. They are then compiled, manipulated and transformed into meaningful variables based on which a spatial database is built up for latter analyses. This is followed by habitat modeling of fifty chosen species with three multivariate statistical methods. The models are then compared and the statistically rigorous one is chosen and merged to form a species richness map showing areas with high conservation value. After that, with further input of tourism-related attributes, Multiple Criteria Analysis (MCA) is used to identify potential recreational and tourism development sites. Finally, the results from potential conservation areas as well as potential recreational and tourism development sites are combined through the Multi-objective Land Allocation (MOLA) with a view to formulate zoning plans simulating views from different perspectives. The in-depth explanation of each step is discussed in following sessions.

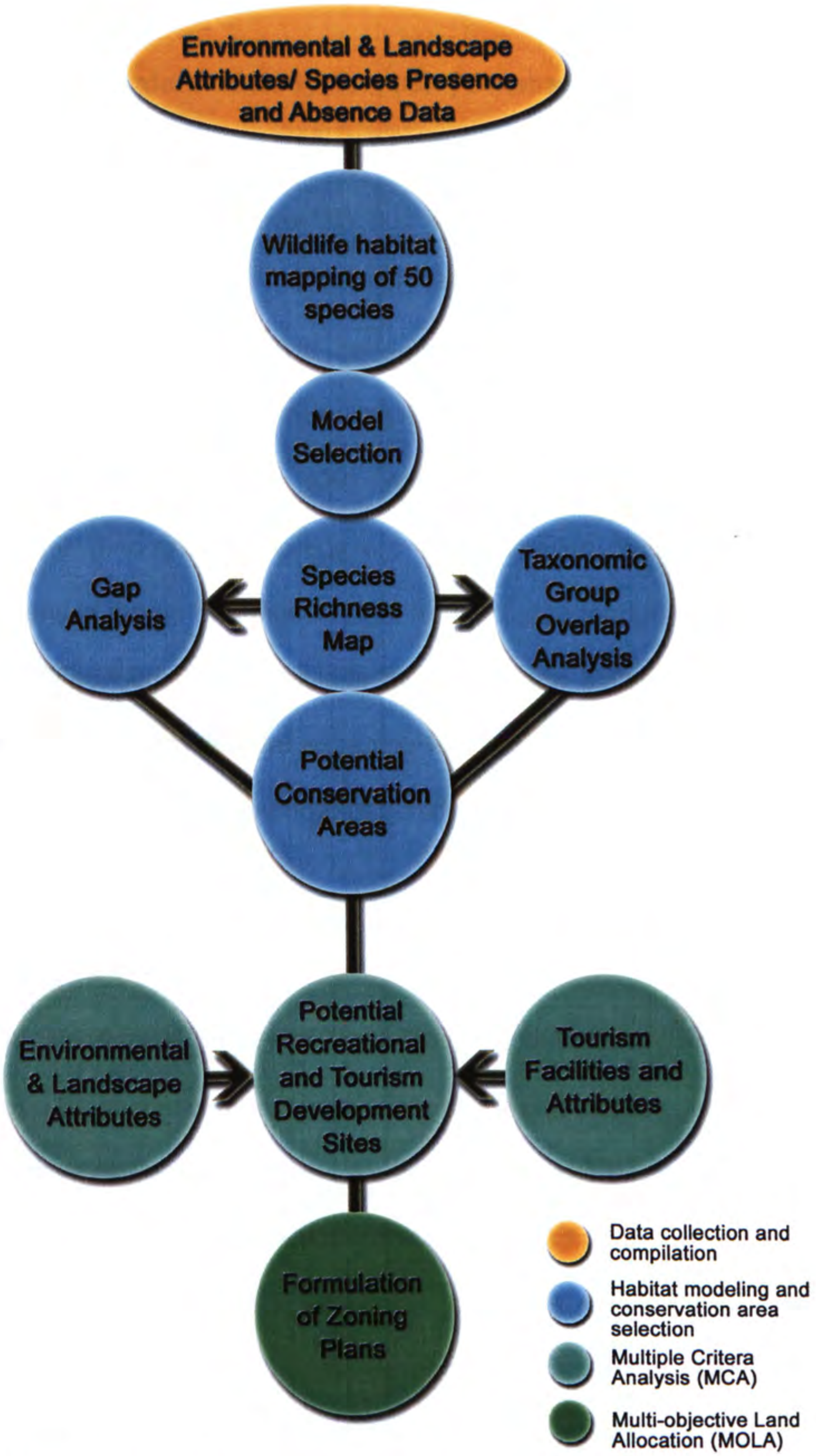


Figure 3.1 The summary of research methodology

3.4 Geographical Information System (GIS) Database

Prior to analyses, data collected from different sources are compiled and manipulated. With reference to the first stage of analysis – wildlife habitat modeling – the data can be divided into two components, namely dependent and independent variables. The dependent variables refer to the species surveyed point data extracted from the Hong Kong Biodiversity Survey v.3.0. The independent variables, also named as environmental gradients, environmental predictors or predictors are compiled from two sources – remotely-sensed image and digital maps from 1:5,000 topographic map sheets. The remotely-sensed image provides the latest land cover for the territory in which the vegetation covers are extracted for further computation while the GIS data are used to generate a number of ecological-related predictors.

3.4.1 Hong Kong Biodiversity Survey

The Biodiversity Survey of Hong Kong conducted by the Department of Ecology and Biodiversity, the University of Hong Kong (DEB) aims to establish a comprehensive ecological database for the territory. The earliest version can be traced back to August 1999 in which Version 1.0 of this database was published. The latest version (version 3.0) which integrated the results from the previous two versions and incorporated some new species data was published in 2002. The database contains more than 5,000 species from a wide variety of taxonomic groups including amphibians, birds, reptiles, fishes, mammals, ants, butterflies, moths, dragonflies, spiders, snails, diptera, hemiptera, hymenoptera, stream invertebrates, wetland invertebrates, rare bryophytes, rare vascular plants and feng shui woods. The fields of attribute table for each taxonomic group are not identical but basically, they all contain x- and y-coordinates, species name (either common or scientific or both) and source. The database is readily available in GIS point coverages to the nearest of 10m, 100m and 1km and is geo-referenced to the HK 1980 grid system.

Apart from field survey, the database was also complied from published sources and personal records (Yip *et al.*, 2004). The detailed data source of the survey is shown in Appendix 1. On account of varied data source, the sampling strategy is not identical throughout the database. In other words, some sites with prior understanding of rich diversity of certain taxonomic groups such as amphibians and birds are prejudiced with higher sampling effort (Yip *et al.*, 2004). As a result, the database does not have a distinctive sampling strategy though the field survey is well organized.

In this study, 50 species are chosen based on three criteria. The first criterion is that only the survey points with 100m resolution is selected. It is because this resolution is the finest available for all the species and taxonomic groups. The second criterion is that the species should be reported or had at least one sample point in Lantau in the biodiversity survey. It makes sure that all the chosen species have records in Lantau. Although species are found in Lantau, the number of data points may be insufficient to conduct subsequent analysis and modeling. So, the availability of sufficient number of data point is the third concern. The final species list is shown in Table 3.1. Each individual species is queried and extracted from their taxonomic group using the extracted wizard in ESRI® ArcToolbox^{TM} 8.3. Although the targeted study area is Lantau, the number of sample points on Lantau is so scarce that points covering the whole Hong Kong territory are extracted.

The chosen species belong to five taxonomic groups in the biodiversity survey of Hong Kong version 3, namely, amphibians, birds, butterflies, dragonflies and mammals. Except all the aves and *H. brachyura* (mammal), no species have statutory protection in Hong Kong. Only one species, *M. migrans* (aves), has been listed in the protection of endangered species ordinance (Cap. 187). And the status of *H. brachyura* has been listed as 'vulnerable' under IUCN Red List Status. All in all, the species are all common in Hong Kong. The last column shows the number of survey points of the corresponding species from the biodiversity survey. Since some of the points fall outside the terrestrial boundary of Hong Kong, they are deleted from the records. Figures in brackets show the number of effective sample points for the species.

Table 3.1 The species list of five taxonomic groups with their protection status and number of points in biodiversity survey.

Class	Order	Family	Species	Common English names	Chinese names	Statutory Protection in HK		No. of points from Bd. Survey
						Cap. 170	Cap. 187	
Amphibia	Anura	Bufonidae (蟾蜍科)	*Bufo melanostictus*	Asian Common Toad	黑眶蟾蜍	No	No	130 (129)
Amphibia	Anura	Microhylidae (姬蛙科)	*Kaloula pulchra*	Asiatic Painted Frog	花狹口蛙	No	No	100 (99)
Amphibia	Anura	Rhacophoridae (樹蛙科)	*Polypedates megacephalus*	Brown Tree Frog	斑腿泛樹蛙	No	No	271 (259)
Amphibia	Anura	Ranidae (蛙科)	*Rana livida*	Green Cascade Frog	大綠蛙	No	No	48 (48)
Amphibia	Anura	Ranidae (蛙科)	*Rana guentheri*	Günther's Frog	沼蛙	No	No	209 (207)
Amphibia	Anura	Ranidae (蛙科)	*Rana exilispinosa*	Lesser Spiny Frog	小棘蛙	No	No	129 (128)
Amphibia	Anura	Microhylidae (姬蛙科)	*Microhyla ornata*	Ornate Pigmy Frog	飾紋姬蛙	No	No	103 (100)
Amphibia	Anura	Ranidae (蛙科)	*Rana limnocharis*	Paddy Frog	澤蛙	No	No	158 (155)
Aves	Falconiformes	Accipitridae (鷹科)	*Milvus migrans*	Black Kite	黑鳶	Yes	Yes	67 (44)
Aves	Passeriformes	Pycnonotidae (鵯科)	*Pycnonotus sinensis*	Chinese Bulbul	白頭鵯	Yes	No	97 (74)
Aves	Passeriformes	Sylviidae (鶯科)	*Orthotomus sutorius*	Common Tailorbird	長尾縫葉鶯	Yes	No	86 (69)
Aves	Passeriformes	Pycnonotidae (鵯科)	*Pycnonotus jocosus*	Crested Bulbul	紅耳鵯	Yes	No	92 (72)

Aves	Passeriformes	Paridae (山雀科)	*Parus major*	Great Tit	大山雀	Yes	No	59 (52)
Aves	Cuculiformes	Cuculidae (杜鵑科)	*Centropus sinensis*	Greater Coucal	褐翅鴉鵑	Yes	No	46 (32)
Aves	Passeriformes	Zosteropidae (繡眼鳥科)	*Zosterops japonica*	Japanese White-eye	暗綠繡眼鳥	Yes	No	79 (64)
Aves	Passeriformes	Corvidae (鴉科)	*Corvus macrorhynchus*	Jungle Crow	大嘴烏鴉	Yes	No	47 (36)
Aves	Ciconiiformes	Ardeidae (鷺科)	*Egretta garzetta*	Little Egret	小白鷺	Yes	No	25 (19)
Aves	Passeriformes	Laniidae (伯勞科)	*Lanius schach*	Rufous-backed shrike	棕背伯勞	Yes	No	44 (31)
Aves	Columbiformes	Columbidae (鳩鴿科)	*Streptopelia chinensis*	Spotted Dove	珠頸斑鳩	Yes	No	82 (64)
Aves	Passeriformes	Turdidae (鶇科)	*Myiophoneus caeruleus*	Violet Whistling Thrush	紫嘯鶇	Yes	No	47 (33)
Aves	Gruiformes	Rallidae (秧雞科)	*Amaurornis phoenicurus*	White-breasted Waterhen	白胸苦惡鳥	Yes	No	25 (19)
Insecta	Lepidoptera	Satyridae (眼蝶科)	*Melanitis leda leda*	Common Evening Brown	暮眼蝶	No	No	94 (82)
Insecta	Lepidoptera	Pieridae (粉蝶科)	*Cepora nerissa nerissa*	Common Gull	黑脈園粉蝶	No	No	38 (34)
Insecta	Lepidoptera	Papilionidae (鳳蝶科)	*Chilasa clytia clytia*	Common Mime	斑鳳蝶	No	No	82 (77)
Insecta	Lepidoptera	Papilionidae (鳳蝶科)	*Papilio polytes polytes*	Common Mormon	玉帶鳳蝶	No	No	182 (168)
Insecta	Lepidoptera	Pieridae (粉蝶科)	*Pieris canidia canidia*	Common White	東方菜粉蝶	No	No	131 (123)
Insecta	Lepidoptera	Papilionidae (鳳蝶科)	*Papilio memnon agenor*	Great Mormon	美鳳蝶	No	No	129 (119)
Insecta	Lepidoptera	Pieridae (粉蝶科)	*Hebomoia glaucippe glaucippe*	Great Orange Tip	鶴頂粉蝶	No	No	86 (81)

Insecta	Lepidoptera	Lycaenidae (灰蝶科)	*Zizeeria maha serica*	Pale Grass Blue	酢漿灰碟	No	No	104 (96)
Insecta	Lepidoptera	Papilionidae (鳳蝶科)	*Papilio paris paris*	Paris Peacock	巴黎翠鳳蝶	No	No	143 (133)
Insecta	Lepidoptera	Nymphalidae (蛺蝶科)	*Junonia ncludi almana*	Peacock Pansy	美眼蛺蝶	No	No	95 (87)
Insecta	Lepidoptera	Riodinidae (蜆蝶科)	*Abisara echerius echerius*	Plum Judy	蛇目褐蜆蝶	No	No	142 (128)
Insecta	Lepidoptera	Pieridae (粉蝶科)	*Ixias pyrene pyrene*	Yellow Orange Tip	橙粉蝶	No	No	32 (29)
Insecta	Odonata	Protoneuridae (原蟌科)	*Prodasineura autumnalis*	Black Threadtail	烏齒原蟌	No	No	46 (46)
Insecta	Odonata	Euphaeidae (溪蟌科)	*Euphaea decorata*	Black-banded Gossamerwing	方帶幽蟌	No	No	58 (57)
Insecta	Odonata	Platycnemididae (扇蟌科)	*Copera ciliata*	Black-kneed Featherlegs	白狹扇蟌	No	No	41 (41)
Insecta	Odonata	Platycnemididae (扇蟌科)	*Coeliccia cyanomelas*	Blue Forest Damsel	黃紋長腹蟌	No	No	39 (39)
Insecta	Odonata	Chlorocyphidae (鼻蟌科)	*Rhinocypha ncluding perforata*	Common Blue Jewel	三斑鼻蟌	No	No	56 (56)
Insecta	Odonata	Libellulidae (蜻科)	*Orthetrum pruinosum neglectum*	Common Red Skimmer	赤褐灰蜻	No	No	71 (68)
Insecta	Odonata	Libellulidae (蜻科)	*Trithemis aurora*	Crimson Dropwing	曉褐蜻	No	No	60 (58)
Insecta	Odonata	Libellulidae (蜻科)	*Zygonyx iris insignis*	Emerald Cascader	彩虹蜻	No	No	44 (44)
Insecta	Odonata	Aeshnidae (蜓科)	*Anax immaculifrons*	Fiery Emperor	黃偉蜓	No	No	26 (25)
Insecta	Odonata	Libellulidae (蜻科)	*Orthetrum nclud sabina*	Green Skimmer	狹腹灰蜻	No	No	70 (68)

Insecta	Odonata	Libellulidae (蜻科)	*Trithemis festiva*	Indigo Dropwing	慶褐蜻	No	No	67 (66)
Insecta	Odonata	Libellulidae (蜻科)	*Pantala flavescens*	Wandering Glider	黃蜻	No	No	107 (103)
Insecta	Odonata	Platycnemididae (扇蟌科)	*Copera marginipes*	Yellow Featherlegs	黃狹扇蟌	No	No	53 (53)
Mammalia	Rodentia	Muridae (鼠科)	*Niviventer fulvescens*	Chestnut Spiny Rat	針毛鼠	No	No	64 (63)
Mammalia	Rodentia	Hystricidae (豪豬科)	*Hystrix brachyura*	East Asian Porcupine	豪豬	Yes	No	41 (41)
Mammalia	Artiodactyla	Suidae (豬科)	*Sus scrofa*	Eurasian Wild Pig	野豬	No	No	53 (53)
Mammalia	Rodentia	Muridae (鼠科)	*Rattus sikkimensis*	Sikkim Rat	黑緣齒鼠	No	No	66 (63)

3.4.2 Land Cover Classification of Hong Kong

As mentioned in the previous chapter, remotely-sensed imagery plays an important role in facilitating modeling effort by providing up-to-date, extensive/ large-scale and spatio- and tempo-continuous land-cover information, especially vegetation/ habitat information, for the study area. A SPOT 5 image is acquired and pre-processed. Then, supervised classification is applied to classify the image into fourteen land cover categories. Post-editing and accuracy assessment are carried out after the classification.

3.4.2.1 Acquisition and Pre-processing of Remotely-Sensed Data

A SPOT 5 imagery taken on 11th Dec 2004 covering the Hong Kong territory is acquired for this study as shown in Figure 3.2.

The digital data possesses green, red and near infrared channels in 10-meter spatial resolution. By using PCI Geomatica® v.9.1.6 OrthoEngine (2005), Forty-nine Ground Control Points (GCPs) are collected at road and footpath junctions with reference to the 5-meter Digital Elevation Model (DEM) and vector of road network archived in the Department of Geography and Resource Management, CUHK. The overall RMS error is of 0.02 pixels and the image is ortho-rectified based on the cubic convolution resampling method. The residual error report of ortho-rectification is shown in Appendix 2.

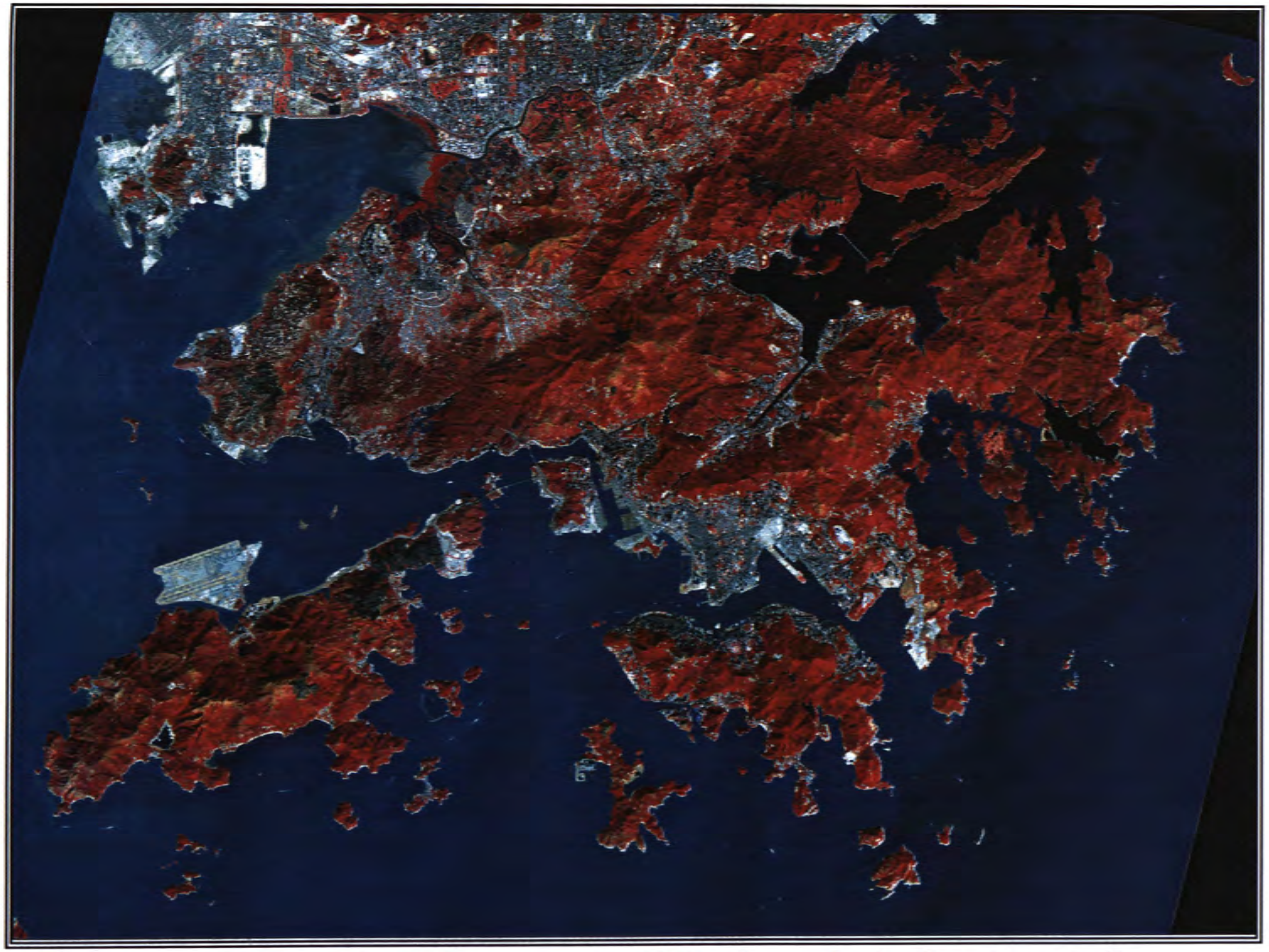


Figure 3.2 False Color SPOT 5 composite (IR, R, G) covering the Hong Kong territory

3.4.2.2 Land Cover Classification and Post Classification

Based on the ortho-rectified image, the image channels are transferred to IDRISI to conduct supervised image classification based on the maximum likelihood image classifier. A total of fifteen classes have been originally developed as shown Table 3.2.

Table 3.2 The classification scheme for SPOT 5 image classification

No.	**Classes**	**No.**	**Classes**
1	Sea water	9	*Illuminated shrubby grassland*
2	Fresh water	10	*Shaded shrubby grassland*
3	Fish pond	11	*Illuminated grassland*
4	Mangrove	12	*Shaded grassland*
5	*Illuminated woodland*	13	Hill-fire regions
6	*Shaded woodland*	14	Bare soil/ land
7	*Illuminated mixed shrubland*	15	Built-up areas
8	*Shaded mixed shrubland*		

The classification result is shown in Figure 3.3 with the illuminated and shaded vegetation classes are grouped and the number of classes reduces to a total of eleven. Besides, the 'fresh water' class is edited with the reservoir vector polygons archived in Department of Geography and Resource Management, CUHK. In order to compute classification accuracy, 1,000 stratified random sample points are generated throughout the Lantau Island with 892 points fall within the Lantau boundary. The overall classification accuracy is 78%.

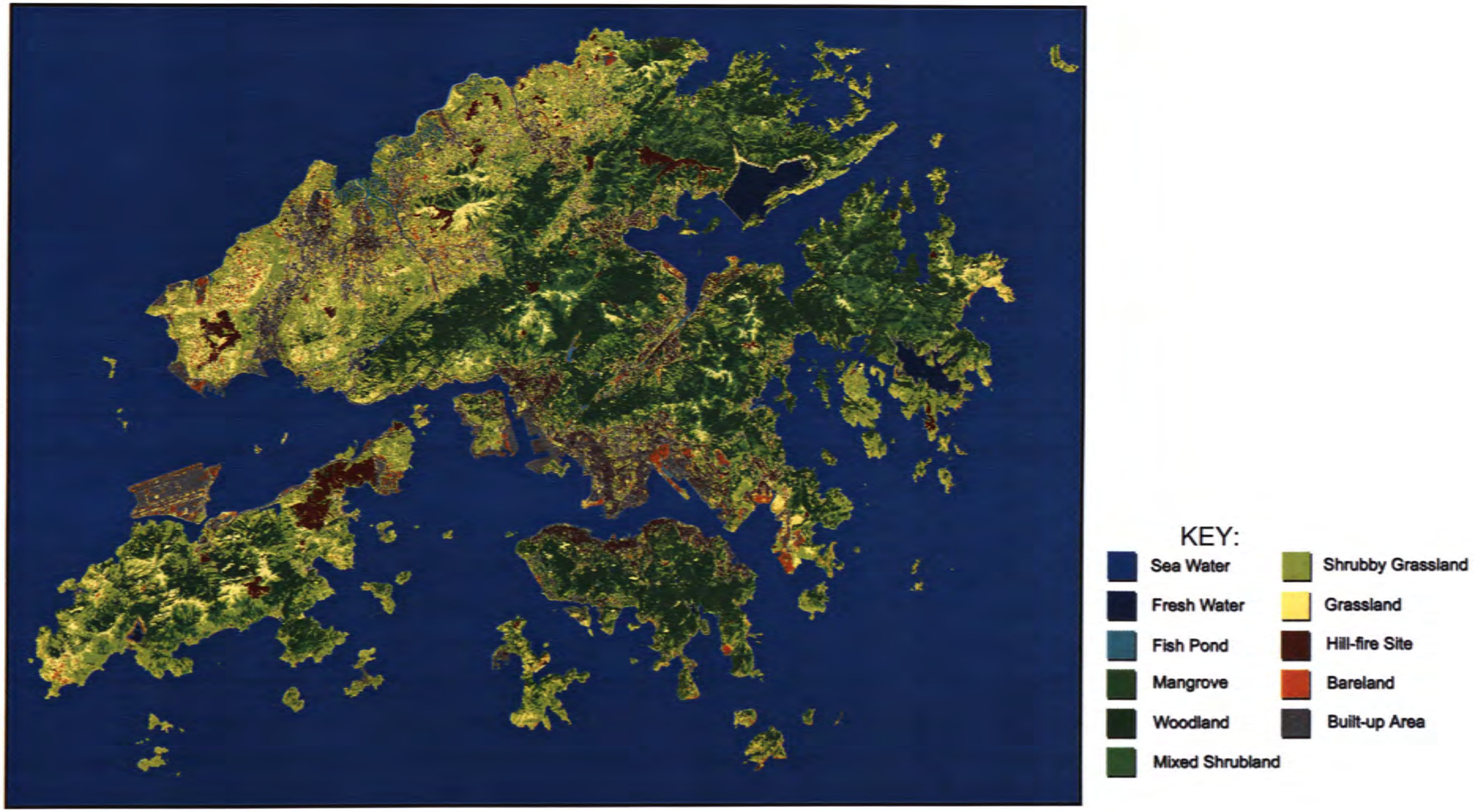


Figure 3.3 Supervised image classification result of 10-meter SPOT 5

3.4.3 GIS Database

Instead of using the vegetation maps as the sole predictors in habitat modeling, with the assistance of GIS, mapping of various land attributes into separate data layers becomes feasible (Leeuw *et al.*, 2002). The attributes include all types of environmental gradients though resources affecting the distribution of species are always difficult to measure and quantify. The direct and indirect gradients are the most commonly used ones. The attributes/ predictors can be grouped into four types including the vegetation/ habitat maps, resource-related maps, landscape factor maps and human-disturbance maps.

3.4.3.1 Acquisition of GIS Data

Apart from the satellite image, B5000 and B10000 digital topographic map data archived in Department of Geography and Resource Management, CUHK are acquired. These data are originally collected and digitized by the Survey and Mapping Office (SMO), Lands Department, the Government of HKSAR (GRM). The map layers extracted from the B5000 database include spot height, contour, coastline, road, railway, hydrographic features and building. They are all available in vector format. As from the B10000 database, map layers including hydrography polygon, facility, Reserve Park and road are extracted.

3.4.3.2 GIS Operations

The GIS operations are performed in IDRISI v.14.02, Biomapper v.3.1 and GRASS v.6.0. The summary of operations is shown in Figure 3.4. The environmental gradients can be divided into four categories including (1) vegetation, resource-related factor, (3) landscape factor and (4) human-disturbance factor maps.

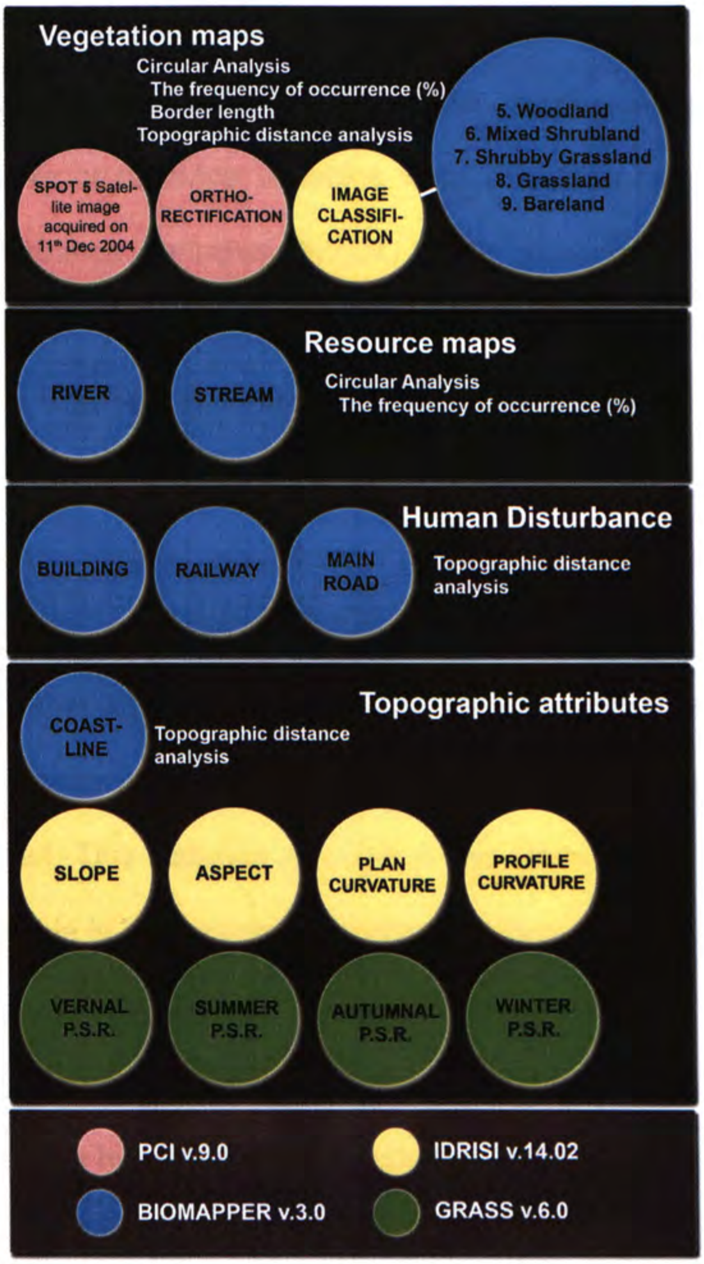


Figure 3.4 The environmental predictors for wildlife habitat mapping (with color representing the software used for the analysis)

First, the vegetation maps including woodland, mixed shrubland, shrubby grassland, grassland and bare land are extracted from the classification result. Each individual class is transformed into a single binary map with 1 representing the location of the vegetation type while 0 as none. These Boolean maps are then input into Biomapper v.3.1 to generate maps with ecological meanings through circular analysis and distance analysis. The circular analysis is useful in making attractive or resource variables while the distance analysis is usually used for disturbance variables (Hirzel, 2005). Among the circular analysis module the frequency of occurrence (%) and border length are used. The former one acts like a filter with a moving window of certain size. In this case, a 500 meter radius is used. The aim is to transform the binary vegetation maps into percentage of frequency of occurrence. The latter one is useful to species which are living or feeding near vegetation boundaries (Hirzel, 2005). In this study, the radius of calculation of border length is 200 meter. As for the distance analysis, instead of using the tradition Euclidean distance calculation, the topographic distance is used. This distance calculation has taken slope into consideration which is applicable in mountainous regions like Hong Kong.

Second, the resource-related factor maps, river and stream are extracted separately from the hydrographic line features. The frequency of occurrence (%) with radius of 300 meter is applied to river while the binary stream map is transformed with both 100 meter and 500 meter radius.

Third, the landscape factor maps are generated based on a 5-meter Digital Elevation Model (DEM) archived in GRM. The DEM is firstly refined by removing local depression. It is then used to generate the primary topographic attributes including slope, aspect, curvature and the secondary topographic attribute which is the potential solar radiation. The coastal effect is also taken into consideration by calculating the topographic distance from the coastline. First, the slope is calculated from IDRISI by the following equation:

$$\text{tan\_slope} = \sqrt{\left(\frac{\text{right - left}}{\text{res x 2}}\right)^2 + \left(\frac{\text{top - bottom}}{\text{res x 2}}\right)^2} \qquad \text{Eq. 3.1}$$

Where tan_slope is the tangent of the angle that has the maximum downhill slope; left, right, top, bottom are the height values of the neighboring cells; and res is the cell resolution (IDRISI, 2005).

The aspect is calculated and further divided into east aspect and south aspect by the two equations below:

$$Eastness = \sin (aspect) \qquad \text{Eq. 3.2}$$

$$Southness = \cos [(Aspect) + 180] \qquad \text{Eq. 3.3}$$

The curvature is divided into plan curvature and profile curvature. The former one describes surface's curvature along the contour line while the latter one is the curvature of a surface in the direction of slope. The two landscape factors somehow reflect soil moisture and flow characteristics (Florinsky, 1998). The higher the curvature value, the lower the moisture content and the faster the flow and vice versa.

The potential solar radiation is calculated for four single days including the Vernal Equinox, Summer Solstice, Autumnal Equinox and Winter Solstice. The solar parameters used to determine the potential solar radiation is shown in Table 3.3. Once the day and latitude are set, the solar constant, extraterrestrial irradiance, declination, sunrise time and sunset time are calculated automatically. The time step and ground albedo is set as default. The linke turbidity is calculated with reference to the land usage of Hong Kong and the average monthly values of the Linke turbidity as shown in Table 3.4.

Table 3.3 Parameters input for the calculation of potential solar radiation for four single days using GRASS v.6.0

Solar Parameters	**Vernal Equinox**	**Summer Solstice**	**Autumnal Equinox**	**Winter Solstice**
Day	80	172	265	355
Solar constant (W/ m^2)	1367			
Extraterrestrial irradiance (W/ m^2)	1378.02	1332.51	1357.8	1411.56
Declination (rad)	0.004235	0.409115	0.00705	-0.409078
Latitude (degree)	22.25			
Sunrise time (hr)	5.99	5.32	5.99	6.68
Sunset time (hr)	18.01	18.68	18.01	17.32
Time step (hr)	0.5			
Linke turbidity	2.25	2.85	2.60	1.92
Ground albedo	0.2			

Table 3.4 Average monthly values of the Linke turbidity coefficient for mild climatic region

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
mountains	1.5	1.6	1.8	1.9	2	2.3	2.3	2.3	2.1	1.8	1.6	1.5	1.9
rural	2.1	2.2	2.5	2.9	3.2	3.4	3.5	3.3	2.9	2.6	2.3	2.2	2.75
city	3.1	3.2	3.5	4	4.2	4.3	4.4	4.3	4	3.6	3.3	3.1	3.75
industrial	4.1	4.3	4.7	5.3	5.5	5.7	5.8	5.7	5.3	4.9	4.5	4.2	5

Based on Table 3.4, the land usage scheme published in the Hong Kong Year 2004 is reclassified into four categories. Mountains, rural, city and industrial account 69.9%, 9.8%, 18.2% and 2.3% respectively. The linke turbidity coefficient is the summation of product of the turbidity coefficient and proportion of land use. The equations are listed below:

$$\textit{Linke turbidity coefficient} = \sum [(\textit{values}_i \times \textit{proportion of land use}_i)] \quad \text{Eq. 3.4}$$

Where, i is the number of land use which is four here. By inputting the essential parameters into GRASS v.6.0, the potential solar radiation of the four days are computed.

Finally, three human-disturbance factor maps are computed using the topographic distance operation for main roads, railways and buildings. Main roads are all those constructed for vehicle passage while railways include the East Rail of KCR, Light Railway Transit (LRT) and Mass Transit Railway (MTR). Buildings consist of all those structures concentrated mainly in urban areas. It is assumed that the urban development is affecting the habitat of animals.

Table 3.5 shows the definitions and some basic statistical descriptions of the thirty-one environmental predictors. The maps showing the environmental predictors are shown in Appendix 4b.

Table 3.5 Definitions and statistical descriptions of the environmental variables. Indices are provided for later reference in the result.

	VARIABLES	INDICES	DEFINITION/ DESCRIPTION	UNITS	STATISTICAL DESCRIPTION			
					MEAN	SD	MIN	MAX
Landcover derived from Maximum Likelihood Classification on Spot 5 remotely-sensed image acquired on 11th Dec 2004	**Woodland** — Lands covered with natural forests including both montane forest and lowland forest.	WOOD_dist	Topographic distance operation on the Boolean *woodland* map	Meter	109.555	194.585	0	1588.387
		WOOD(_fq)	Circular Analysis (Frequency of Occurrence) on the Boolean *woodland* map with radius of 500m	Percentage	26.526	27.883	0	100
		WOOD_bl	Circular Analysis (Border Length) on the Boolean *woodland* map with radius of 200m	Meter	354.525	675.386	0	5140
	Shrubby Grassland — Lands covered predominantly (50% or more) by grasses and contained visible woody plants covering up to 50% of the area.	SHGRASS_dist	Topographic distance operation on the Boolean *shrubby grassland* map	Meter	43.799	86.673	0	1233.797
		SHGRASS(_fq)	Circular Analysis (Frequency of Occurrence) on the Boolean *shrubby grassland* map with radius of 500m	Percentage	27.933	21.075	0	98
		SHGRASS_bl	Circular Analysis (Border Length) on the Boolean *shrubby grassland* map with radius of 200m	Meter	983.431	1102.334	0	6990
	Grassland including Hillfire — Lands covered predominantly (50% or more) by grasses with no visible woody plants.	GRASS_dist	Topographic distance operation on the Boolean *grassland* (combined with hillfire region) map	Meter	54.567	70.547	0	729.399
		GRASS(_fq)	Circular Analysis (Frequency of Occurrence) on the Boolean *grassland* (combined	Percentage	17.089	15.186	0	93

			with hillfire region) map with radius of 500m					
		GRASS_bl	Circular Analysis (Frequency of Occurrence) on the Boolean *grassland* (combined with hillfire region) map with radius of 500m	Meter	1064.792	1323.643	0	7910
	Mixed shrubland — Lands covered with less than 50% grasses with shrubs the major woody life form.	MIXSHRUB_dist	Topographic distance operation on the Boolean *mixed shrubland* map	Meter	118.046	183.687	0	1621.694
		MIXSHRUB(_fq)	Circular Analysis (Frequency of Occurrence) on the Boolean *mixed shrubland* map with radius of 500m	Percentage	9.901	13.206	0	93
		MIXSHRUB_bl	Circular Analysis (Border Length) on the Boolean *mixed shrubland* map with radius of 200m	Meter	204.434	521.691	0	5420
	Bareland — Naturally open rock faces or disturbed lands or "badlands" denuded of vegetation.	BARE_dist	Topographic distance operation on the Boolean *bareland* map	Meter	304.703	327.951	0	2523.846
		BARE(_fq)	Circular Analysis (Frequency of Occurrence) on the Boolean *bareland* map with radius of 500m	Percentage	2.314	5.696	0	87
Elevation	Elevation	ELEV(ATION)	The altitude recorded on the 10-meter digital elevation model	Meter	128.919	137.977	0	957
Aspect	Aspect – Southness index	SOUTH(NESS)	Derived from equation: cos [(Aspect) + 180]	Unitless	-0.155	0.729	-1	1
	Aspect – Eastness index	EAST(NESS)	Derived from equation: sin (aspect)	Unitless	-0.098	0.711	-1	1
Slope	Slope	SLOPE	Derived from 10-meter digital elevation model	Degree	17.627	12.417	0	85.788

Curvature	Planimetric curvature	PLAN(IMETRIC)	Surface curvature in the direction of slope derived from 10-meter digital elevation model	Unitless	-0.51	2.141	-37.752	37.752
	Profile curvature	PROFILE	Surface curvature along contour derived from 10-meter digital elevation model	Unitless	0.503	1.973	-37.752	37.752
Potential Solar Radiation	Vernal Equinox	VERNAL	Potential solar radiation of vernal equinox (21 Mar) derived from the combination of elevation, aspects and slope from GRASS v.6.0	W/ m^2	10.064	1.121	0	12.013
	Summer Solstice	SUMMER	Potential solar radiation of summer solstice (22 Jun) derived from the combination of elevation, aspects and slope from GRASS v.6.0	W/ m^2	11.225	1.181	0	13.362
	Autumnal Equinox	AUTUMN	Potential solar radiation of autumnal equinox (21 Sept) derived from the combination of elevation, aspects and slope from GRASS v.6.0	W/ m^2	10.072	1.119	0	12.022
	Winter Solstice	WINTER	Potential solar radiation of winter solstice (22 Dec) derived from the combination of elevation, aspects and slope from GRASS v.6.0	W/ m^2	8.139	1.657	0	10.638
Topographic Distance operations	Coast	COAST(_dist)	Distance from coastline derived from the topographic distance operation from BIOMAPPER v.3.1	meter	1847.014	1748.237	0	8294.278
	Railway	RAILWAY(_dist)	Distance from railways derived from the topographic distance operation from BIOMAPPER v.3.1	Meter	8510.225	6021.775	0	26742.79

	Main Road	MAINROAD(_dist)	Distance from mainroads derived from the topographic distance operation from BIOMAPPER v.3.1	Meter	3583.598	4113.923	0	20750.79
	Building	BLDG(_dist)	Distance from buildings derived from the topographic distance operation from BIOMAPPER v.3.1	Meter	2098.879	3053.41	0	19243.63
Frequency of occurrence operation	River	RIVER(_fq)	Frequency of occurrence operation (circular analysis) from BIOMAPPER v.3.1 with 300m radius	Percentage	1.05	1.843	0	19
	Stream	STREAM100(_fq)	Frequency of occurrence operation (circular analysis) from BIOMAPPER v.3.1 with 100m radius	Percentage	4.629	5.28	0	35
		STREAM500(_fq)	Frequency of occurrence operation (circular analysis) from BIOMAPPER v.3.1 with 500m radius	Percentage	2.538	3.584	0	19

3.4.3.3 Criteria for Multiple Criteria Analysis (MCA)

The environmental gradients as well as the results from habitat modeling are chosen and regarded as criteria in MCA while extra criteria are computed through GIS operations. Boundary of the North and South Lantau Country Parks (from reserve park layer); hiking trails (from road layer); reservoirs (hydrography polygon layer); community facilities including deemed monument, declared monument/ antiquity, pavilion, toilet and ancestral hall (from facility layer); religious meeting places including temple and church (from facility layer); recreational and sports facilities including playground (from facility layer) are extracted from B10000 database. All the features are exported to IDRISI format.

Apart from the information from existing database, extra conservation-and-tourism related features are manually digitized and transferred into IDRISI format. The existing ten public campsites together with the barbecue sites are digitized in point vector with reference to the map published by the Universal Publication Ltd. The proposals in the Concept Plan for Lantau including the extension portion of North Lantau Country Park, proposed cycle tracks; hiking trails, museum; eco-tour centre and Tung Chung cable car are digitized. Prior to digitization, the image of the plan is aligned with georeferenced data using the georeferencing toolbar in ArcGIS v.9.0. Moreover, the building layer in B5000 database is edited with Tung Chung and Discovery Bay being removed from the layer. The remaining building polygons are regarded as village houses which are then exported to IDRISI.

3.5 Wildlife Habitat Mapping

Wildlife habitat mapping/ modeling is to determine the relationship between various attributes of the environment and the distribution of each individual species. It relates species' occurrences at points to a set of predictor variables that are available across the whole study area (Osborne and Tigar, 1992; Buckland and Elston, 1993; Augustin *et al.*, 1996). The developed relationship is then used to generate models that predict the distribution of species by identifying suitable habitat of area concerned (Cowley *et al.*, 2000). In this study, the modeling is species-based and the process basically consists of three elements – dataset, mathematical model and model assessment. The dataset includes both the species occurrence points and the environmental predictors as described in the previous section. Prior to modeling, ranges of occurrence for each predictor as well as the correlation of the predictors are examined. After that, three multivariate statistical modeling methods are used to model the potential habitat for each of the fifty species. They are Ecological Niche Factor Analysis (ENFA), Binary Logistic Regression Model (BLRM) under the family of Generalized Linear Model (GLM) and the Generalized Additive Model (GAM). The ENFA requires the presence-only data points while the regression models require both presence and absence data. Since the data from biodiversity survey provides only the presence data point, the absence data point is generated based on the results from ENFA. Then, statistical significance derived from Mann-Whitney U independent-samples tests is tested for the ranges of absence for each predictor and that of the presence. Mann-Whitney

U-test is non-parametric with the distribution assumptions. The models are finally assessed by measuring their goodness-of-fit and discriminatory ability. The modeling methods are summarized in Figure 3.5 and the methodology of each modeling technique is described below.

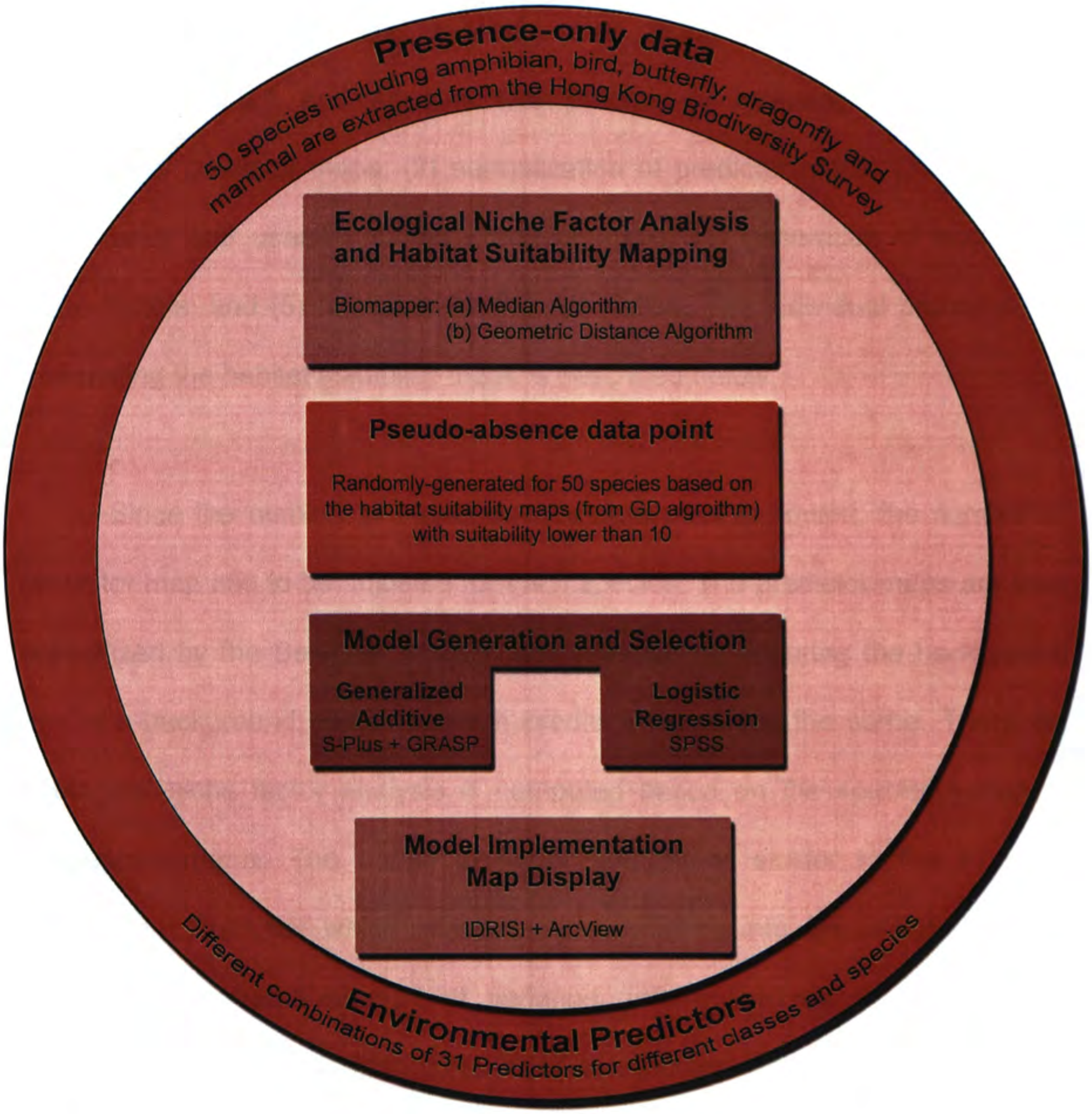


Figure 3.5 The summary of multivariate statistical habitat modeling methods used in the study.

3.5.1 Ecological Niche Factor Analysis (ENFA)

ENFA, developed by Hirzel *et al.* (2002), quantified the ecological niche concept defined by Hutchinson in 1957 by two sets of factors. The strength of analysis is that it requires presence-only data point in the modeling process. The computation of habitat suitability map using ENFA is conducted in BIOMAPPER v.3.1 and involves five procedures including (1) input and selection of predictor maps; (2) normalization of predictor maps; (3) verify the consistency and usability of the predictor maps; (4) generation of ecological niche factors; and (5) habitat suitability estimation. The individual procedure in formulating the habitat suitability maps is described below.

Since the number of presence-only data point is limited, the number of predictor map has to be adjusted for each species. The predictor maps are then normalized by the Box-Cox function and followed by ensuring the background and non-background pixels for each predictor maps are the same. Then, the ecological niche factor analysis is computed based on the species variance-covariance matrix. The notion of factor analysis is similar to the Principal Component Analysis, which converts the predictors into uncorrelated factors explaining the same amount of variance (information) as they are in the predictors (Hirzet *et al.*, 2002). However, the factors computed by ENFA have ecological meanings represented by two groups of factors. Marginality is named as the first factor which explains the maximum amount of variance and the subsequent factors are named as specializations (Hirzet *et al.*, 2002). A score matrix is formed describing the correlation between the factors and the original variables/ predictors. Predictors with high absolute coefficient value in the matrix are corresponding to high importance in explaining the distribution of species. The choice of the number of factors retained is consistent with the broken-stick advice, which compared the eigenvalues of the distribution with that of the random one in order to make sure the significant ones are kept. However, the amount of information explained is expected to be at least 70%.

Apart from the factors, three global statistics – Marginality, Specialization and Tolerance, are provided describing the general habitat requirements when compared with the whole study area. The global marginality (*M*) compares the difference between the species habitat with the available environment setting based on all the input predictors. A value close to one indicates extreme habitats are preferable while a value close to zero shows that the species is favourable towards the average condition throughout the study area. The global specialization (*S*) and tolerance (*T*) is in reciprocal relationship but the latter one is easier to interpret. The global tolerance (*T*) compares the range of living condition of the species within the study area (Hirzet *et al.*, 2002). A high value (close to one) means that the species accepts a wide range of living environment while a low value (close to zero) indicates that the species is specialized and restricted to a limited range of living condition. The equations for the three statistics are shown below (Hirzel, 2005):

Global Marginality (*M*) = $$\frac{\sqrt{\sum_{i=1}^{V} m_i^2}}{1.96}$$ Eq. 3.5

Global Specialization (*S*) = $$\sqrt{\frac{\sum_{i=1}^{V} \lambda_i}{V}}$$ Eq. 3.6

Global tolerance (*T*) = 1/*S* Eq. 3.7

Where M_i are the coefficients of the marginality factor, V is the number of variables and λ_i are the eigenvalues. After understanding the preferable living conditions of the species from the two sets of factors, the habitat suitability can be computed. Two habitat suitability algorithms are used – (1) the medians algorithm and (2) the distance geometric mean algorithm.

The medians algorithm calculates the suitability of each cell by identifying the position of the targeted cell under the frequency distribution of values of ecological niche factor (Hirzet *et al.*, 2002). Figure 3.6 shows the frequency distribution in terms of the ranges of a factor for a species with the median separates exactly the two sides. For each cell in the study area, it will fall into a specific range of values in the factor indicated here as focal class. By summing up the frequency or number of cells from the species distribution (the shaded bars); twice this number and then normalized the number by dividing it by the total number of pixels/ cells in the species distribution (summing up all the bars), the habitat suitability index ranged from 0 to 1 in terms of this particular factor is formed. The overall suitability index of the targeted cell is computed by combining the scores on each selection ecological factor. It can be imagined that the closer the targeted cell towards the median, the higher the suitability on a factor, and vice versa.

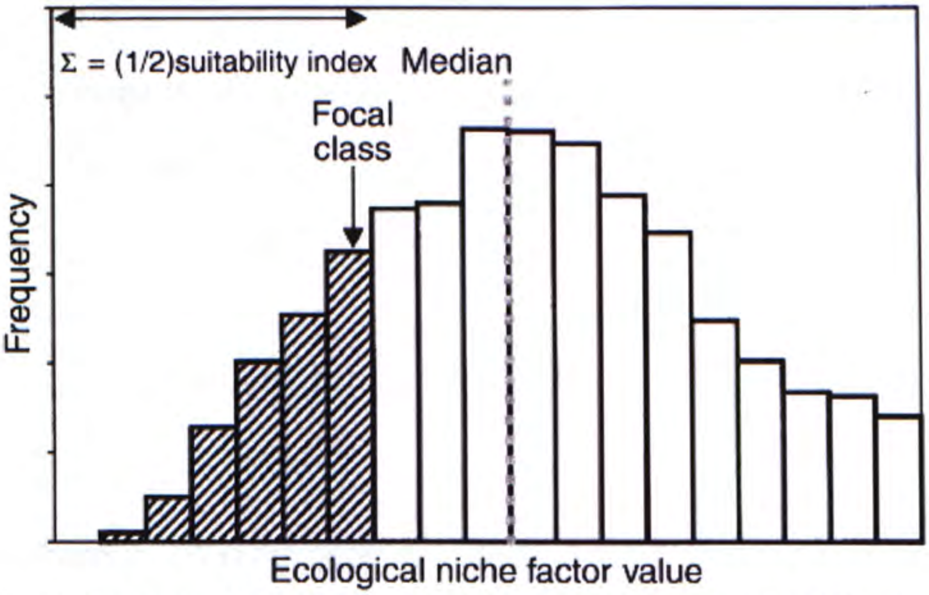


Figure 3.6 The computation of suitability index for a targeted cell in an ecological factor using the medians algorithm in Biomapper v.3.1 (Extracted from Hirzet *et al.*, 2002)

The distance geometric mean algorithm rooted in the concept of environmental-envelope (Hirzel and Arlettaz, 2003). Every single species' presence point (*O*) can be represented and positioned in a D-dimensional environmental space (with *D* predictors). Within the *D*-dimensional environmental space, the position of the species' presence and that of any point (*P*) can be compared, calculated and expressed in the form of Euclidean distance given as

$$\delta(P, O) = \sqrt{\sum_{i=1}^{D} w_i(O_i - P_i)^2} \quad \text{Eq. 3.8}$$

Where O_i represent a single species presence observation point in i dimension; P_i is any point in the study area in i dimension; D is the number of predictors/ dimensions and w_i are weights of the predictors. In ENFA, the weights are determined by the information explained by the ecological niche factors. Through the computation of the distances from a particular pixel/ cell of interest (P) to every single presence observation point (O), the geometric mean of all the distances is expressed as

$$\mu_G(\mathrm{P}) = \sqrt[N]{\prod_{i=1}^{N} \delta(P, O_i)} \quad \text{Eq. 3.9}$$

Where $\mu_G(P)$ is the geometric mean of any point (P), N is the number of species' observations and $\delta(P, O_i)$ is the Euclidean distance given in Eq. 3.9. The habitat suitability of individual pixel/ cell is generated based on this geometric mean functions (Hirzel and Arlettaz, 2003). ENFA produces habitat suitability map with range of 0-100 and based on which the pseudo-absence data are generated.

3.5.1.1 Generation of Pseudo-absence Data-point

Unlike the ENFA, the regression models require both the presence and absence data for model calibration. Since the biodiversity survey lacks the absence one, the generation of pseudo-absence data is necessary. Some scholars suggested that the way in which pseudo-absences are generated affects the final quality of the model (Zaniewski *et al.*, 2002). On the other hand, some argued that choosing wrong absence may not cause problems when common species are concerned. As long as the presence records are of good quality, it will offset its effect (Engler *et al.*, 2004). In this study, rather than generating randomly throughout the whole study area, the pseudo-absences are created based on the habitat suitability results from ENFA (distance geometric mean algorithm) in Biomapper v.3.1. With a view to produce quality pseudo-absences, binary maps indicated areas with suitability lower than 10 is formed for each species based on which random sampling is carried out in these areas only. The number of pseudo-absences is the same as the presences which make the prevalence equal to 0.5. These pseudo-absences are used in both the BLRM and GAM as discussed below.

3.5.2 Binary Logistic Regression Model (BLRM)

Binary Logistic Regression Model (BLRM) is one of the most popular habitat modeling methods extremely suitable when the dependent variable is dichotomy characterized in many field surveys (Osborne and Tigar, 1992). The link function of logistic regression is logit transformation and the error structure is assumed to be binomial (Hosmer and Lemeshow, 1989). With the logit link function, the results are more closely related to ecological and biological sense (Osborne and Tigar, 1992). After establishing the relationship between a species and the environmental predictors, the model is used to predict the probability of occurrence of species ranged between 0 and 1 in each individual site.

In the study, the model building part for BLRM is conducted in SPSS® 13.0 for Windows while the results of prediction are calibrated in IDRISI v14.02. The values of each predictor are queried, extracted and exported for each species for both the presences and pseudo-absences in IDRISI v14.02. After importing all the values into SPSS® 13.0, the predictors are explored for their minimum value, maximum value, mean value, standard deviation and most importantly, their correlation. The uncorrelated independent variables are then used for the backward stepwise logistic regression model calculation. All the predictors in the model are restricted to have significant level with $p<0.05$ in order to ensure that all variables are important in explaining the presence of the species.

Model evaluation is essential for examination of the predictive power of the logistic models. In this study, since the number of sample points is so limited that an independent evaluation dataset is not available. Using the same dataset, the models for each species are evaluated for their reliability (goodness-of-fit) and their discriminatory ability (Pearce and Ferrier, 2000). The goodness-of-fit is measured by Hosmer and Lemeshow Goodness-of-Fit Test (*H-L*) and the deviance reduction with significant testing all provided in the output of SPSS.

The pseudo-R^2 is used to measure the strength of association between dependents and predictors.

The *H-L* statistic is the computation of p-value from the chi-square distribution of the observed and expected frequencies with eight degrees of freedom. A well-fitting model is indicated by its insignificance in p-value ($p>0.05$), which fails to reject the null hypothesis (H_0) that there is no difference between observed and model-predicted one (Garson, 2005). This implies that the observations and predicted values agree with each other.

The second reliability test is for non-Normal models is the deviance reduction with Likelihood Ratio Chi-square test. A model is said to be optimized if the deviance cannot be significantly reduced by including or excluding a variable. The model deviance is represented by -2 Log Likelihood ($-2LL$) in the SPSS output. The initial deviance is shown at the bottom of the "Iteration History" table while the residual deviance is shown in the "Model Summary" table. The percentage of deviance reduction is calculated as

$$R = \left[\frac{1-(-2LL_1)}{(-2LL_0)} \right] 100\% \qquad \text{Eq.3.10}$$

Where R is percentage of deviance reduction, $-2LL_0$ is the deviance of the null or initial model with constant only and $-2LL_1$ is the deviance of the final model with independent variables (IVs) or the model chi-square. The larger the reduction of deviance, the better the logistic model fits the data (Peeters and Gardeniers, 1998). The Likelihood Ratio Chi-square Test which is the test for the *overall* model is then used to test the H_0 that the effects of the IVs do not significantly differ from 0. The significance test is reported in "Model" row under the "Omnibus Tests of Model Coefficients" table. A rejection of null hypothesis requires $p<0.05$. For the "Step" row under the same table, it determines if the effect of IV removal significantly differs from zero with $p>0.05$ indicates that the IV removed is not an important variable (Williams, 2006).

SPSS reports two pseudo-R^2 statistics, namely, the Cox-Snell R^2 and the Nagelkerke R^2 which measure the strength of association between dependent (species) and the independent (predictors). The Cox-Snell R^2 is given as (Williams, 2006)

$$\text{Cox-Snell } R^2 = 1 - exp[-(-2LL_1)/N] \qquad \text{Eq. 3.11}$$

Where $-2LL_1$ is the model chi-square and N is the total number of data points (both presence and absence). Since the maximum is always less than one and makes the statistic difficult to interpret and compare, the Nagelkerke R^2 is a modified Cox-Snell R^2 in order to assure the value fell between 0 and 1 given as (Williams, 2006)

$$\text{Nagelkerke } R^2 = \frac{1 - exp[-(-2LL_1)/N]}{1 - exp[-(-2LL_0)/N]} \qquad \text{Eq. 3.12}$$

With respect to the discrimination performance, it is evaluated by the leave-one-out cross validation classification accuracy as well as threshold-independent Receiver Operating Characteristic (ROC). The leave-one-out cross-validation is conducted under the discriminant function analysis in SPSS® 13.0. The result from cross validation is compared with observed one to form a 2 x 2 accuracy classification table in which the percentages of correct and incorrect classification for both the presence and absence are shown.

Another complementary validation statistics is ROC. Instead of using an arbitrary defined threshold like the case in cross validation, an unbiased threshold-independent ROC plot is proposed through comparing the observed and predicted result. Typically, the ROC analysis plots the sensitivity (true positives) against the false positive fractions for a range of predicted probability by varying across the decision threshold continuously. In other words, for each pair of sensitivity and false positive fraction, it is plotted as the *y* and *x* coordinates respectively to form a graph as shown in Figure 3.7. This forms the so-called ROC curve or plot (Metz, 1978). The curve is used to illustrate the overlap between the two distributions in graphical form (Zwei and Campbell, 1993). The 45-degree diagonal line represents a model with no discrimination ability. The sensitivity and the false positive fraction for all the threshold values are in fact the same distribution. Model with perfect discrimination ability will generate an ROC curve passing through the top left corner. It represents for all the threshold probability, the sensitivity equals one (perfect sensitivity) and the false positive fraction equals zero (perfect specificity) with no overlay for the two distributions (Zwei and Campbell, 1993; Pearce and Ferrier, 2000). Apart from the curve, the area under the ROC curve (AUC) is regarded as a vital approximation index to quantify the discrimination ability and a measure of overall accuracy (Deleo, 1993). The value of AUC ranges from 0.5 to 1, which represents no discrimination and perfect discrimination respectively. Typically, the values will fall between the limits. Values between 0.5 and 0.7 show poor discrimination ability; values between 0.7 and 0.9 indicate reasonable discrimination ability; values higher than 0.9 specify very good discrimination (Swets, 1986a). Hanley and McNeil (1982) interpreted the ROC index as the probability that a model can correctly distinguish between two observations. Westin (2005) realized that the area is essentially a 'measurement of the probability that the distribution of the positive diagnosis is statistically larger than the distribution of the negative diagnosis.'

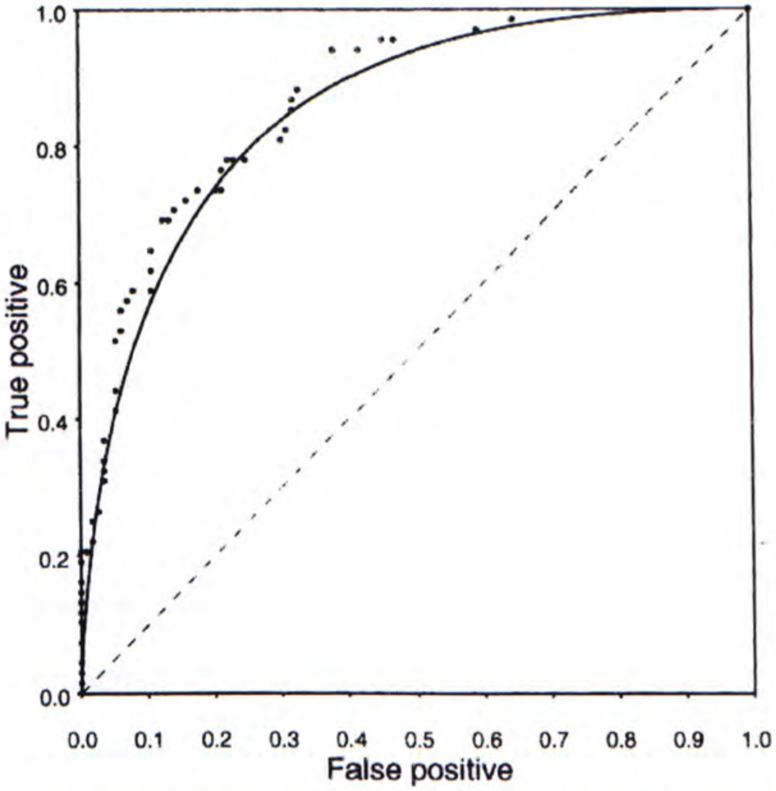


Figure 3.7 The Receiver Operating Characteristics (ROC) curve/ plot with y axis showing the sensitivity and x axis showing the false positive fraction. *Source*: Pearce and Ferrier, 2000, p.232

After choosing the best models from evaluation, the logit denoted $g(x)$ is extracted in "Beta" column under the "Variables in the Equation" table in the form of

$$g(x) = In\left[\frac{\pi(x)}{1-\pi(x)}\right] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k \qquad \text{Eq. 3.13}$$

Where $\beta_i(x_i)$, $i = 1, \ldots, k$ are beta values correspond to the x Ivs. The $g(x)$ for each species are noted and input into IDRISI v.14.02 to generate predictive maps through the transformed equation using the image calculator

$$\pi(x) = \frac{e^{g(x)}}{1 + e^{g(x)}} \qquad \text{Eq. 3.14}$$

Where $\pi(x) = P(Y = 1 \mid x = x_k)$ is the likelihood of occurrence of the species as a function of environmental predictors x. The likelihood of occurrence ranges between 0 and 1. The predictive maps are generated for the whole territory and the Lantau part is extracted.

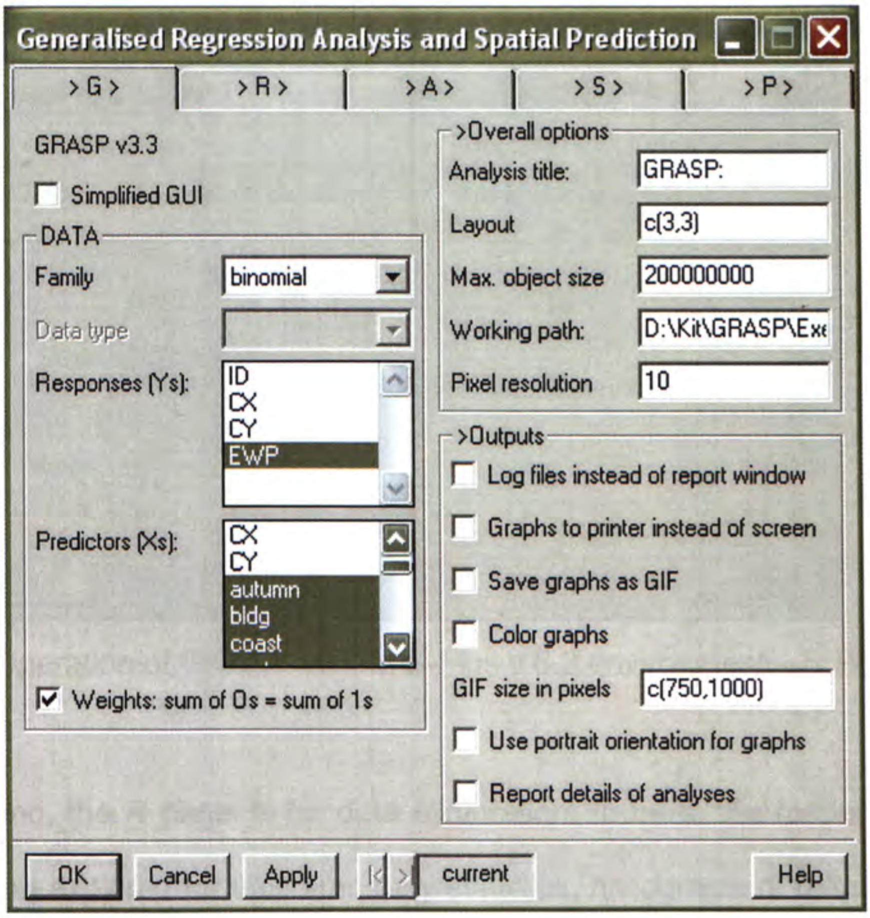
3.5.3 Generalized Additive Model (GAM)

GAM is another popular species modeling method which is a non-parametric extension of GLM. But it distinguishes itself from the GLM family by allowing the Ivs to be non-linear in nature (Hastie and Tibshirani, 1990; Yee and Mitchell, 1991). When linking with the logistic term, the general form of the logit(p) is given as

$$g(x) = s_0 + s_1(x_1) + s_2(x_2) + \ldots + s_k(x_k) \qquad \text{Eq. 3.15}$$

Where $s_i(x_i)$, $i = 1, \ldots, k$ are smooth functions. Similar to BLRM, GAM predicts the probability of occurrence of species ranged between 0 and 1. And the transformation of logit(p) follows the equation 3.14.

The model building is conducted in the Generalized Regression Analysis and Spatial Prediction (GRASP) v.3.0 in S-Plus v.6.2. For each species, their corresponding presence and pseudo-absence data point (response variables) and environmental predictors (predictor variables) are imported into the GRASP working environment. Since the prediction dataset is more than 250,000 pixels/ observations, which is regarded so large that the prediction is recommended to be performed in ArcView rather in S-Plus. The procedure is shown in Figures 3.8 – 3.11 and described below (Lehmann *et al.*, 2004):



GRASP v3.3

☐ Simplified GUI

DATA

Family: binomial

Data type:

Responses (Ys): ID, CX, CY, EWP

Predictors (Xs): CX, CY, autumn, bldg, coast

☑ Weights: sum of 0s = sum of 1s

>Overall options

Analysis title: GRASP:

Layout: c(3,3)

Max. object size: 200000000

Working path: D:\Kit\GRASP\Ex

Pixel resolution: 10

>Outputs

☐ Log files instead of report window

☐ Graphs to printer instead of screen

☐ Save graphs as GIF

☐ Color graphs

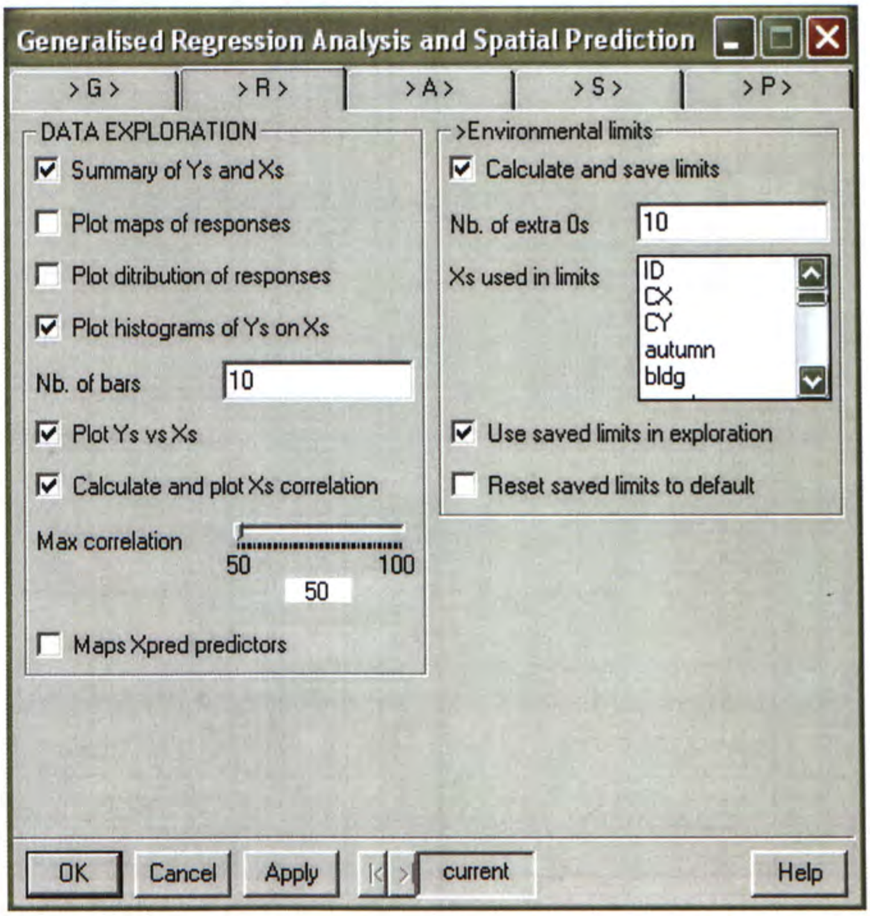
GIF size in pixels: c(750,1000)

☐ Use portrait orientation for graphs

☐ Report details of analyses

Figure 3.8 Operation of GRASP v3.0 in S-Plus v.6.2 environment – G Panel

First, the *G* panel is the data selection and overall option part. With the presence-absence data, the binominal family is selected. The responses (Ys) referred to the presence-absence dataset for the modeling species while the predictors (Xs) are those entered for prediction.



DATA EXPLORATION

☑ Summary of Ys and Xs

☐ Plot maps of responses

☐ Plot ditribution of responses

☑ Plot histograms of Ys on Xs

Nb. of bars: 10

☑ Plot Ys vs Xs

☑ Calculate and plot Xs correlation

Max correlation: 50 (50–100)

☐ Maps Xpred predictors

>Environmental limits

☑ Calculate and save limits

Nb. of extra 0s: 10

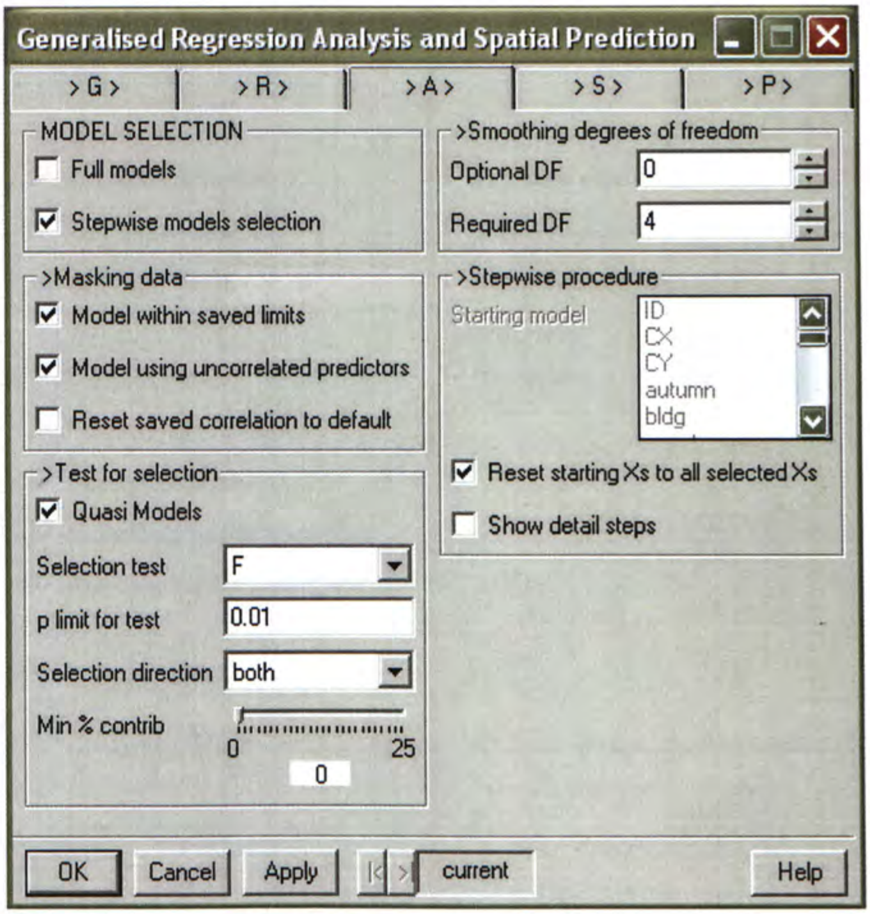
Xs used in limits: ID, CX, CY, autumn, bldg

☑ Use saved limits in exploration

☐ Reset saved limits to default

Figure 3.9 Operation of GRASP v3.0 in S-Plus v.6.2 environment – R Panel

Second, the *R* panel is for data exploration. In here, the responses and predictors are explored for their summary statistics, histograms of responses on predictors as well as calculating the correlation among predictors in the form of both statistics and graphs. The maximum correlation of 0.5 is set and saved as environmental limits, which ensure the predictors do not correlate with each other and avoid multicollinearity.



MODEL SELECTION

☐ Full models

☑ Stepwise models selection

>Smoothing degrees of freedom

Optional DF: 0

Required DF: 4

>Masking data

☑ Model within saved limits

☑ Model using uncorrelated predictors

☐ Reset saved correlation to default

>Stepwise procedure

Starting model: ID, CX, CY, autumn, bldg

☑ Reset starting Xs to all selected Xs

☐ Show detail steps

>Test for selection

☑ Quasi Models

Selection test: F

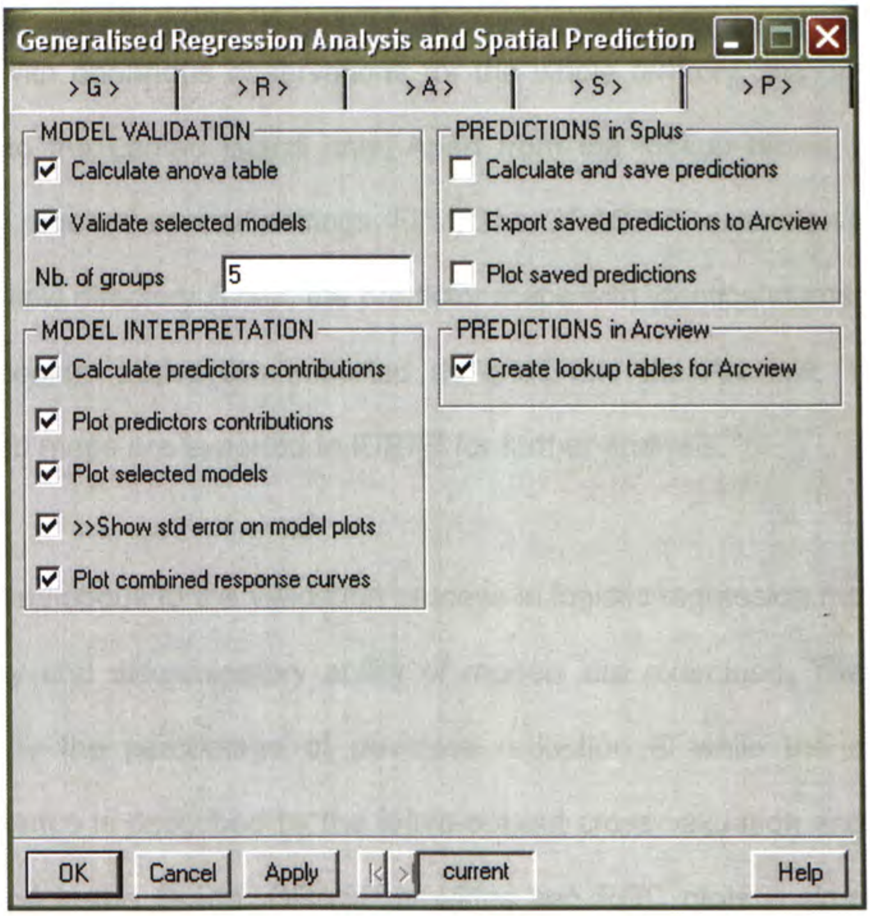
p limit for test: 0.01

Selection direction: both

Min % contrib: 0 (0–25)

Figure 3.10 Operation of GRASP v3.0 in S-Plus v.6.2 environment – A Panel

The third panel, *A*, the model building and selection section, is the main focus of the module. The stepwise models selection masking with uncorrelated predictors is chosen. The smoothing spine smoother with four degrees of freedom is set as the default generalized method. The Akaike information criterion (AIC) is used as the variable selection method. AIC is information theoretic model selection approach based on the calculation of Kullback-Leibler (K-L) information or distance (Burnham and Anderson, 2002).



MODEL VALIDATION
☑ Calculate anova table
☑ Validate selected models
Nb. of groups 5

MODEL INTERPRETATION
☑ Calculate predictors contributions
☑ Plot predictors contributions
☑ Plot selected models
☑ >>Show std error on model plots
☑ Plot combined response curves

PREDICTIONS in Splus
☐ Calculate and save predictions
☐ Export saved predictions to Arcview
☐ Plot saved predictions

PREDICTIONS in Arcview
☑ Create lookup tables for Arcview

Figure 3.11 Operation of GRASP v3.0 in S-Plus v.6.2 environment – S Panel

The final panel, *P*, is the model interpretation, validation and prediction session. The model validation is based on ANOVA table calculation. The predictors' contribution, response curves, ROC plots are plotted to assist model interpretation. Among the three methods in calculating predictors' contribution, the "model contribution" is used to indicate the contribution of individual variable within the selected model. Finally, in order to carry out prediction in Arcview, lookup tables for each species is exported.

With enormous observations for the whole territory, the predictions are limited to the Lantau Island only. Apart from the lookup tables, prediction in Arcview requires several settings. First, The GRASP-IT extension is installed in the Arcview directory. Then, the predictor maps with identical names as they are in the lookup tables are imported as grids into the Arcview. The resultant predicted maps are exported to IDRISI for further analysis.

Analogous to the validation process in logistic regression model, both the reliability and discriminatory ability of models are examined. The reliability is tested by the percentage of deviance reduction ® while the discrimination performance is described by the leave-out-out cross validation and the AUC as illustrated in the BLRM. GRASP provides two ROC plots – simple ROC and cross-validated ROC. Lehmann *et al.* (2002) suggest that the close agreement between the simple validation ROC area and cross validation ROC areas indicate model stability.

3.5.4 Model Comparison and Selection

For each of the fifty species, the habitat predictions are made through the three multivariate statistical methods. The ENFA acts as a preliminary examination of the habitat for the species as well as a base to generate pseudo-absence data for the later regression modeling. It is revealed that ENFA tends to more capable in predicting regions with average to high suitability. However, owing to the lack of absences to act as a "bottom line" in the prediction, the low suitability areas are likely to be explained with caution (Hirzel, 2005). Therefore, only the two regression modeling methods, BLRM and GAM are compared statistically based on the deviance reduction, AUC of ROC plot and the leave-one-out classification accuracy. The distribution of the species is represented by either regression models.

3.5.5 Identification of Biodiversity Hotspots

With her subtropical location as well as large variation in topography, Hong Kong is rich in species. A biodiversity hotspot "is a site that supports a significant proportion of the species in a particular taxon or group (Dudgeon and Corlett, 2004)". It is the composition of species richness, endemism and rarity. However, owing to simplicity, measurable ability and data availability, it is commonly measured in terms of the number of species – high species richness (Gaston, 1996). The biodiversity hotspots are usually used as a guide in defining conservation boundary, such as the Gap analysis though the practice is still doubted (Reid, 1998). However, this method is also endorsed by many researchers (Balmford *et al.*, 1996; Williams *et al.*, 1997). This study sums and averages the probability of occurrence maps of the 50 species to form the species richness map with range from zero to one. One indicates sites with the highest species richness. Biodiversity hotspots are represented and defined using three different cut-off thresholds including 0.5, 0.7 and 0.9.

3.5.6 Overlap Analysis of Taxonomic Groups

In this study, five taxonomic groups with 50 species are used to compute biodiversity hotspots. In reality, more taxa are required for computation. However, constrained by data availability and time, the correlations between the five taxonomic groups are examined through overlapping the taxonomic-grouped species richness map. It is assumed that high overlap reflects the possibility of predicting the diversity of modeled groups to un-modeled groups (Reid, 1998; Dudgeon and Corlett, 2004). Species maps for each taxonomic group are combined to form taxonomic-grouped richness maps. With a cut-off threshold of p=0.7 above which the pixel/cell is considered as species-rich, the amount of overlap of diversity hotspots among groups are computed and calculated.

3.5.7 Gap Analysis

The Gap Analysis Program (GAP), launched in 1987, tackles the habitat loss problems in the United States through identifying gaps under existing conservation system. Gaps are defined as potential biodiversity hotpots computed from common or ordinary species that are under-represented by current conservation network (U.S. Geological Survey, 2004). This study compares the species richness map with the North and South Lantau Country Park and the eight SSSIs through simple overlay analysis with a view to identify possible gaps in Lantau. Three cutoff thresholds, 0.5, 0.7 and 0.9 above which represent potential biodiversity hotspots sites are selected. Apart from identifying the so-called "gaps", the results also show the correspondences between hotspots and the protection networks in Lantau through counting the amount of species-rich pixels falling within the three protection boundaries.

3.6 Site Selection for Compatible Tourism Activities through MCA

Multiple Criteria Analysis/ Evaluation (MCA) is an objective process which provides a platform to combine various factors, constraints and preferences to aid decision making. The determination of ideal sites for various recreational activities or tourism facilities proposed in the Concept Plan fall essentially into the category of spatial allocation or land-suitability problem in which MCA plays a major role. In this study, MCA is performed in IDRISI v.14.02 to generate land suitability maps and search sites for three kinds of existing and proposed compatible tourism activities including (1) camping; (2) hiking for natural and cultural exploration; (3) cycling and picnicking as well as for (4) tourism facilities development. The availability of GIS allows the criteria corresponded to the geographical attributes being readily represented and displayed in the form of maps; takes into consideration of a number of factors and constraints; assigns decision maker's preference; and finally applies decision rules to form feasible plans. The procedures are discussed below.

3.6.1 Establishment of Evaluation Criteria: Constraints and Factors

For each proposed activity, the constraints and factors are determined prior to the analysis. A constraint is "a criterion that limits the alternatives under consideration (Eastman, 2001b, p.3)." The constraint we refer here in the analysis is Boolean constraint in which areas being coded as zero are rejected and those coded with 1 are kept for further evaluation. Two constraints are employed for all four activities, specifically, the sea constraint and reservoir constraint in which the water areas are restricted from calculation.

As for factor, by definition, a factor is "a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration (Eastman, 2001b, p.2)." The factors selected for individual activity in MCA is subjected to the nature of the activity. The considerations are mainly fallen into a two categories concerning the site attributes and interests of tourists. For instances, the ecological sensitivity; accessibility; significant tourism interests; facilities availability of sites and the safety of tourists have all been taken into considerations.

3.6.2 Standardization of Factors

Since the evaluation criteria have various measuring scales, it is necessary to transform them into dimensionless units before they are combined for further decision analysis. The process is referred to the standardization of factors. The values for each factor are transformed to the level of suitability ranging from 0 to 255 through different fuzzy membership functions. Eastman (2001b) has proposed four kinds of membership functions – sigmoidal, J-shaped, linear and user-defined as shown in Figure 3.12. The sigmoidal and linear membership function are two mostly used because of their simplicity. Except for the use-defined, four different function shapes are identified for each type. The monotonically increasing function indicates the criterion value is positively related to the level of suitability, i.e. the larger the factor value, the more suitable is the factor related to a specific objective. The monotonically decreasing function is just the opposite, which shows an inverse relationship between the factor value and suitability. That is, the higher value of a criterion is inferior to suitability. The third type of function shape is geometric symmetric. The highest suitability does not locate in both ends; rather, it concentrates on the middle range of the factor value. The fourth type is also symmetric function but with two maximum points when compared with the third type. The factor value between the two vertices indicates the maximized suitability. Provided with these functions, the choice of them is subjected to the relationship between the criterion and the decision set (the set of chosen alternatives). After choosing the fuzzy shape for the factors, the control points, i.e. data value, are set to indicate the corresponding suitability for each factor.

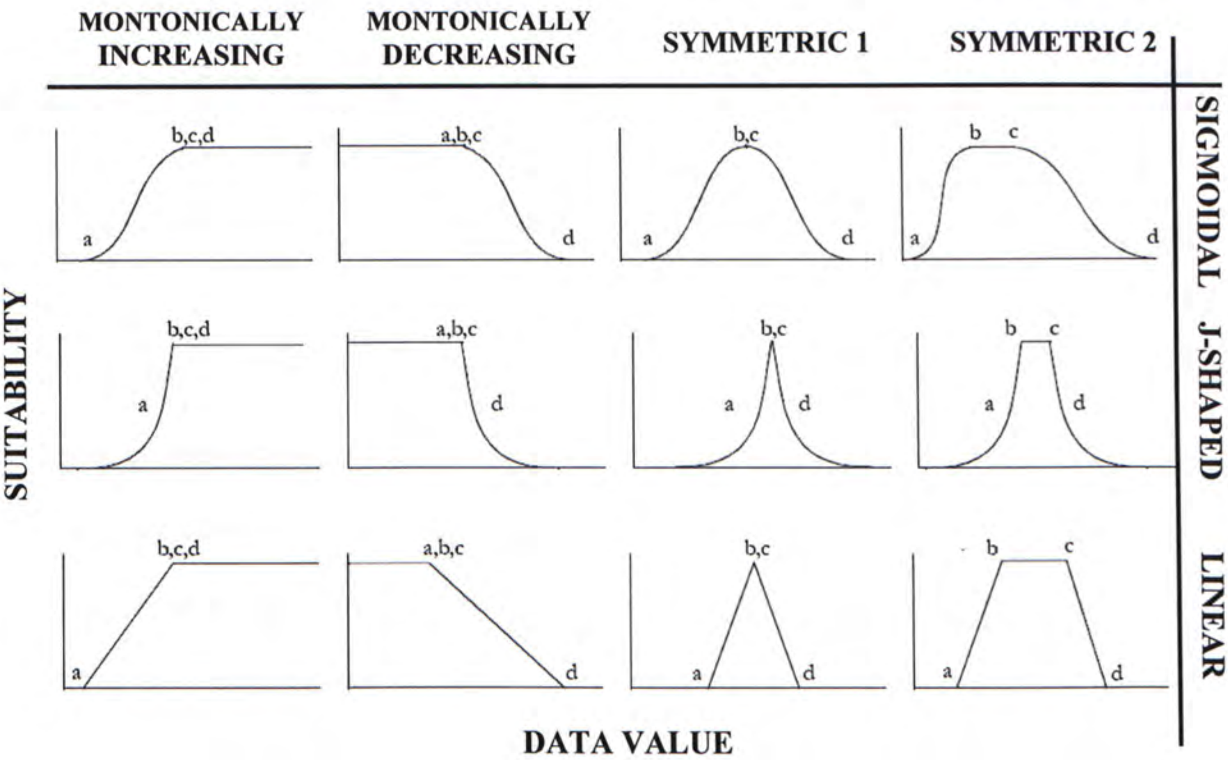


Figure 3.12 Three kinds of fuzzy membership functions in idrisi – Sigmoidal, J-shaped and Linear, used in standardizing the evaluation criteria.
Source: Eastman (2001b)

3.6.3 Weights Assignment and Analytic Hierarchy Process (AHP)

Decision makers' preferences are represented in the form of weights. By assigning a heavier weight on a certain factor, it indicates that the factor is more important than the others. Both equal and unequal weights are assigned in this study to simulate different situations. Referring to the generation of unequal weights, the Analytic Hierarchy Process (AHP) developed by Thomas Saaty in 1980 is used. The AHP allows pairwise comparison of factors which can determine weights more efficiently and robustly (Eastman, 2001b).

The pairwise comparison method consists of three steps – generation of the pairwise comparison matrix, the computation of the criterion weights and the consistency testing (Malczewski, 1999). Firstly, given a pair of criteria each time, a value from 1 to 9 (nine-point scale) is used to describe and rate the relative performance for all the pairs. The definition of the value is shown in Table 3.6. The comparison forms a ratio matrix which is shown in Table 3.7. The diagonal starting from the upper left corner to the lower right corner is essentially 1 because the criterion is compared with itself. Divided by the diagonal cells, the upper right of the matrix is the values assigned by a decision maker. The lower left of the matrix is then filled up with the reciprocal value corresponding to the respective cell. For example, cell $x_{21} = 1/\ x_{12}$; cell $x_{31} = 1/\ x_{13}$, etc. Secondly, the values of each column of the pairwise matrix are summed (y_1, y_2, y_3 and y_4). Then, each cell in the matrix (x) is divided by its corresponding column total (y) as shown in Table 3.8. The score in this matrix is called the normalized score. Finally, the normalized scores for each row are summed and averaged by the number of criteria which is 4 in this case as shown in Table 3.9. The final output is the relative weights (w) of the criteria being compared. Regardless of the number of criterion considered, the sum of weight must equal 1.

Table 3.6 Rating Scale for AHP

Intensity of Importance	**Definition**
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

Source: Saaty (1980)

Table 3.7 Pairwise comparison ratio matrix (step 1)

Criterion	x_1	x_2	x_3	x_4
x_1	$x_{11} = 1$	x_{12}	x_{13}	x_{14}
x_2	x_{21}	$x_{22} = 1$	x_{23}	x_{24}
x_3	x_{31}	x_{32}	$x_{33} = 1$	x_{34}
x_4	x_{41}	x_{42}	x_{43}	$x_{44} = 1$
	$y_1 = 1 + x_{21} + x_{31} + x_{41}$	$y_2 = x_{12} + 1 + x_{32} + x_{42}$	$y_3 = x_{13} + x_{23} + 1 + x_{43}$	$y_4 = x_{14} + x_{24} + x_{34} + 1$

Table 3.8 Normalized pairwise comparison matrix (step 2)

Criterion	x_1	x_2	x_3	x_4
x_1	$1/y_1$	x_{12}/y_2	x_{13}/y_3	x_{14}/y_4
x_2	x_{21}/y_1	$1/y_2$	x_{23}/y_3	x_{24}/y_4
x_3	x_{31}/y_1	x_{32}/y_2	$1/y_3$	x_{34}/y_4
x_4	x_{41}/y_1	x_{42}/y_2	x_{43}/y_3	$1/y_4$
	1.00	1.00	1.00	1.00

Table 3.9 Computation of weight for each criterion (step 3)

Criterion		Weight
x_1	$(1/y_1 + x_{12}/y_2 + x_{13}/y_3 + x_{14}/y_4)/4$	w_1
x_2	$(x_{21}/y_1 + 1/y_2 + x_{23}/y_3 + x_{24}/y_4)/4$	w_2
x_3	$(x_{31}/y_1 + x_{32}/y_2 + 1/y_3 + x_{34}/y_4)/4$	w_3
x_4	$(x_{41}/y_1 + x_{42}/y_2 + x_{43}/y_3 + 1/y_4)/4$	w_4
		1.00

After the generation of weights through the pairwise comparison ratio matrix, any inconsistency of the weights is tested by computing consistency ratio (CR) through a number of steps (Malczewski, 1999). First, the consistency vector (c) for each criterion shown in Table 3.10 is calculated. The consistency vector is computed by dividing the weighted sum vector by each individual criterion weight. As shown in Table 3.10, the weighted sum vector is summation of the multiplication of weight of the first criterion (w_1) by the first row of the original pairwise comparison matrix (x_{11}, x_{12}, x_{13} and x_{14}); the multiplication of second weight (w_2) by the second row (x_{21}, x_{22}, x_{23} and x_{24}); the third weight (w_3) by the third row (x_{31}, x_{32}, x_{33} and x_{34}) and the fourth weight (w_4) by the fourth row (x_{41}, x_{42}, $x_{43}$and x_{44}). Second, the average of the consistency vectors (c) named as lambda (λ_{max}) is calculated. Followed that is the computation of the consistency index (CI) by the formula below:

$$\mathrm{CI} = (\lambda_{max} - n) / (n - 1) \qquad \text{Eq. 3.16}$$

Where λ_{max} is the average consistency vectors; n is the number of criterion. $\lambda_{max} - n$ is regarded as the measurement of the degree of inconsistency. Based on the consistency index, the consistency ratio (CR) is calculated by dividing the consistency index (CI) by the random index (RI). The comparison of the two values is actually representing the estimation of the proximity of pairwise comparison matrix to being logically consistent or being random (Saaty, 1990). For different number of criteria being considered, the RI varied and it can be checked out from Table 3.11. The random index used should be 0.90 since there are four criteria under consideration. The upper limit suggested by Saaty (1980) should be ten percent above which the comparison matrix is regarded as inconsistent. That is, if the resultant CR < 0.10, it indicates that the weights generated from pairwise comparison table is consistent. However, if CR ≥ 0.10, the weights developed in the pairwise comparison matrix should be revised and recomputed since there appears to be inconsistency in the weighting process (Malczewski, 1999).

Table 3.10 Consistency testing – Consistency vector, (step 4)

Criterion	**Weighted sum vector divided by criterion weights**		
X_1	$(W_1)(X_{11}) + (W_2)(X_{12}) + (W_3)(X_{13}) + (W_4)(X_{14}) / W_1$	=	C_1
X_2	$(W_1)(X_{21}) + (W_2)(X_{22}) + (W_3)(X_{23}) + (W_4)(X_{24}) / W_2$	=	C_2
X_3	$(W_1)(X_{31}) + (W_2)(X_{32}) + (W_3)(X_{33}) + (W_4)(X_{34}) / W_3$	=	C_3
X_4	$(W_1)(X_{41}) + (W_2)(X_{42}) + (W_3)(X_{43}) + (W_4)(X_{44}) / W_4$	=	C_4

Table 3.11 Random inconsistency indices (RI) for n = 1, 2, …, 15

n	**RI**	**n**	**RI**	**n**	**RI**
1	0.00	6	1.24	11	1.51
2	0.00	7	1.32	12	1.48
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

Source: Saaty (1980)

By altering the rating scale of different factors in the pairwise comparison step, various weighting schemes are created for each individual activity stressing on important aspect of concern. In other words, the variation of weights and trade-off between factors generates scenes of land suitability for different tourism activities. The EW shows no special preferences on factors, which is therefore regarded as objective and neutral in generating the land suitability for the activities. The AHPW is used to create land suitability map with particular interest towards a (number of) factor(s). Therefore, high suitability in EW and AHPW are of different meanings. The high suitability sites under AHPW are dominated sites in terms of a single or a few factors, which has the possibility of under- or over-estimate the potential suitability of a site for different activities. As for EW, it identifies sites that are generally high in suitability when all the factors are taken into consideration. The results are more representative and useful for further planning purpose.

3.6.4 Decision Rule: The Simple Additive Weighting method (SAW)

Decision rules can be regarded as the procedure to order the alternatives from which the best or most-preferred alternatives can be chosen. It is the procedure amalgamates the previously collected data and information as well as the decision makers' preferences into an overall evaluation of alternatives (Malczewski, 1999). The Simple Additive Weighting method (SAW) also named as weighted linear combination (WLC) is the most popular and widely-used method owing to its simplicity. This study used the SAW as decision rule to combine the standardized factors and weights to form final suitability map for each proposed activity. There are two very basic assumptions behind, namely linearity and additivity (Malczewski, 1999). The first assumes the attributes are linear in nature, i.e. the attractiveness of an extra unit of a criterion is constant for every level of that criterion. The second assumes there is no correlation between attributes. The score of an alternative is computed by multiplying the factor weight assigned for each evaluation criteria and the products are summed up as shown below:

$$\text{Max } A_i = \Sigma_j w_j x_{ij} \qquad \text{Eq.3.17}$$

Where A_i is the overall score for the ith alternative or pixel; x_{ij} is the score of the ith alternative regarding the jth criterion and w_j is the normalized weight with sum equal 1. The weights which are pre-defined in the previous section represent importance of individual factor. Scenarios are created based on the variation weights for different factors generated in the AHP pairwise comparison. The alternatives or pixels with high overall score are chosen as sites that are highly suitability for the particular activity.

3.7 Formulation of Zoning Plan through MOLA

Zone allocation is a one of the widely used planning technique in tourism environments to control and minimize environmental impact. The zoning maps act as a general guide to whether a place/ site should be unlocked to the public (Page and Dowling, 2002). With the previous efforts in identifying sites of species richness as well as for different recreational and tourism activities, zones are developed based on the classification and definition of zones in the Regional Ecotourism Development Planning Approach (REDPA) proposed by Page and Dowling (2002, p.214). The zones are:

1) ***Sanctuary zones*** – *areas requiring special preservation*
2) ***Nature conservation zones*** – *areas sustaining a combination of protection and use but with emphasis on the former*
3) ***Outdoor recreation zones*** – *natural areas that can accommodate compatible outdoor recreation activities*
4) ***Tourism development zones*** – *small areas of concentrated attractions*

Zone allocation is conducted in IDRISI v.14.02 with the Multi-Objective Land Allocation (MOLA) module. "MOLA provides a procedure for solving multi-objective land allocation problems for cases with conflicting objectives. It determines a compromise solution that attempts to maximize the suitability of lands for each objective given the weights assigned (IDRISI 2005, MOLA module)". The four zones correspond to the four objectives in MOLA. The first objective, sanctuary, is the special preservation zone with ecologically significant attributes within its boundary. It is represented by the combination of the eight Sites of Special Scientific Interest (SSSIs) and two Special Areas (SA) and sites with level of species richness of 0.9 or above. The incorporation of the SSSIs and SAs into the objective is owing to the under-representation of ecologically important sites by the species richness map itself. As shown by the result later in

Chapter 4, the species richness map can only represent 1% of these pre-defined ecologically significant areas. Consequently, the Boolean map SSSIs and SAs is added to the species richness map to form the map for the sanctuary objective. Areas are highly ecologically sensitive will have a value greater than one.

The second objective, nature conservation, suggests a mixture of conservation and use with the stress on the protection. This is analogous to the function Country Parks in Hong Kong. The map concerning this objective is the combination of the North and South Lantau Country Parks as well as sites with level of species richness above 0.5 but below 0.9. The species richness map in whatever threshold can only embrace around 50% of areas of Country Parks which is also regarded as under representation. Hence, the two maps, with the former one transformed into Boolean map are summed together to form the objective map for nature conservation. In this case, areas with value over one are protected under existing Country Park system within which they are given higher priority to fall within this zone.

The third objective, outdoor recreation refers to areas compatible with outdoor recreational activities. The map is formulated by the sum of average of the suitability maps (generated from EW) of 3 proposed activities, namely, camping, hiking and cycling and picnicking. The equal weighting of factors is chosen on account of its objectivity in presentation of results.

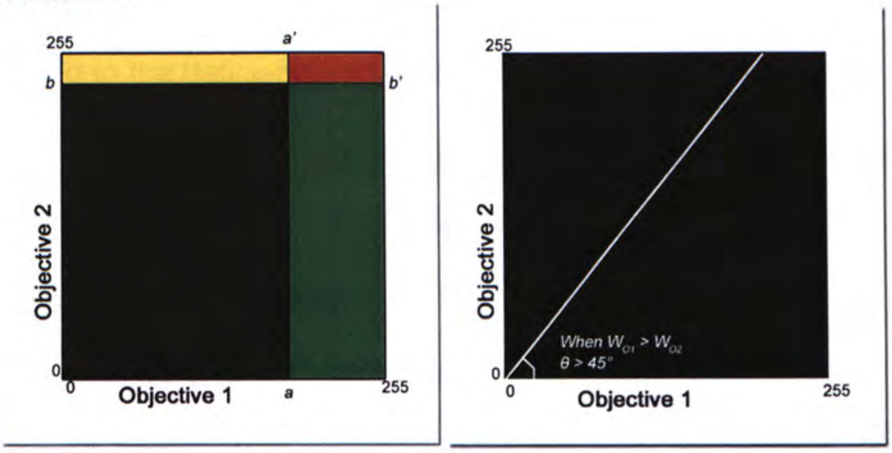
Finally, the fourth objective, tourism development, refers to sites with concentration of tourism facilities and attractions. The corresponding map is the suitability map of tourism development (with EW) formerly computed with MCA.

Prior to the analysis, the four maps are ranked in descending order meaning that the rank value 1 will be assigned to the highest value in the input image (Eastman, 2001b). After that, the weight and areal requirements for each objective are specified. Three simulated scenarios are generated by varying the weight and amount of area requirements to represent three different circumstances. The mechanism behind which MOLA allocates areas to the objectives is illustrated in Figure 3.13. To simplify explanation, two objectives are considered in the explanation. The suitability level of every individual pixel regarding each of the objectives can be represented as a single point within the *d*-dimensional (i.e. 2 in this illustration and 4 in the study) decision space. The decision line which acts as the suitability axis is shifted from the highest suitability (255) to a certain level until targeted number of areas allocated to the objective is met. In scenario 1, *aa'* and *bb'* are suitability axes of objectives 1 and 2 respectively and from which four regions are formed in the decision space. The dark grey region indicates region that are unsuitable for both objectives. The choices located in green portion best suits objective one, so, they are indisputably allocated to while those alternatives fall within. Similarly, the alternatives in the yellow section are allocated to objective two. The region in red is the conflict zone in which alternatives are allocated in accordance with the weights of the objectives predetermined in the analysis. The weights are transformed into a dividing line which splits the decision space into two further regions – closer to ideal point (maximum suitability of 255) of Objective 1 and closer to that for Objective 2 through the equation:

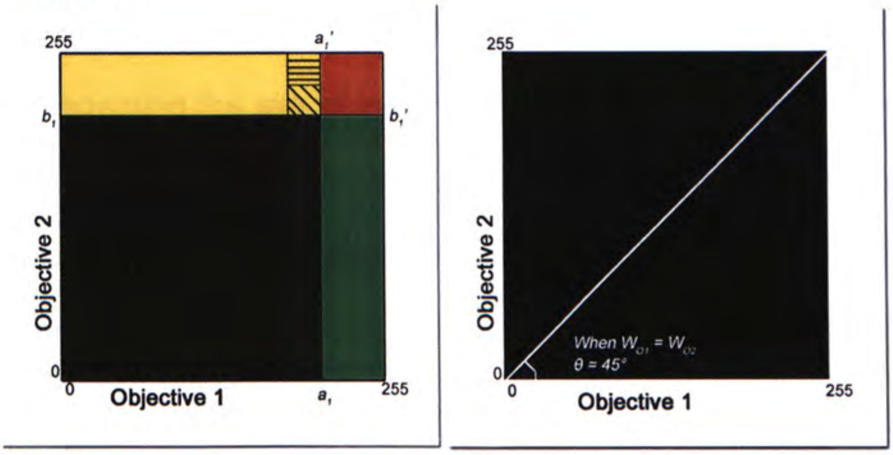
$$\Theta = (w_1/ w_2) \tan^{-1} \qquad \textit{Eq. 3.18}$$

Where, Θ is the angle of the dividing line between the two objectives and w_1 and w_2 are weights assigned to objective 1 and objective 2 respectively. With equal weighting, the dividing line is 45-degree sloping (scenario 2). In case of unequal weighting and if $w_1 > w_2$ (scenario 1) are, the slope of the dividing line is greater than 45-degree. In the reverse case where $w_1 < w_2$ (scenario 3), the slope angle is smaller than 45-degree. Alternatives are assigned to their closest ideal point. Since the alternatives in conflict region will be shared between the objectives, both objectives will be insufficient in satisfying their areal goals. Therefore, the decision lines are continuously adjusted for both objectives in order gain more territory (green and yellow region). The process of conflict resolution and adjustment of the decision lines is repeated constantly until the targeted areas are met (Eastman, 2001b).

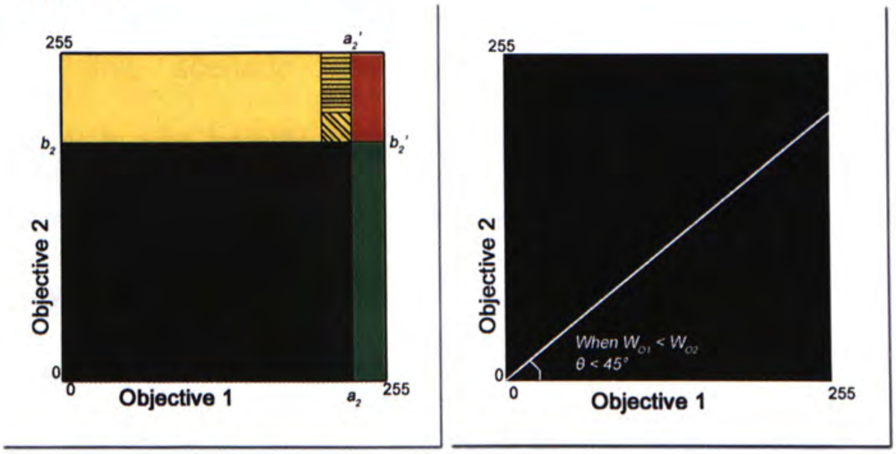
a) Scenario 1



b) Scenario 2



c) Scenario 3



⬛ **Unsuitable choices**

🟥 **Conflict region desired by both**

🟩 **Non-conflict region allocated to obj. 1**

🟨 **Non-conflict region allocated to obj. 2**

▧ **Region orignially assigned to Obj.1 allocated to Obj.2**

▤ **Region orignially in conflict allocated to Obj.2**

Figure 3.13 Mechanism of land allocation to objectives through MOLA

Owing to the deficiency of IDRISI in providing algorithms, the allocation of areas and weights to different objectives are carried out as objectively as possible. In terms of areal assignment, prior examination of the amount of existing protected areas provides a reference which in turns acts as a guide to determine and vary areal allocation in the three scenarios. The current percentage of protection is assumed to be the areal requirement of the equal-preference scenario. As for weight allocation, heavier weights are assigned to objectives regarding the aim of individual scenario. Both significant weight and higher amount of area are assigned to objectives that are of particular interest. Through adjusting the combination of the two attribute values, three scenarios are generated with each representing a compromise solution in terms of the four objectives.

The first scenario creates from the perspective of extreme conservationists who heavily emphasize on the protection of the island on one hand and minimize the development and recreational uses on the other. This is created by giving strong weights and areal allocation to the first two conservation-related objectives and less on the last two which stress on recreation and tourism development. The second scenario has prone to an unbiased and objective situation with equal weights for the four objectives. The third scenario is recreational- or tourism- oriented which show enormous enthusiasm in turning Lantau into a recreational and tourism destination with just enough conservational measures. The weight and areal allocation focus more on the last two objectives. The three scenarios form a range from conservation-oriented with balanced objectives in the middle to a situation where tourism and recreation dominated.

After the analysis, the three results are refined with filter and buffer analysis. Since the results for the objectives involve dispersed and scattered pixels, the mean filter with size of 5x5 is used to get rid of isolated pixels for each individual objective. The buffer analysis is applied to create two 50-meter (a total of 100-meter) buffer zones along the boundary of sanctuary and natural conservation zones with a view to provide a transitional region for potential impacts induced by recreational and tourism activities. The buffer zones are attached to the final zoning plan for Lantau.

3.8 Evaluation of the Concept Plan for Lantau

The Lantau Development Task Force has drafted a number of development proposals in the Concept Plan for Lantau, which are summarized into four development themes (Lantau Development Task Force, 2004). Twelve proposals associated with conservation and tourism issues are picked for evaluation. Table 3.12 shows the selected proposals to be compared and assessed with the MCA and MOLA results. In order to facilitate assessments, the proposals are rearranged and categorized in accordance with the four planning objectives, namely, sanctuary, nature conservation, outdoor recreation and tourism development.

Table 3.12 Proposals reclassified into four objectives with descriptions extracted from the Concept Plan for Lantau public consultation digest and report

Objectives	Code*	Proposed Items	Descriptions
Sanctuary	D3	Exploration of Ecological Sensitive Sites for Protection	Continuous investigation of the need and feasibility of designating SSSIs supporting rare species of fauna and flora
Nature Conservation	D1	Proposed Extension of Lantau North Country Park	2,360 hectares extension of Lantau North Country Park for its conservation value landscape amenity and recreational potential
Outdoor recreation	A5	Golf Course cum Resort at Tsing Chau Tsai East	An upland golf course cum resort in Tsing Chau Tsai East for business visitors
	B4	Cycle tracks in South Lantau and Mui Wo	11-km long cycle track network along the coast from Pui O to Shek Pik and 4-km continuous cycle track linking ferry pier to Mui Wo Old Town. Beaches, picnic areas and campsites are found along the tracks
	C1	Eco-Trails and Heritage Trails	Improvement of existing footpaths and trails linking up Tai Ho, Tung Chung, Tai O and Yi O, with extension to Mui Wo, Shui Han and Fan Lau in order to enhance accessibility and connectivity to both cultural and ecological interests
	C2	High-quality Camping Sites	Campsites with basic shared facilities at Pui O, Nam Shan and Kwun Yam Shan are proposed
Tourism Development	A3	Leisure and Entertainment Node at Sunny Bay	North East Lantau Tourism Hub with entertainment, dining, fashionable stores, performance venues, theme attractions and indoor leisure and sports facilities on reclaimed land
	A4	Theme Park or recreational uses at Tung Chung East	Second international theme park or large recreational uses for locals and overseas visitors on reclaimed land in Tung Chung East

	A6	Resort Facilities in South Lantau	Environmental compatible resorts with natural beaches, scenic beauty and tranquility at Tai Long Wan and Lower Cheung Sha Beach
	A7	Hotel Facilities	Further scope for hotel use to complement tourism development in Lantau
	B1	Museum and Eco-tour Center	Museum of Lantau acts as showcases for historical, cultural and archaeological interests while eco-tour center introduces visitors to rich ecological resources and eco-tourism spots
	B5	Watersports centres in South Lantau	Watersports centres at Pui O and Cheung Sha Beach with non-motorized activities in the former
		Boardwalks in South Lantau	Boardwalks at Pui O and from Lower Cheung Sha to Tong Fuk Beach

Three types of recreational activities including cycling tracks in South Lantau and Mui Wo (B4); eco-trails and heritage trails (C1); and high-quality camping sites (C2) are compared with the corresponding result from MCA while the remaining proposal are evaluated with the MOLA results.

3.9 Summary

To summarize, through remote sensing and GIS, the study is three-folded including habitat mapping, site selection and zonation. Prior to any analysis, a database is constructed. Fifty species from five taxonomic groups are extracted from the Biodiversity Survey of Hong Kong and represented by individual binary maps. The records of one are treated as presence data point in latter analysis.

Apart from the species, environmental gradients are created based on the SPOT 5 satellite image and GIS vector data. The image provides the up-to-date land cover information. The vegetation-related maps from the land cover classification are extracted to generate several parameters by circular and distance analysis. The vector data are used to create resource-related; landscape factor and human-disturbance factors through GIS calculation and computation. Both the species maps and environmental gradient maps are used for habitat mapping. Some of the gradient maps also act as criteria maps in Multiple Criteria Analysis while extra criteria are manually digitized as well as generated through extra GIS vectors.

The habitat mapping is conducted through three multivariate statistical analyses to form a species richness map. ENFA which requires presence-only data is used as a preliminary exploration of the habitat requirements of the fifty chosen species through marginality and tolerance statistics. Based on the result from distance geometric mean algorithm conducted in Biomapper v.3.1, pseudo-absence data points are generated in areas with suitability lower than 10. The pseudo-absences combined with the true-presences from the Biodiversity Survey are then used to compute two types of regression models, namely, the BLRM and GAM. The former one is conducted in SPSS® 13.0 for Windows while the results of prediction are calibrated in IDRISI v.14.02. The later one is performed in S-Plus v.6.2 with GRASP v.3.0 module. Constrained by the small samples as well as the lack of independent dataset, the model validation is computed based on the training dataset. The results from two regression models are compared for their reliability and discriminatory ability statistically through deviance reduction (R), ROC plot and leave-one-out cross validation. The better model is then chosen to represent the probability distribution of each species. Finally, the species are grouped into the five taxonomic groups – amphibian, bird, butterfly, dragonfly and mammal to form the taxonomic-grouped richness maps. The groups are compared for their overlap areas in order to explore their representativeness for other taxonomic groups. After that, the overall species diversity is calculated by combing the taxonomic-grouped maps which act as a guide in selecting conservation areas in subsequent analysis. Finally, Gap analysis is conducted to identify possible under-protected areas.

Multi-Criteria Analysis (MCA) is used to select sites that are potentially suitable for four compatible tourism activities including camping, hiking, cycling and picnicking, and tourism facilities development. For each individual activity, constraints and factors are specified prior to analysis; factors are then standardized using fuzzy membership function; followed by design of weights through AHP pairwise comparison; and finally, factors and weights are combined through Simple Additive Weighting Method. The pixels with the highest overall score are regarded as the sites highly suitable for that particular activity. The results are compared with the existing and proposed tourism-related activities in Lantau.

The final part of the study concerns the formulation of a zoning plan for Lantau Island using Multi-Land Allocation Analysis (MOLA). The zoning plan consists of four major zones – Sanctuary, Nature Conservation, Outdoor Recreation and Tourism Development. An extra 100-meter buffer zone is added to the sanctuary and nature conservation areas to separate them from disturbance. Three scenarios are simulated through the adjustment of weight and areal allocation to each objective in order to form a range of pictures from conservation-oriented to recreation-oriented. The results from MCA and MOLA are compared and evaluated the proposals in the Concept Plan for Lantau.

CHAPTER 4 RESULTS and DISCUSSION (I) – MULTIVARIATE STATISTICAL WILDLIFE HABITAT MAPPING AND BIODIVERSITY HOTSPOTS IDENTIFICATION

4.1 Introduction

This chapter reveals the results of habitat modeling from the three statistical models – (1) Ecological Niche Factor Analysis (ENFA); (2) Binary Logistic Regression Model (BLRM); and (3) Generalized Additive Model (GAM). First, the independent variables (environmental predictors) are examined for the dependent variables (species maps) for their species range and correlation. Afterwards, the habitat modeling results from three statistical methods are revealed. The fifty species are grouped into five taxonomic groups including amphibian, bird, butterfly, dragonfly and mammal within which the statistical results are examined and summarized. Detailed statistical results for individual species are shown in Appendix 5 while the resultant distributional maps are shown in Appendix 6. Second, the models from the BLRM and GAM are tested and compared statistically for their reliability and discriminatory ability in terms of taxonomic group. The best model for each group are selected and then combined to form a species richness map representing the biodiversity hotspots in Lantau. Third, the species richness map is evaluated for its representativeness by taxonomic group overlap analysis. And finally, possible "gaps" are identified in existing protection system through Gap Analysis.

4.2 Data Exploration

Prior to the modeling, the ranges of occurrence for each predictor as well as the correlation among predictors are revealed. After generating pseudo-absences from results of ENFA, the mean and standard deviation of presence and absence of each species are tested for their statistical differences by non-parametric Mann-Whitney U-test. The results are shown in Appendix 3. All in all, some factors are not significantly different ($p>0.05$) with reference to individual species. The problem is either inherited in the presence data of the biodiversity survey or due to the selection of pseudo-absence data. Referring to the latter problem, although generation of another set of data point is possible, any set of pseudo-absence data point with statistical significant difference from the presence in terms of all the predictors is not guaranteed.

4.3 Identification of Habitat for Amphibian Species

In the whole territory of Hong Kong, 24 amphibian species are recorded which accounts for 8 percent of the total number of amphibian species in China (Chan *et al.*, 2005). They are classified into two groups – (1) the Caudata (tailed amphibian) and (2) the Anura (untailed amphibian) (Hong Kong Agriculture, Fisheries and Conservation Department, 2005a). In this study, all the eight species belong to the Anura. Among all the amphibian species in Hong Kong, only three species are legally protected under the Wild Animals Protection Ordinance (Cap. 170). The amphibian species action plans are implemented by AFCD to protect two most concerned species. The eight amphibian species in the modeled list are all outside the two conservation measures. However, native species inside Country Parks are protected by Country Parks Ordinance (Cap. 208) in which disturbance or collection are prohibited (Chan *et al.*, 2005).

Since the life mode of amphibians is intimately related to water, they are generally found in wide range of habitats associated with water throughout the Hong Kong territory including various kinds of forest, shrublands, low-lying grasslands, freshwater marshes, wet agricultural fields, upland mountain streams, catchwaters and fish ponds (Chan *et al.*, 2005). Some species are widespread in various habitats at all altitude, such as the Asian Common Toad (*B. melanostictus*), Brown Tree Frog (*P. megacephalus*), Gunther's Frog (*R. guentheri*) and Paddy Frog (*R. limnocharis*). Others are found in agricultural fields and marshes, for instance, the Asiatic Painted Frog (*K. pulchra*), Ornate Pigmy Frog (*M. ornata*) and Paddy Frog (*R. limnocharis*). The Lesser Spiny Frog (*R. exilispinosa*) is found in and near mountain streams.

4.3.1 Ecological Niche Factor Analysis (ENFA)

Table 4.1 shows the statistical summary of ENFA for the eight modeled amphibian species. Among the five groups, the amphibian group has the most abundant survey points from the biodiversity survey. The number of EGVs input is more flexible without producing negative eigenvalue through the conversion of EGVs into ecological-niche factors. According to the broken-stick advice, Lesser Spiny Frog (*R. exilispinosa*) selects ten ecological-niche factors which is the maximum within the group. Although Brown Tree Frog (*P. megacephalus*) has the highest survey point in the group, they together with Paddy Frog (*R. limnocharis*) and Günther's Frog (*R. guentheri*) retain only three ecological-niche factors.

The amount of information explained ranges from 70 % to 91% with an average and standard deviation of 79.8% and ±9.0% respectively. The overall living habitat is summarized by three statistics, namely global marginality (*M*), global tolerance (*T*) and global specialization (*S*). The difference between the species optimal living condition and the environmental conditions within the territory of Hong Kong is described by global marginality (*M*), Brown Tree Frog (*P. megacephalus*) is the most adaptive species reflected by the low $M = 0.35$. The majority of species tend to live in habitats which are moderately different from the mean conditions in the territory of Hong Kong (mean $M = 0.771 \pm 0.451$) with the exception of Green Cascade Frog (*R. livida*) ($M = 1.634$) and Lesser Spiny Frog (*R. exilispinosa*) ($M = 1.331$) which require an extremely special living environment. The range of living condition is explained by the global tolerance (*T*) or global specialization (*S*). Since the two statistics is reciprocal of one another, *T* is suggested for its easy interpretation by Hirzel (2005). The tolerance level of most species is quite high with the maximum 0.87 (*P. megacephalus*) and mean equal to 0.713 ± 0.177. Green Cascade Frog (*R. livida*) is the one with the lowest tolerance ($T = 0.302$). Together with the high *M*, *R. livida* is likely to be restricted to a specific range of living condition for which they are mostly different from background Hong Kong condition. In Appendix 5a, Table A5a.4, it reveals that the species is sensitive to shift away from their optimal condition in potential solar radiation, bareland frequency and woodland frequency as indicated by the high values in factor 2 (sp.1) and factor 3 (sp.2).

Table 4.1 Summary statistics of ENFA for the eight amphibian species

Species Scientific name	Common English name	No. of points from Bd. Survey	^{N}umber of input EGVs	^{N}umber of Ecological-niche Factors	$^{\#}$Amount of information *(variance)* explained (%)	$^{\Omega}$M	$^{\partial}$T	$^{\wedge}$S
Bufo melanostictus	Asian Common Toad	130	27	4	70 *(38.9)*	0.656	0.756	1.324
Kaloula pulchra	Asiatic Painted Frog	100	12	7	91 *(83)*	0.52	0.77	1.3
Polypedates megacephalus	Brown Tree Frog	271	13	3	71 *(42)*	0.35	0.87	1.15
Rana livida	Green Cascade Frog	48	27	4	91 *(82)*	1.634	0.302	3.309
Rana guentheri	Günther's Frog	209	13	3	73 *(46)*	0.49	0.82	1.22
Rana exilispinosa	Lesser Spiny Frog	129	27	10	87.7 *(75.5)*	1.331	0.656	1.525
Microhyla ornata	Ornate Pigmy Frog	103	13	4	81 *(63)*	0.65	0.75	1.33
Rana limnocharis	Paddy Frog	158	13	3	74 *(48)*	0.54	0.78	1.29

4.3.2 Binary Logistic Regression Model (BLRM)

Table 4.2 shows the statistical summary of BLRM for the eight amphibian species and Table 4.3 illustrates the predictors and corresponding coefficients (β_i) of the models. The amphibian is the family with the highest number of survey points among other families from the biodiversity survey which ranges from 48 to 259 for the eight chosen species. Lesser Spiny Frog *(R. exilispinosa*) and Paddy Frog (*R. limnocharis*) employ seven predictors which is the largest while the lowest is Green Cascade Frog (*R. livida*) with three only. Among the predictors selected by the eight species, woodland appears in seven species, followed by shrubby grassland and river which are found in six species. All the three factors are positively associated with the species which suggest that these three factors govern the distribution of most of the amphibian species in our models. Besides, river is always the factor with the highest explanatory power in the regression equations revealing that most amphibian species inhabit closely to constant water source. Moreover, four species react negatively towards slope steepness which suggests gentle slope is also important.

Regarding the Hosmer and Lemeshow goodness of fit test, all the regression equations are well-fitting except one species (*B. melanostictus*). The Nagelkerke R-squared shows the amount of variance explained varies from 66% (*P. megacephalus*) to 92% (*R. livida*) with a mean of 78%±11%. The distribution data of *R. lividia*, *R. exilispinosa*, *K. pulchra* and *R. limnocharis* have relatively strong association with the predictors while others are just moderate. The percentage of deviance reduction ranges from the lowest 49% to the highest 84%. Four species including *B. melanostictus*, *P. megacephalus*, *R. guentheri* and *M. ornata* have the percentage of deviance reduction around 50%. The mean deviance reduction of 64%±15% explains that the majority of logistic models do not fit the data well. The mean LOOCV classification accuracy with 0.5 as cutoff-threshold is 89%±5.5 with a range between 80% and 95%. The AUC from the ROC plot varies from 0.924 to 0.992 with mean equal to 0.958±0.028. The LOOCV suggests a moderate to high discriminatory ability while the AUC suggests that all the BLR models have good discriminatory ability.

Table 4.2 Summary statistics of BLRM for the eight amphibian species

Species Scientific name	Common English name	No. of points from Bd. Survey	No. of predictors	Extracted Model Summary					
				Hosmer and Lemeshow Goodness-of-Fit Test	Cox & Snell R^2	Nagelkerke R^2	% Deviance Reduction	ROC-AUC	LOOCV - Classification accuracy (%)
Bufo melanostictus	Asian Common Toad	130 (129)	10 (5)	p = 0.002	0.54	0.71	55%	0.942	80.0
Kaloula pulchra	Asiatic Painted Frog	100 (99)	6 (4)	p = 0.859	0.66	0.88	79%	0.984	93.9
Polypedates megacephalus	Brown Tree Frog	271 (259)	5	p = 0.795	0.50	0.66	49%	0.924	84.2
Rana livida	Green Cascade Frog	48 (48)	8 (3)	p = 0.246	0.69	0.92	84%	0.992	95.8
Rana guentheri	Günther's Frog	209 (207)	8 (5)	p = 0.550	0.51	0.68	51%	0.938	86.5
Rana exilispinosa	Lesser Spiny Frog	129 (128)	12 (6)	p = 0.692	0.67	0.90	81%	0.988	94.5
Microhyla ornata	Ornate Pigmy Frog	103 (100)	10 (5)	p = 0.502	0.51	0.68	51%	0.930	87.5
Rana limnocharis	Paddy Frog	158 (155)	10 (7)	p = 0.212	0.60	0.80	66%	0.965	90.3

Table 4.3 Predictors and corresponding coefficients (β_i) of BLRM selected for the eight amphibian species

Species Scientific name	Common English name	AUTU	BLDG	COAST	EAST	ELEV	MAIN ROAD	BARE	GRASS	MSHRUB	SH-GRASS	WOOD	PLAN	PRO-FILE	RAIL	RIVER	SLOPE	STREAM 100
Bufo melanostictus	Asian Common Toad				+1.37				-0.038			+0.109				+0.281	-0.049	
Kaloula pulchra	Asiatic Painted Frog		-0.006									-0.036				+3.96	-0.167	
Polypedates megacephalus	Brown Tree Frog		-0.006							+0.044	+0.017	+0.035				+0.591		
Rana livida	Green Cascade Frog		+0.04									+0.154				+1.151		
Rana guentheri	Günther's Frog					-0.011				+0.107	+0.034	+0.071				+0.586		
Rana exilispinosa	Lesser Spiny Frog					+0.014				+0.074	+0.073	+0.129				+0.638		+0.153
Microhyla ornata	Ornate Pigmy Frog					-0.006		+0.33			+0.3						-0.093	-0.181
Rana limnocharis	Paddy Frog				+0.969	-0.017				+0.148	+0.06	+0.104				+0.943	-0.187	

4.3.3 Generalized Additive Model (GAM)

Table 4.4 shows the summary statistics of GAM for the eight amphibian species. Table 4.5 lists the predictors selected for the GAMs. Among the eight species, Brown Tree Frog (*P. megacephalus*) employs the largest group of predictors of thirteen while Green Cascade Frog (*R. livida*) with two only. The predictors selected through AIC with potential solar radiation (AUTUMN) appears in eight species, followed by GRASS (seven species), MSHRUB and RIVER (six species). Variables such as distance-from-building and grassland show distinctive trend of association with species distribution. The negative response to both factors reveals that most amphibian species inhabit away from grassland and they are found also in urban areas.

Statistics show that Lesser Spiny Frog (*R. exilispinosa*) has the fittest model with the highest deviance reduction (97%). Except Asian Common Toad (*B. Melanostictus*) which has the lowest (70%) deviance reduction, all the models have deviance reduction over or nearly 80%. The relatively high average deviance reduction of 87%±9% suggests that the majority of species logistic models fit the data reasonably well. Models of *R. livida*, *R. exilispinosa* and *R. limnocharis* with deviance reduction over 90% are regarded as models of good reliability. The overall LOOCV classification accuracy with 0.5 as cut-off threshold are all over 90% with average of 95.5%±3.2%. As for the threshold-independent ROC, the simple one has a mean AUC of 0.994±0.009 while the one for cross-validated is 0.930±0.047. Both the LOOCV and AUC statistics show that the discriminatory ability of the models is extremely good. However, the model of Lesser Spiny Frog (*R. exilispinosa*) is the only species in the taxonomic group being considered as unstable owing to the difference between the two AUC values greater than or equal to 0.2.

Table 4.4 Summary statistics of GAM for the eight amphibian species

Species Scientific name	Common English name	No. of points from Bd. Survey	No. of predictors	Extracted Model Summary				
				% Deviance Reduction	Residual DF	cvROC	ROC	LOOCV - Classification Accuracy (%)
Bufo melanostictus	Asian Common Toad	130 (129)	13 (7)	70%	228.93	0.925	0.975	91.9
Kaloula pulchra	Asiatic Painted Frog	100 (99)	11 (6)	89%	173.32	0.933	1.000	97.5
Polypedates megacephalus	Brown Tree Frog	271 (259)	15 (13)	87%	463.77	0.966	0.995	91.5
Rana livida	Green Cascade Frog	48 (48)	12 (2)	96%	87.20	0.939	1.000	100.0
Rana guentheri	Günther's Frog	209 (207)	14 (9)	78%	377.92	0.959	0.986	93.2
Rana exilispinosa	Lesser Spiny Frog	129 (128)	14 (8)	97%	223.59	0.821	1.000	99.2
Microhyla ornata	Ornate Pigmy Frog	103 (100)	12 (7)	87%	171.61	0.928	0.995	95.5
Rana limnocharis	Paddy Frog	158 (155)	13 (9)	92%	279.94	0.966	0.999	94.8

Table 4.5 Predictors selected by AIC for GAM models of the eight amphibian species

Species Scientific name	Common English name	AUTU	BLDG	COAST	EAST	ELEV	MAIN ROAD	BARE	GRASS	MSHRUB	SH-GRASS	WOOD	PLAN	PRO-FILE	RAIL	RIVER	SLOPE	STREAM 100
Bufo melanostictus	Asian Common Toad	√			√		√		√	√						√		√
Kaloula pulchra	Asiatic Painted Frog	√	√		√		√		√		√							
Polypedates megacephalus	Brown Tree Frog	√	√	√	√	√	√	√	√		√		√	√	√	√		
Rana livida	Green Cascade Frog	√							√									
Rana guentheri	Günther's Frog	√	√	√	√			√	√	√	√					√		
Rana exilispinosa	Lesser Spiny Frog	√		√		√	√	√	√	√						√		
Microhyla ornata	Ornate Pigmy Frog	√	√	√				√		√	√					√		
Rana limnocharis	Paddy Frog	√	√					√	√	√	√		√		√	√		

4.4 Identification of Habitat for Bird Species

Hong Kong has 465 bird species which comprise over thirty percent of total species recorded in China (Hong Kong Agriculture, Fisheries and Conservation Department, 2005b). The diversified sub-tropical environments and habitats have supported not only a large number of resident species, but also migrating birds and passage migrants. A comprehensive breeding bird survey was carried out in the period 1993-1996 with a view to build up an inventory for Hong Kong bird species (Carey, 2001). Apart from individual species data, the survey has also identified and ranked individual and overall species diversity of the territory.

All the modeled species are protected under the Wild Animals Protection Ordinance (Cap. 170) in Hong Kong. The Black Kit (*M. migrans*) is listed in the protection of endangered species ordinance (Cap. 187). According to Hong Kong breeding bird survey, nine of the model species are regarded as the twenty most widespread breeding birds in Hong Kong. Arranging in descending rank order, they are Chinese Bulbul (*P. sinensis*), Crested Bulbul (*P. jocosus*), Common Tailorbird (*O. sutorius*), Spotted Dove (*S. chinensis*), Japanese White-eye (*Z. japonica*), Black Kite (*M. migrans*), Great Tit (*P. major*), Rufous-backed Shrike (*L. schach*) and Greater Coucal (*C. sinensis*). Except *L. schach*, the other eight birds are also regarded as the most common breeding bird in urban areas (Carey, 2001).

Since the species are mostly common and widespread, they tend to tolerate and adapt to a wide variety of habitats from rural to urban landuses. However, each of them has specific habitat preference and level of tolerance. Apart from the eight common urban breeding birds, Little Egret (*E. garzetta*) and White-breasted Waterhen (*A. phoenicurus*) are well adapted to the urban settings and human disturbance; Violet Whistling Thrush (*M. caeruleus*) is also commonly found in urban parks, gardens and cultivated lands. Besides, Many species such as the Great Tit (*P. major*), Japanese White-eye (*Z. japonica*), Jungle Crow (*C. macrorhynchus*), Greater Coucal (*C. sinensis*) and Spotted Dove (S. chinensis) are found in fung shui woodlands while Crested Bulbul (*P. jocosus*), Jungle Crow (*C. macrorhynchus*) and Rufous-backed shrike (*L. schach*) are absent from closed woodlands and shrublands (Strange, 1998; Carey, 2001; Hong Kong Agriculture, Fisheries and Conservation Department, 2005b). Furthermore, some species like Little Egret (*E. garzetta*), Black Kite (*M. migrans*), Greater Coucal (*C. sinensis*), Japanese White-eye (*Z. japonica*) and White-breasted Waterhen (*A.phoenicurus*) are found in wetland habitats such as mangroves, inter-tidal mudflats, fish ponds while Rufous-backed Shrike (*L. schach*) stays away from them. Moreover, Black Kite (*M. migrans*) and Great Tit (*P. major*) adapts to all altitude while Common Tailorbird (*O. sutorius*) and Japanese White-eye (*Z. japonica*) tend to be limited to an altitude of 700m and 650m respectively (Carey, 2001).

4.4.1 Ecological Niche Factor Analysis (ENFA)

Table 4.6 shows the statistical summary of ENFA for the thirteen bird species. Since the number of survey point for the bird group is not very large, the number of EGVs input is quite restrictive (all have sixteen input EGVs). According to the broken-stick advice, Great Tit (*P. major*) selects the maximum amount of ecological-niche factors (eleven) while the minimum number of factors (two) is retained by Black Kite (*M. migrans*) and Violet Whistling Thrush (*M. caeruleus*) within the group.

The amount of information explained ranges from 71.3% to 98.5% with an average and standard deviation of 85.8%±9.2%.The overall living habitat is summarized by three statistics, namely global marginality (*M*), global tolerance (*T*) and global specialization (*S*). According to *M* which describes the difference between the species optimal living condition and the environmental conditions within the territory of Hong Kong, Spotted Dove (*S. chinensis*) is the most adaptive species to the environment of Hong Kong reflected by the lowest *M* = 0.473 in the group. The majority of species tend to inhabit in environment moderately different from the mean conditions in the territory of Hong Kong (mean *M* = 0.610±0.095). The range of living condition explained by the global tolerance (*T*) has the overall mean and standard deviation of 0.568±0.202, which is just moderately tolerant. Chinese Bulbul (*P. sinensis*) has the highest tolerance level (0.809), which suggests that the species tends to live in general range of living conditions. Little Egret (*E. garzetta*) has the lowest tolerance (T =

0.16), which reveal that the species is likely to be restricted to a very specific range of living condition. In Appendix 5a, Table A5a.17, *E. garzetta* is sensitive to shift away from the optimal conditions of grass frequency, east-facing aspect, and woodland frequency (factor 2) as well as distance from railway, shrubby grassland frequency and elevation (factor 3).

Table 4.6 Summary statistics of ENFA for the thirteen bird species

Species Scientific name	Common English names	No. of points from Bd. Survey	^{N}umber of input EGVs	^{N}umber of Ecological-niche Factors	$^{\#}$Amount of information *(variance)* explained (%)	$^{\Omega}$M	$^{\partial}$T	$^{\wedge}$S
Milvus migrans	Black Kite	67	16	2	71.3 *(42.6)*	0.553	0.604	1.655
Pycnonotus sinensis	Chinese Bulbul	97	16	3	71.6 *(43.2)*	0.511	0.809	1.236
Orthotomus sutorius	Common Tailorbird	86	16	10	93.7 *(87.5)*	0.696	0.677	1.477
Pycnonotus jocosus	Crested Bulbul	92	16	5	81.1 *(62.2)*	0.623	0.748	1.337
Parus major	Great Tit	59	16	11	95 *(90)*	0.683	0.673	1.486
Centropus sinensis	Greater Coucal	46	16	3	86.9 *(73.8)*	0.602	0.433	2.31
Zosterops japonicus	Japanese White-eye	79	16	4	74.7 *(49.4)*	0.525	0.755	1.325
Corvus macrorhynchus	Jungle Crow	47	16	3	82.7 *(65.5)*	0.656	0.54	1.85
Egretta garzetta	Little Egret	25	16	4	98.5 *(97)*	0.639	0.16	6.243
Lanius schach	Rufous-backed shrike	44	16	6	91.6 *(83.1)*	0.639	0.476	2.1
Streptopelia chinensis	Spotted Dove	82	16	10	92.2 *(84.5)*	0.473	0.77	1.299
Myiophoneus caeruleus	Violet Whistling Thrush	47	16	2	83.2 *(66.5)*	0.815	0.486	2.058
Amaurornis phoenicurus	White-breasted Waterhen	25	16	3	93.2 *(86.3)*	0.511	0.251	3.98

4.4.2 Binary Logistic Regression Model (BLRM)

Table 4.7 summarizes the statistics of BLRM and Table 4.8 shows the predictors and corresponding coefficients (β_i) of BLRM selected for the thirteen bird species. Since the maximum number of sample points from the survey provided for chosen bird species was only 74 while the lowest was 19 only, the number of predictors can be used for modeling was limited. *O. sutorius* had the highest number of predictor (5) while Little Egret (*E. garzetta*) and White-breasted Waterhen (*A. phoenicurus*) had the lowest (2). Among the predictors selected for thirteen bird species, woodland appears to be the most frequently-chosen one (seven species), followed by grassland (6 species). For the seven species, they are all positively related to woodland which indicates that woodland is the preferable habitat type for most of the modeled birds. While for grassland, they are all negatively associated with the six bird species suggesting that grassland is not a favourable habitat for the birds.

With reference to the Hosmer and Lemeshow goodness of fit test, all the regression equations are well-fitting except one, *P. sinensis*. According to the Nagelkerke R-squared, the amount of variance explained varies from 44% (*A. phoenicurus*) to 87% (*P. jocosus*) with the mean of 72%±11%. The distribution data of *P. jocosus*, *C. sinensis*, *M. migrans* and *E. garzetta* have relatively strong association with the predictors while others are just moderate. The percentage of deviance reduction ranges from the lowest 29% to the highest 76%. Six species including *P. sinensis*, *C. macrorhynchus*, *L. schach*, *S.*

chinensis, *M. caeruleus* and *A. phoenicurus* with the percentage of deviance reduction stay around only 50% while the mean is 57%±12%. The low deviance reduction reveals that the logistic models do not fit the data well. The mean LOOCV classification accuracy of the taxonomic group with 0.5 as cutoff-threshold is 88%±5% and ranges from 76% to 96%. The AUC from the ROC plot varies from 0.848 to 0.975 with mean AUC of 0.933±0.035. BLR models of *L. schach* and *A. phoenicurus* have reasonable discriminatory ability while others have high discriminatory ability.

Table 4.7 Summary statistics of BLRM for the thirteen bird species

Species Scientific name	Common English names	No. of points from Bd. Survey	No. of predictors	Extracted Model Summary					
				Hosmer and Lemeshow Goodness-of-Fit Test	Cox & Snell R^2	Nagel-kerke R^2	% Deviance Reduction	ROC - AUC	LOOCV - Classification accuracy (%)
Milvus migrans	Black Kite	67 (44)	11 (3)	p = 0.845	0.60	0.80	66%	0.951	92.0
Pycnonotus sinensis	Chinese Bulbul	97 (74)	10 (4)	p = 0.022	0.52	0.69	53%	0.929	89.9
Orthotomus sutorius	Common Tailorbird	86 (69)	8 (5)	p = 0.620	0.58	0.77	63%	0.960	89.9
Pycnonotus jocosus	Crested Bulbul	92 (72)	13 (3)	p = 0.926	0.65	0.87	76%	0.975	95.8
Parus major	Great Tit	59 (52)	10 (2)	p = 0.863	0.56	0.74	59%	0.941	88.5
Centropus sinensis	Greater Coucal	46 (32)	11 (2)	p = 0.758	0.62	0.82	69%	0.966	90.6
Zosterops japonicus	Japanese White-eye	79 (64)	9 (2)	p = 0.575	0.56	0.75	59%	0.954	89.1

Corvus macrorhynchus	Jungle Crow	47 (36)	6 (1)	p = 0.064	0.53	0.71	54%	0.905	87.5
Egretta garzetta	Little Egret	25 (19)	6 (2)	p = 0.647	0.60	0.80	67%	0.964	92.1
Lanius schach	Rufous-backed shrike	44 (31)	8 (3)	p = 0.225	0.47	0.62	46%	0.903	83.9
Streptopelia chinensis	Spotted Dove	82 (64)	12 (4)	p = 0.369	0.51	0.68	51%	0.927	88.3
Myiophoneus caeruleus	Violet Whistling Thrush	47 (33)	10 (2)	p = 0.906	0.46	0.61	44%	0.908	81.8
Amaurornis phoenicurus	White-breasted Waterhen	25 (19)	8 (1)	p = 0.477	0.33	0.44	29%	0.848	76.3

Table 4.8 Predictors and corresponding coefficients (β_i) of BLRM selected for the thirteen bird species

Species Scientific name	Common English name	AUTU	BLDG	COAST	EAST	ELEV	MAIN ROAD	BARE	GRASS	MSHRUB	SH-GRASS	WOOD	PLAN	PRO-FILE	RAIL	RIVER	SLOPE	STREAM 100
Milvus migrans	Black Kite				+1.733							+0.126				-0.731		
Pycnonotus sinensis	Chinese Bulbul						+0.001			+0.075	+0.049	+0.086						
Orthotomus sutorius	Common Tailorbird					+0.009					+0.079	+0.113				-0.52		-0.163
Pycnonotus jocosus	Crested Bulbul								-0.141	+0.572							+0.16	
Parus major	Great Tit					+0.013						+0.098						
Centropus sinensis	Greater Coucal				+2.944				-0.268									
Zosterops japonicus	Japanese White-eye										+0.077	+0.158						
Corvus macrorhynchus	Jungle Crow											+0.136						
Egretta garzetta	Little Egret					-0.016			-0.191									
Lanius schach	Rufous-backed shrike			-0.001					-0.085	+0.137								
Streptopelia chinensis	Spotted Dove									+0.104	+0.046	+0.054					+0.067	
Myiophoneus caeruleus	Violet Whistling Thrush								-0.087								+0.129	
Amaurornis phoenicurus	White-breasted Waterhen								-0.123									

4.4.3 Generalized Additive Model (GAM)

Table 4.9 shows the summary statistics of GAM and Table 4.10 shows the predictors selected for GAM models of thirteen bird species. Of the thirteen bird species, Common Tailorbird (*O. sutorius*) and Violet Whistling Thrush (*M. caeruleus*) select nine predictors in their models while Little Egret (*E. garzetta*) and White-breasted Waterhen (*A. phoenicurus*) retain three only. Grassland (GRASS) appears in eleven species through AIC selection, followed by MSHRUB (eight species), AUTUMN (seven species) and BLDG and RIVER (six species). The prominent negative response to GRASS illustrates that almost all bird species tend not to select grassland as their habitat.

Greater Coucal (*C. sinensis*) has the highest deviance reduction (99%) while Japanese White-eye (*Z. japonicus*) has the lowest (73%). Apart from C. sinensis, six other models including *M. migrans*, *O. sutorius*, *C. macrorhynchus*, *E. garzetta*, *L. schach* and *M. caeruleus* have percentage of deviance reduction all over 90%. The mean deviance reduction of 89%±9% suggests that the logistic models fit the species data quite well. The overall LOOCV classification accuracy with 0.5 as cut-off threshold are all over 90% with five species get 100% and the average is 97.6%±2.9%. The threshold-independent ROC shows that the simple one has mean AUC of 0.996±0.008 and the mean cross-validated AUC is 0.847±0.056. The LOOCV suggests that the models have high discriminatory ability. Although the simple AUC is very high, the relatively low cross-validated AUC reveals only reasonable discrimination between presence and absence. Besides, six out of thirteen species have 0.2 or larger discrepancy between two AUC statistics including Greater Coucal (*C. sinensis*), Jungle Crow (*C. macrohynchus*), Little Egret (*E. garzetta*), Rufous-backed shrike (*L. schach*), Violet Whistling Thrush (*M. caeruleus*) and White-breasted Waterhen (*A. phoenicurus*). The models of these species are regarded as unstable.

Table 4.9 Summary statistics of GAM for the thirteen bird species

Species Scientific name	**Common English names**	**No. of points from Bd. Survey**	**No. of predictors**	**Extracted Model Summary**				
				% Deviance Reduction	**Residual DF**	**cvROC**	**ROC**	**LOOCV - Classification Accuracy (%)**
Milvus migrans	Black Kite	67 (44)	12 (6)	95%	63.6	0.853	1.000	98.9
Pycnonotus sinensis	Chinese Bulbul	*97 (74)*	13 (6)	86%	123.34	0.919	0.996	96.6
Orthotomus sutorius	Common Tailorbird	*86 (69)*	12 (9)	92%	101.65	0.876	1.000	100.0
Pycnonotus jocosus	Crested Bulbul	92 (72)	13 (4)	86%	127.46	0.936	0.992	96.5
Parus major	Great Tit	59 (52)	12 (5)	74%	83.49	0.873	0.989	91.3
Centropus sinensis	Greater Coucal	46 (32)	11 (4)	99%	47.54	0.777	1.000	100.0
Zosterops japonicus	Japanese White-eye	79 (64)	12 (5)	73%	107.58	0.917	0.973	93.8
Corvus macrorhynchus	Jungle Crow	47 (36)	13 (5)	96%	51.42	0.829	1.000	100.0
Egretta garzetta	Little Egret	25 (19)	8 (3)	96%	25.429	0.820	1.000	100.0
Lanius schach	Rufous-backed shrike	44 (31)	13 (5)	98%	41.48	0.761	1.000	100.0
Streptopelia chinensis	Spotted Dove	82 (64)	13 (8)	84%	94.06	0.849	0.995	94.5
Myiophoneus caeruleus	Violet Whistling Thrush	47 (33)	12 (6)	94%	41.68	0.789	1.000	100.0
Amaurornis phoenicurus	White-breasted Waterhen	25 (19)	10 (3)	87%	25.25	0.816	1.000	97.4

Table 4.10 Predictors selected by AIC for GAM models of thirteen bird species

Species Scientific name	Common English name	AUTU	BLDG	COAST	EAST	ELEV	MAIN ROAD	BARE	GRASS	MSHRUB	SH-GRASS	WOOD	PLAN	PRO-FILE	RAIL	RIVER	SLOPE	STREAM 100
Milvus migrans	Black Kite	√	√		√				√				√			√		
Pycnonotus sinensis	Chinese Bulbul		√				√		√	√						√		√
Orthotomus sutorius	Common Tailorbird		√		√		√	√	√	√	√					√		√
Pycnonotus jocosus	Crested Bulbul	√							√	√								√
Parus major	Great Tit	√						√	√	√	√							
Centropus sinensis	Greater Coucal							√	√		√					√		
Zosterops japonicus	Japanese White-eye	√	√		√				√	√								
Corvus macrorhynchus	Jungle Crow	√	√	√					√									√
Egretta garzetta	Little Egret				√				√									√
Lanius schach	Rufous-backed shrike		√	√						√					√	√		
Streptopelia chinensis	Spotted Dove	√						√	√	√	√		√	√		√		
Myiophoneus caeruleus	Violet Whistling Thrush	√		√			√		√	√				√				
Amauromis phoenicurus	White-breasted Waterhen			√			√	√										

4.5 Identification of Habitat for Butterfly Species

Hong Kong has 239 butterfly species which accounts for 15 percent of the total species recorded in China (Chou, 1994; Lo and Hui, 2004). The abundance of butterfly species is apparently related to the favourable subtropical climates with plenty of rainfall and non-extreme temperature range (Young and Yiu, 2002). In terms of family, Hong Kong has 10 butterfly families when compared with 17 and 12 in the world and China respectively (Chou, 1994). The twelve modeled species are from six families including Satyridae, Pieridae, Papilionidae, Lycaenidae, Nymphalidae and Riodinidae. All the modeled species are common in Hong Kong with no protection by the Wild Animals Protection Ordinance (Cap. 170) as well as Endangered Species Ordinance (Cap. 187).

The butterflies generally prefer sites adjacent to woodlands, shrublands and agricultural fields which are open with plenty of sunshine rather than permanently shaded forest and windy areas (Lo and Hui, 2004; Hong Kong Agriculture, Fisheries and Conservation Department, 2005c). Fung Shui Woodlands next to villages are also ideal breeding sites for common and rare butterfly species (Young and Yiu, 2002). Generally, species occur in densely vegetated lands are Common Evening Brown (*M. leda leda*), Great Orange Tip (*H. glaucippe glaucippe*), Yellow Orange Tip (*I. pyrene pyrene*) and Great Mormon (*P. memnon agenor*). Many species including Common Gull (*C. nerissa nerissa*), Common Mime (*C. clytia clytia*), Common Mormon (*P. polytes polytes*) and Paris Peacock (*P. paris paris*) prefer woodland and shrubland edges. Some of them have adapted to proximity to human habitation such as urban parks and agricultural fields, they are Common Gull (*C. nerissa nerissa*), Common White (*P. canidia canidia*), Great Mormon (*P. memnon agenor*), Pale Grass Blue (*Z. maha serica*), Peacock Pansy (*J. almana almanac*) and Yellow Orange Tip (*I. pyrene pyrene)*.

4.5.1 Ecological Niche Factor Analysis (ENFA)

Table 4.11 shows the statistical summary of ENFA for the twelve butterfly species. For all species in the butterfly group, twenty-six original EGVs are input. Half of the species determine the number of ecological-niche factor based on the broken-stick advice. For the remaining half, since the advice from broken-stick can only retain factors producing a low explained information, extra factors are deliberately retained to keep the information explained higher than 70%. These species include Common Mormon (*P. polytes polytes*), Great Mormon (*P. memnon agenor*), Pale Grass Blue (*Z. maha serica*), Paris Peacock (*P. paris paris*), Peacock Pansy (*J. almana almana*) and Plum Judy (*A. echerius echerius*). Under the column "Number of Ecological-niche Factors", the figure in blanket is the number of advised retained factors while another one is the number of ultimately kept factors. Great Orange Tip (*H. glaucippe glaucippe*) retains eight factors and Yellow Orange Tip (*I. pyrene pyrene*) keep four, which is regarded as the maximum and minimum number of factors within the group respectively.

The amount of information explained ranges from 70.9% to 92.8% with an average and standard deviation of 77%±7.4%. According to global marginality (*M*) which compares the difference between the species optimal living condition and the environmental conditions within the territory of Hong Kong, the majority of species tend to inhabit in environment moderately different from the mean conditions in the territory of Hong Kong (mean $M = 0.652 \pm 0.060$). The range of living condition is quite high explained by the global tolerance (*T*) with the overall mean and standard deviation of 0.677±0.180. Plum Judy (*A. echerius echerius*) has the highest tolerance level ($T = 0.811$), which suggests that the species tends to live in general range of living conditions. Yellow Orange Tip (*I. pyrene pyrene*) has the lowest tolerance ($T = 0.24$), which suggests that the species is restricted to limited range of living condition. In Appendix 5, Table A5a.33, *I. pyrene pyrene* is sensitive to shift away from the optimal values of planimetric curvature, elevation, eastness, slope and woodland frequency in factor 2 (sp.1) as well as potential solar radiation and border length of shrubby grassland in factor 3 (sp.2).

Table 4.11 Summary statistics of ENFA for the twelve butterfly species

Species Scientific name	Common English names	No. of points from Bd. Survey	^{N}umber of input EGVs	^{N}umber of Ecological-niche Factors	$^{\#}$Amount of information *(variance)* explained (%)	$^{\Omega}$M	^{a}T	$^{\wedge}$S
Melanitis leda leda	Common Evening Brown	94	26	6	78 *(56)*	0.711	0.702	1.424
Cepora nerissa nerissa	Common Gull	38	26	5	89.3 *(78.6)*	0.638	0.369	2.71
Chilasa clytia	Common Mime	82	26	5	73.6 *(47.2)*	0.664	0.708	1.413
Papilio polytes polytes	Common Mormon	182	26	**5 (2)**	71.8 *(43.6)*	0.598	0.797	1.255
Pieris canidia canidia	Common White	131	26	5	72.7 *(45.3)*	0.652	0.762	1.312
Papilio memnon agenor	Great Mormon	129	26	**5 (2)**	70.9 *(41.9)*	0.58	0.766	1.305
Hebomoia glaucippe glaucippe	Great Orange Tip	86	26	8	83 *(65.9)*	0.579	0.712	1.405
Zizeeria maha serica	Pale Grass Blue	104	26	**5 (4)**	72.5 *(45.1)*	0.61	0.756	1.322

Papilio paris paris	Paris Peacock	143	26	**5 (4)**	71.5 *(43)*	0.653	0.802	1.247
Junonia almana almana	Peacock Pansy	95	26	**5 (2)**	75.3 *(50.6)*	0.756	0.696	1.436
Abisara echerius echerius	Plum Judy	142	26	**6 (3)**	72.8 *(45.6)*	0.63	0.811	1.233
Ixias pyrene pyrene	Yellow Orange Tip	32	26	4	92.8 *(85.7)*	0.75	0.24	4.171

4.5.2 Binary Logistic Regression Model (BLRM)

Table 4.12 summarizes the statistics of BLRM and Table 4.13 shows the predictors and corresponding coefficients (β_i) of BLRM selected for the twelve butterfly species. The number of survey points ranges from 29 to 168 for the twelve butterfly species. Common White (*P. canidia canidia*) selects seven predictors which is the highest. Owing to the low number of sample points from the survey, Yellow Orange Tip (*I. pyrene pyrene*) retains only one variable. Among the predictors retained by the twelve species, shrubby grassland appears in eleven species, followed by woodland in ten species and mixed shrubland in nine species. They are all positively-related to the occurrence of the species which suggests that most species do not have a preference on specific vegetation types. Besides, two predictors – 'distance to building' and 'elevation' appear in seven species. Although their explanatory power is not very high (low coefficient value) in the regression equations, they indicate some potential characteristics for the species. For example, the negative response to building distance suggests that the species are commonly found in urban areas. And the elevation reveals the altitude limit for the species.

According to the Hosmer and Lemeshow goodness of fit test, all equations except three (*P. polytes polytes*, *P. memnon agenor* and *A. echerius echerius*) are well-fitting. The Nagelkerke R-squared which shows the amount of variance explained varies from 42% (*C. clytia*) to 91% (*M. leda leda*) with mean of 73%±14%. The distribution data of *M. leda leda*, *P. paris paris*, *I. pyrene*

pyrene and *A. echerius echerius* have relatively strong association with the predictors while others are just moderate. The percentage of deviance reduction ranges from the lowest 27% to the highest 83%. Half of the twelve species including *C. nerissa nerissa*, *C. clytia*, *P. canidia canidia*, *P. memnon agenor*, *H. glaucippe glaucippe* and *J. almanac almanac* have the percentage of deviance reduction around 50% while the mean is 59%±16%. The overall low deviance reduction suggests that the majority of logistic models do not fit the data well. The mean LOOCV classification accuracy with 0.5 as cut-off threshold has the mean of 88%±5.3 and the range is within 79% to 94%. The AUC from the ROC plot varies from 0.851 to 0.991 with mean equal to 0.938±0.041. Both statistics suggest that the BLR models have moderate to high discriminatory ability between presence and absence.

Table 4.12 Summary statistics of BLRM for the twelve butterfly species

Species Scientific name	Common English names	No. of points from Bd. Survey	No. of predictors	Extracted Model Summary					
				Hosmer and Lemeshow Goodness-of-Fit Test	Cox & Snell R^2	Nagel-kerke R^2	% Deviance Reduction	ROC - AUC	LOOCV - Classification accuracy (%)
Melanitis leda leda	Common Evening Brown	94 (82)	11 (5)	p = 0.481	0.68	0.91	83%	0.991	93.9
Cepora nerissa nerissa	Common Gull	38 (34)	13 (4)	p = 0.198	0.47	0.63	46%	0.903	80.9
Chilasa clytia	Common Mime	82 (77)	11 (5)	p = 0.426	0.32	0.42	27%	0.851	79.2
Papilio polytes polytes	Common Mormon	182 (168)	13 (4)	p = 0.000	0.58	0.77	62%	0.963	90.8
Pieris canidia canidia	Common White	131 (123)	10 (7)	p = 0.313	0.41	0.55	39%	0.878	79.7
Papilio memnon agenor	Great Mormon	129 (119)	12 (4)	p = 0.002	0.55	0.73	57%	0.950	89.1
Hebomoia glaucippe glaucippe	Great Orange Tip	86 (81)	13 (3)	p = 0.768	0.55	0.73	58%	0.943	88.9
Zizeeria maha serica	Pale Grass Blue	104 (96)	13 (6)	p = 0.272	0.57	0.76	61%	0.952	90.6

Papilio paris paris	Paris Peacock	143 (133)	12 (6)	p = 0.650	0.65	0.87	76%	0.977	93.2
Junonia almana almana	Peacock Pansy	95 (87)	11 (6)	p = 0.312	0.55	0.73	57%	0.947	86.8
Abisara echerius echerius	Plum Judy	142 (128)	13 (5)	p = 0.020	0.60	0.80	66%	0.966	91.8
Ixias pyrene pyrene	Yellow Orange Tip	32 (29)	8 (1)	p = 0.843	0.62	0.83	71%	0.933	93.1

Table 4.13 Predictors and corresponding coefficients (β_i) of BLRM selected for the twelve butterfly species

Species Scientific name	Common English name	AUTU	BLDG	COAST	EAST	ELEV	MAIN ROAD	BARE	GRASS	MSHRUB	SH-GRASS	WOOD	PLAN	PRO-FILE	RAIL	RIVER	SLOPE	STREAM 100
Melanitis leda leda	Common Evening Brown		-0.028			+0.036				+0.264	+0.073	+0.437						
Cepora nerissa nerissa	Common Gull		-0.005			+0.018			-0.001		+0.002							
Chilasa clytia	Common Mime					-0.007	-0.001			+0.11	+0.028	+0.02						
Papilio polytes polytes	Common Mormon		-0.008							+0.191	+0.04	+0.091						
Pieris canidia canidia	Common White				+0.464	-0.003				+0.094	+0.021	+0.023				+0.867	-0.083	
Papilio memnon agenor	Great Mormon		-0.008							+0.088	+0.047	+0.096						
Hebomoia glaucippe glaucippe	Great Orange Tip		-0.008						-0.067		-0.04							
Zizeeria maha serica	Pale Grass Blue		-0.007		+0.894					+0.159	+0.023	+0.066				+0.552		
Papilio paris paris	Paris Peacock		-0.01			+0.016				+0.166	+0.029	+0.268				+0.342		
Junonia almana almana	Peacock Pansy					-0.01	-0.002			+0.286	+0.073	+0.076					-0.065	
Abisara echerius echerius	Plum Judy		-0.009			+0.013				+0.123	+0.036	+0.144						
Ixias pyrene pyrene	Yellow Orange Tip											+0.344						

4.5.3 Generalized Additive Model (GAM)

Table 4.14 shows the summary statistics of GAM and Table 4.15 lists the predictors selected for GAM models of twelve butterfly species. Of the twelve butterfly species, three species retain maximum amount of predictors (nine) in their models including Pale Grass Blue (*Z. maha serica*), Paris Peacock (*P. paris paris*) and Plum Judy (*A. echerius echerius*) while Common Gull (*C. nerissa nerissa*) and Common Mime (*C. clytia*) keep five which are regarded as the maximum and minimum within the group respectively. The predictors selected through AIC with distance-from-building (BLDG) as well as mixed shrubland (MSHRUB) appear in ten species, followed by RIVER and SHGRASS (eight species), GRASS (seven species) and ELEV and MAINROAD (six species). Distance-from-building shows distinctive trend of association with species distribution. The negative response to the factor explains that most butterfly species are commonly found in urban areas.

From statistical perceptive, the highest deviance reduction belongs to Yellow Orange Tip (*I. pyrene pyrene*) (100%) while Common Mime (*C. clytia*) has the lowest (69%). Apart from *I. pyrene pyrene*, six models of species including *M. leda leda*, *C. nerissa nerissa*, *p. canidia canidia*, *Z. maha serica*, *P. paris paris* and *J. almana almana* have percentage of deviance reduction all above or at 90%. The mean deviance reduction of 86%±10% reveals that the logistic models fit the species data quite well. The overall LOOCV classification accuracy with 0.5 as cut-off threshold are all over 90% with two species get

100% and the average is 97.2%±2.8%. The threshold-independent ROC shows that the simple one has mean AUC of 0.993±0.009 and the mean cross-validated AUC is 0.912±0.072. Both the LOOCV and AUC statistics suggest high discriminatory ability of all models. However, two species have 0.2 or larger discrepancy between two AUC values including Common Gull (*C. nerissa nerissa*) and Yellow Orange Tip (*I. pyrene pyrene*). The models of the two species are regarded as unstable.

Table 4.14 Summary statistics of GAM for the twelve butterfly species

Species Scientific name	Common English names	No. of points from Bd. Survey	No. of predictors	Extracted Model Summary				
				% Deviance Reduction	Residual DF	cvROC	ROC	LOOCV - Classification Accuracy (%)
Melanitis leda leda	Common Evening Brown	94 (82)	13 (6)	94%	139.56	0.953	1.000	98.8
Cepora nerissa nerissa	Common Gull	38 (34)	15 (5)	93%	47.64	0.846	1.000	100.0
Chilasa clytia	Common Mime	82 (77)	12 (5)	73%	133.29	0.898	0.980	93.5
Papilio polytes polytes	Common Mormon	182 (168)	14 (7)	76%	307.68	0.961	0.986	94.3
Pieris canidia canidia	Common White	131 (123)	12 (6)	90%	221.77	0.956	0.998	97.6
Papilio memnon agenor	Great Mormon	129 (119)	13 (6)	69%	213.45	0.936	0.976	91.6
Hebomoia glaucippe glaucippe	Great Orange Tip	86 (81)	13 (7)	84%	133.57	0.938	0.991	99.4
Zizeeria maha serica	Pale Grass Blue	104 (96)	14 (9)	92%	155.9	0.919	1.000	99.0

Papilio paris paris	Paris Peacock	143 (133)	13 (9)	90%	229.78	0.951	0.997	97.7
Junonia almana almana	Peacock Pansy	95 (87)	14 (6)	94%	149.53	0.959	1.000	98.9
Abisara echerius echerius	Plum Judy	142 (128)	14 (9)	82%	219.86	0.917	0.992	95.7
Ixias pyrene pyrene	Yellow Orange Tip	32 (29)	12 (6)	100%	34.97	0.707	1.000	100.0

Table 4.15 Predictors selected by AIC for GAM models of twelve butterfly species

Species Scientific name	Common English name	AUTU	BLDG	COAST	EAST	ELEV	MAIN ROAD	BARE	GRASS	MSHRUB	SH-GRASS	WOOD	PLAN	PRO-FILE	RAIL	RIVER	SLOPE	STREAM 100
Melanitis leda leda	Common Evening Brown	√	√		√	√				√								√
Cepora nerissa nerissa	Common Gull	√						√	√				√					√
Chilasa clytia	Common Mime		√					√	√	√						√		
Papilio polytes polytes	Common Mormon		√			√	√			√	√	√				√		
Pieris canidia canidia	Common White		√	√	√					√						√		√
Papilio memnon agenor	Great Mormon		√			√			√	√	√							√
Hebomoia glaucippe glaucippe	Great Orange Tip		√		√	√	√		√		√					√		
Zizeeria maha serica	Pale Grass Blue		√		√		√	√	√	√	√	√				√		
Papilio paris paris	Paris Peacock	√	√	√		√		√	√	√	√					√		
Junonia almana almana	Peacock Pansy		√				√			√	√	√				√		
Abisara echerius echerius	Plum Judy	√	√			√	√	√	√	√	√					√		
Ixias pyrene pyrene	Yellow Orange Tip				√		√			√	√					√		√

4.6 Identification of Habitat for Dragonfly Species

Hong Kong has recorded 111 dragonfly species since 1854 in which the first record was made (Wilson *et al.*, 2003; Hong Kong Agriculture, Fisheries and Conservation Department, 2005d). The thirteen modeled species cover six families out of fourteen found in Hong Kong. All the modeled dragonfly species are regarded as common in Hong Kong with no protection from the Wild Animals Protection Ordinance (Cap. 170) as well as Endangered Species Ordinance (Cap. 187).

Dragonflies are commonly found in mountain streams, rivers and ponds. For individual species, the habitat requirements vary. Among the thirteen species, the Black Threadtail (*R. autumnalis*), Green Skimmer (*O. sabina sabina*) and Yellow Featherlegs (*C. marginipes*) are widespread in Hong Kong. Species like the Black-banded Gossamerwing (*E. decorate*), Common Blue Jewel (*R. perforata perforata*), Emerald cascader (*Z. iris insignis*) and Indigo dropwing (*T. festiva*) occurs in fast flowing streams and rivers with strong current while the Common Red Skimmer (*O. pruinosum*) and Fiery Emperor (*A. immaculifrons*) prefers slow streams. Other species like Blue-forest Damsel (*C. cyanomelas*) which is shade-demanded and Wandering Glider (*P. flavescens*) which evades windy sites are commonly found in forests. Ponds and lakes attract *C. ciliate* (Black-kneed featherlegs), *O. pruinosum neglectum* (Common red skimmer), *T. aurora* (Crimson dropwing), *P. flavescens* (Wandering glider).

4.6.1 Ecological Niche Factor Analysis (ENFA)

Table 4.16 shows the statistical summary of ENFA for the thirteen dragonfly species. The number of survey point varies in the group; some species input twenty-six EGVs while others have sixteen. Wandering Glider (*P. flavescens*) is the only species has the amount of information explained lower than 70% when keeping the ecological-niche factors according to the broken-stick advice. So, three more factors are deliberately selected for the species. The remaining species retains the factors based on the broken-stick advice. Three species – Black-banded Gossamerwing (*E. decorate*), Common Red Skimmer (*O. pruinosum neglectum*) and Fiery Emperor (*A. immaculifrons*) retain ten factors and Black-kneed Featherlegs (*C. ciliate*) keeps four, which is regarded as the maximum and minimum number of factors within the group respectively.

The amount of information explained ranges from 71.2% to 96.9% with an average and standard deviation of 84.8%±7.1%. According to global marginality (*M*) which describes the difference between the species optimal living condition and the environmental conditions within the territory, the majority of species tend to inhabit in environment moderately different from the mean conditions in the territory of Hong Kong (mean M = 0.709±0.103) with the exception of Common Blue Jewel (*R. perforata perforate*) whose living condition is extremely different from the territory. The range of living condition is quite high as explained by the global tolerance (*T*) with the overall mean and standard deviation of

0.656±0.079. Wandering Glider (*P. flavescens*) has the highest tolerance level (*T* = 0.786), which suggests that the species tends to live in general range of living conditions. Fiery Emperor (*A. immaculifrons*) has the lowest tolerance (*T* = 0.491), which suggests that the species is restricted to limited range of living condition. In Appendix 5a, Table A5a.42 shows that *A. immaculifrons* is quite sensitive to shift away from the optimal condition of factors including stream frequency, woodland frequency and distance from main roads (sp.1) as well as distance from coast, elevation and river frequency (sp.2).

Table 4.16 Summary statistics of ENFA for the thirteen dragonfly species

Species Scientific name	Common English name	No. of points from Bd. Survey	^{N}umber of input EGVs	^{N}umber of Ecological-niche Factors	$^{\#}$Amount of information *(variance)* explained (%)	$^{\Omega}$M	$^{\partial}$T	ˆS
Prodasineura autumnalis	Black Threadtail	46	16	5	83.5 *(66.9)*	0.679	0.642	1.556
Euphaea decorata	Black-banded Gossamerwing	58	16	10	94 *(88)*	0.737	0.675	1.481
Copera ciliata	Black-kneed Featherlegs	41	16	4	82.2 *(64.3)*	0.675	0.605	1.654
Coeliccia cyanomelas	Blue Forest Damsel	39	16	6	88.2 *(76.4)*	0.711	0.608	1.644
Rhinocypha perforata perforata	Common Blue Jewel	56	26	7	82.7 *(65.5)*	0.918	0.635	1.576
Orthetrum pruinosum neglectum	Common Red Skimmer	71	16	10	93.2 *(86.3)*	0.56	0.776	1.288
Trithemis aurora	Crimson Dropwing	60	26	8	84.4 *(68.8)*	0.728	0.643	1.556
Zygonyx iris insignis	Emerald Cascader	44	16	5	83 *(66.1)*	0.634	0.687	1.456

Anax immaculifrons	Fiery Emperor	26	16	10	96.9 *(93.9)*	0.852	0.491	2.035
Orthetrum sabina sabina	Green Skimmer	70	26	6	77.4 *(54.7)*	0.567	0.725	1.379
Trithemis festiva	Indigo Dropwing	67	26	6	79 *(58)*	0.753	0.67	1.493
Pantala flavescens	Wandering Glider	107	26	**5 (2)**	71.2 *(42.5)*	0.627	0.786	1.272
Copera marginipes	Yellow Featherlegs	53	26	8	86.6 *(73.1)*	0.77	0.586	1.705

4.6.2 Binary Logistic Regression Model (BLRM)

Table 4.17 shows the summary statistics of BLRM while Table 4.18 shows the predictors and corresponding coefficients (β_i) of BLRM selected for the thirteen dragonfly species. The number of survey points ranges from 25 to 103 for the thirteen dragonfly species. Crimson Dropwing (*T. aurora*) and Yellow Featherlegs (*C. marginipes*) retain six predictors while Black-kneed Featherlegs (*C. ciliate*) and Fiery Emperor (*A. immaculifrons*) select two only. Twelve species retain woodland as their predictors; shrubby grassland, mixed shrubland and river were selected for ten species. The four predictors are all positively-related with the occurrence of the species within which the river variable is always the one with the highest explanatory power in the regression equations. It is observed that most of the modeled species responded towards various vegetation types except grassland. And constant water supply seems to be an important factor in affecting their distribution.

With respect to the Hosmer and Lemeshow goodness of fit test, all equations have insignificant probability value which suggests that the models are well-fitting. However, there is a large fluctuation on other statistics. With reference to the Nagelkerke R-squared, the amount of variance explained varies from 54% (*O. sabina sabina*) to 89% (*E. decorate* and *R. perforate perforata*) with a mean of 76%±12%. Apart from the two species with highest amount of variance explained, models of *P. autumnalis*, *C. ciliate*, *T. festiva* and *Z. iris insignis* shows relatively strong association between species and the predictors while others are just moderate. The percentage of deviance reduction ranges from the lowest 38% to the highest 80%. Six out of the thirteen dragonfly species including *O. pruinosum neglectum*, *T. aurora*, *A. immaculifrons*, *O. sabina sabina*, *P. flavescens* and *C. marginipes* with the percentage of deviance reduction stay around 50%. The low mean deviance reduction of 62%±15% suggests that the majority of the logistic models do not fit the data well. The mean LOOCV classification accuracy with 0.5 as threshold is 89%±4.9% and the range is 81% to 95%. As for the AUC from the ROC plot, the lowest is 0.881 while the highest is 0.986 with mean equal to 0.949±0.035. Both statistics suggest the BLR models of the dragonfly group have moderate to high discriminatory ability.

Table 4.17 Summary statistics of BLRM for the thirteen dragonfly species

Species Scientific name	**Common English name**	**No. of points from Bd. Survey**	**No. of predictors**	**Extracted Model Summary**					
				Hosmer and Lemeshow Goodness-of-Fit Test	**Cox & Snell R^2**	**Nagelkerke R^2**	**% Deviance Reduction**	**ROC - AUC**	**LOOCV - Classification accuracy (%)**
Prodasineura autumnalis	Black Threadtail	46 (46)	11 (5)	p = 0.513	0.66	0.88	78%	0.983	94.6
Euphaea decorata	Black-banded Gossamerwing	58 (57)	13 (5)	p = 0.976	0.67	0.89	79%	0.986	94.7
Copera ciliata	Black-kneed Featherlegs	41 (41)	10 (2)	p = 0.989	0.66	0.88	78%	0.978	93.9
Coeliccia cyanomelas	Blue Forest Damsel	39 (39)	8 (3)	p = 0.262	0.57	0.76	61%	0.948	92.3
Rhinocypha perforata perforata	Common Blue Jewel	56 (56)	12 (4)	p = 0.806	0.67	0.89	80%	0.984	94.6
Orthetrum pruinosum neglectum	Common Red Skimmer	71 (68)	14 (5)	p = 0.693	0.46	0.61	44%	0.908	83.8
Trithemis aurora	Crimson Dropwing	60 (58)	10 (6)	p = 0.533	0.52	0.69	53%	0.933	87.1
Zygonyx iris insignis	Emerald Cascader	44 (44)	7 (5)	p = 0.908	0.61	0.81	68%	0.969	92

Anax immaculifrons	Fiery Emperor	26 (25)	10 (2)	p = 0.546	0.55	0.74	58%	0.942	86
Orthetrum sabina sabina	Green Skimmer	70 (68)	8 (4)	p = 0.275	0.41	0.54	38%	0.881	80.9
Trithemis festiva	Indigo Dropwing	67 (66)	12 (4)	p = 0.953	0.63	0.84	72%	0.978	91.7
Pantala flavescens	Wandering Glider	107 (103)	12 (4)	p = 0.198	0.45	0.60	43%	0.903	83
Copera marginipes	Yellow Featherlegs	53 (53)	14 (6)	p = 0.721	0.55	0.74	58%	0.949	87.7

Table 4.18 Predictors and corresponding coefficients (β_i) of BLRM selected for the thirteen dragonfly species

Species Scientific name	Common English name	AUTU	BLDG	COAST	EAST	ELEV	MAIN ROAD	BARE	GRASS	MSHRUB	SH-GRASS	WOOD	PLAN	PRO-FILE	RAIL	RIVER	SLOPE	STREAM 100
Prodasineura autumnalis	Black Threadtail					-0.02				+0.308	+0.088	+0.165				+0.665		
Euphaea decorata	Black-banded Gossamerwing									+0.144	+0.092	+0.188				+0.7	-0.167	
Copera ciliata	Black-kneed Featherlegs											+0.248				+1.22		
Coeliccia cyanomelas	Blue Forest Damsel									+0.063		+0.066				+1.12		
Rhinocypha perforata perforata	Common Blue Jewel									+0.252	+0.078	+0.168				+0.622		
Orthetrum pruinosum neglectum	Common Red Skimmer		-0.004							+0.062	+0.049	+0.58				+0.239		
Trithemis aurora	Crimson Dropwing				+1.397					+0.146	+0.062	+0.062				+0.243	-0.085	
Zygonyx iris insignis	Emerald Cascader		-0.006							+0.157	+0.109	+0.162					-0.135	
Anax immaculifrons	Fiery Emperor							-2.385										+0.356
Orthetrum sabina sabina	Green Skimmer										+0.044	+0.075				+0.528	-0.059	
Trithemis festiva	Indigo Dropwing									+0.143	+0.054	+0.175				+0.44		
Pantala flavescens	Wandering Glider									+0.057	+0.064	+0.083						-0.111
Copera marginipes	Yellow Featherlegs		-0.005				-0.001			+0.091	+0.076	+0.104				+0.317		

4.6.3 Generalized Additive Model (GAM)

Table 4.19 shows the summary statistics of GAM and Table 4.20 lists the predictors selected by AIC for GAM models of thirteen dragonfly species. Among the twelve dragonfly species, Crimson Dropwing (*T. aurora*) keeps the maximum number of predictors (eight) while Black-kneed Featherlegs (*C. ciliate*) retain the minimum (three). The water resources (RIVER) being selected by eleven species is an important predictor to almost all the species, followed by MSHRUB (ten species), BLDG (nine species), MAINROAD (seven species) and GRASS (six species). The dominated negative response to BLDG reveals that most dragonfly species inhabit away from urban flora.

Statistics show that Black Threadtail (*P. autumnalis*) has the highest deviance reduction (100%) while Wandering Glider (*P. flavescens*) has the lowest (46%). Apart from *P. autumnalis*, four species models including *C. cyanomelas*, *R. perforata perforata*, *T. aurora* and *A. immaculifrons* have percentage of deviance reduction all over 90%. The mean deviance reduction of 83%±14% suggests that the logistic models fit the majority of species data well with the exception of *P. flavescens*. The overall LOOCV classification accuracy with 0.5 as cut-off threshold ranges from 86% to 100% and the average is 96.4%±4.3%. The threshold-independent ROC shows the simple one has a mean AUC of 0.987±0.024 and the mean cross-validated AUC is 0.872±0.048. The discriminatory ability of the majority of species is good while *P. flavescens* is just reasonable. In this taxonomic group, two species have 0.2 or larger discrepancy between two AUC statistics including Black Threadtail (*P. autumnalis*) and Blue Forest Damsel (*C. cyanomelas*). The two models are regarded as unstable.

Table 4.19 Summary statistics of GAM for the thirteen dragonfly species

Species Scientific name	Common English name	No. of points from Bd. Survey	No. of predictors	Extracted Model Summary				
				% Deviance Reduction	Residual DF	cvROC	ROC	LOOCV - Classification Accuracy (%)
Prodasineura autumnalis	Black Threadtail	46 (46)	13 (6)	100%	67.47	0.824	1.000	100.0
Euphaea decorata	Black-banded Gossamerwing	58 (57)	12 (6)	84%	89.83	0.880	0.994	96.5
Copera ciliata	Black-kneed Featherlegs	41 (41)	12 (3)	86%	69.27	0.908	0.995	96.3
Coeliccia cyanomelas	Blue Forest Damsel	39 (39)	12 (6)	91%	53.72	0.773	1.000	98.7
Rhinocypha perforata perforata	Common Blue Jewel	56 (56)	13 (6)	93%	87.6	0.877	1.000	99.1
Orthetrum pruinosum neglectum	Common Red Skimmer	71 (68)	13 (6)	64%	111.36	0.839	0.966	89.0
Trithemis aurora	Crimson Dropwing	60 (58)	14 (8)	93%	83.88	0.854	1.000	99.1
Zygonyx iris insignis	Emerald Cascader	44 (44)	12 (5)	83%	68.84	0.870	0.992	97.7

Anax immaculifrons	Fiery Emperor	26 (25)	12 (5)	95%	41.3	0.960	1.000	100.0
Orthetrum sabina sabina	Green Skimmer	70 (68)	12 (7)	85%	107.43	0.888	0.997	97.8
Trithemis festiva	Indigo Dropwing	67 (66)	13 (6)	84%	107.43	0.934	0.987	98.5
Pantala flavescens	Wandering Glider	107 (103)	12 (6)	46%	181.59	0.841	0.914	85.9
Copera marginipes	Yellow Featherlegs	53 (53)	13 (6)	75%	81.79	0.891	0.980	94.3

Table 4.20 Predictors selected by AIC for GAM models of thirteen dragonfly species

Species Scientific name	Common English name	AUTU	BLDG	COAST	EAST	ELEV	MAIN ROAD	BARE	GRASS	MSHRUB	SH-GRASS	WOOD	PLAN	PRO-FILE	RAIL	RIVER	SLOPE	STREAM 100
Prodasineura autumnalis	Black Threadtail		√					√		√					√	√		√
Euphaea decorata	Black-banded Gossamerwing		√			√	√		√		√					√		
Copera ciliata	Black-kneed Featherlegs		√							√						√		
Coeliccia cyanomelas	Blue Forest Damsel		√	√		√	√								√	√		
Rhinocypha perforata perforata	Common Blue Jewel					√	√	√		√	√					√		
Orthetrum pruinosum neglectum	Common Red Skimmer		√				√		√	√	√							√
Trithemis aurora	Crimson Dropwing	√	√			√	√			√			√		√	√		
Zygonyx iris insignis	Emerald Cascader		√				√		√		√					√		
Anax immaculifrons	Fiery Emperor								√	√								
Orthetrum sabina sabina	Green Skimmer		√	√			√	√		√	√					√		
Trithemis festiva	Indigo Dropwing	√		√		√			√	√						√		
Pantala flavescens	Wandering Glider			√				√	√	√						√		√
Copera marginipes	Yellow Featherlegs	√	√		√			√		√						√		

4.7 Identification of Habitat for Mammal Species

Hong Kong has 52 species of terrestrial mammals, which are broadly categorized into flying, small and large mammals. Out of the selected mammal species, three are rodent species within which two are local and small mammal species – the Chestnut Spiny Rat (*N. fulvescens*) and Sikkim Rat (*R. sikkimensis*) (Hong Kong Agriculture, Fisheries and Conservation Department, 2005e). The remaining rodent, the East Asian Porcupine (*H. brachyura*) and Eurasian Wild Pig (S. scrofa) are classified as large mammals. Mammal species are under continuous monitoring program by AFCD launched in 2001. Only one species in the modeled list is protected under the Wild Animals Protection Ordinance (Cap. 170) – the East Asian Porcupine (*H. brachyura*). This species is also listed as "vulnerable" in the IUCN Red List Status.

With diversified food sources, the range of habitats of mammals is so wide that distinctive or specific living habitat is not easily identified. Besides, there are scarce if not lack of well documents regarding the habitat for mammals. However, the two modeled rat species – *N. Fulvescens* and *R. sikkimensis* tend to inhabit everywhere from grassland to woodland (Dudgeon and Corlett, 2004).

4.7.1 Ecological Niche Factor Analysis (ENFA)

Table 4.21 shows the summary statistics of ENFA for the four mammal species. Chestnut Spiny Rat (*N. fulvescens*) is the only species that encounters negative eigenvalue with twenty-six EGVs are input. Therefore, the number of factors is reduced to sixteen. All the species retains the ecological-niche factors based on the broken-stick advice. Sikkim Rat (*R. sikkimensis*) keeps the maximum amount of factor (seven) while Chestnut Spiny Rat (*N. fulvescens*) retains the minimum of three. The amount of information explained ranges from 85.1% to 94.3% with an average and standard deviation of 88.8%±4.3%. According to global marginality (*M*) which compares the difference between the species optimal living condition and the environmental conditions within the territory, all of the four species have values over one and tend to live in environment which extremely varies from the mean conditions in the territory of Hong Kong (mean *M* = 1.067±0.108). The range of living condition is quite restrictive as explained by the global tolerance (*T*) with the overall mean and standard deviation of 0.440±0.095. Sikkim Rat (*R. sikkimensis*) has the highest tolerance level (*T* = 0.545) though the value is just above 0.5 while Eurasian wild pig (*S. scrofa*) has the lowest tolerance (*T* = 0.358). In Appendix 5a, Table A5a.49 shows that S. scrofa is restrictive to the optimal conditions of environmental factors including potential solar radiation in factor 2 (sp.1) as well as frequency of woodland, bareland and shrubby grassland in factor 3 (sp.2).

Table 4.21 Summary statistics of ENFA for the four mammal species

Species Scientific name	Common English name	No. of points from Bd. Survey	^{N}umber of input EGVs	^{N}umber of Ecological-niche Factors	$^{\#}$Amount of information *(variance)* explained (%)	$^{\Omega}$Global Marginality	$^{\partial}$Global Tolerance	$^{\wedge}$Global Speciali-zation
Niviventer fulvescens	Chestnut Spiny Rat	64	16	3	85.7 *(71.3)*	1.014	0.495	2.021
Hystrix brachyura	East Asian Porcupine	41	26	6	89.9 *(84.3)*	1	0.361	2.773
Sus scrofa	Eurasian Wild Pig	53	26	6	94.3 *(83.9)*	1.234	0.358	2.795
Rattus sikkimensis	Sikkim Rat	66	26	7	85.1 *(72.9)*	1.057	0.545	1.835

4.7.2 Binary Logistic Regression Model (BLRM)

Table 4.22 shows the summary statistics of BLRM and Table 4.23 shows the predictors and corresponding coefficients (β_i) of BLRM selected for the four mammal species. The number of survey points ranges from 41 to 63 for the four mammal species. Eurasian Wild Pig (*S. scrofa*) chooses five predictors while Chestnut Spiny Rat (*N. fulvescens*) retains three. All of the four species retain woodland as one of their predictors in the equation which suggest that woodland is the important habitat for mammal species. Besides, two species are associated with stream, elevation and distance from coast which reveal that water supply, altitude and coastal locations all have effects on their distribution.

According to the Hosmer and Lemeshow goodness of fit test, the logistic regression models for all species are well-fitting. The amounts of variance explained are over 80% with respect to the Nagelkerke R-square and the mean amount is 84%±2%. This suggests the associations between species data and predictors are all strong. The percentage of deviance reduction ranges from the lowest 69% to the highest 76%. The percentage of deviance reduction stays around 70% with mean of 72%±3% which advocates that the species models are just fit the data moderately well. The mean LOOCV classification accuracy with 0.5 as cutoff-threshold is 93%±1.8% and all are over 90%. As for the AUC from the ROC plot, they are all above 0.97 with mean of 0.976±0.006. Both statistics suggest that the discriminatory ability of BLR models is very good.

Table 4.22 Summary statistics of BLRM for the four mammal species

Species Scientific name	Common English name	No. of points from Bd. Survey	No. of predictors	Extracted Model Summary					
				Hosmer and Lemeshow Goodness-of-Fit Test	Cox & Snell R^2	Nagel-kerke R^2	% Deviance Reduction	ROC - AUC	LOOCV - Classification accuracy (%)
Niviventer fulvescens	Chestnut Spiny Rat	64 (63)	12 (4)	p = 0.067	0.615	0.820	69%	0.972	91.3
Hystrix brachyura	East Asian Porcupine	41 (41)	9 (4)	p = 0.795	0.618	0.824	69%	0.974	92.7
Sus scrofa	Eurasian Wild Pig	53 (53)	10 (5)	p = 0.880	0.654	0.871	76%	0.984	95.3
Rattus sikkimensis	Sikkim Rat	66 (63)	10 (4)	p = 0.746	0.635	0.847	73%	0.972	94.4

Table 4.23 Predictors and corresponding coefficients (β_i) of BLRM selected for the four mammal species

Species Scientific name	Common English name	AUTU	BLDG	COAST	EAST	ELEV	MAIN ROAD	BARE	GRASS	MSHRUB	SH-GRASS	WOOD	PLAN	PRO-FILE	RAIL	RIVER	SLOPE	STREAM 100
Niviventer fulvescens	Chestnut Spiny Rat							-1.538		+0.169		+0.078				+0.64		
Hystrix brachyura	East Asian Porcupine			-0.001								+0.06					+0.109	+0.535
Sus scrofa	Eurasian Wild Pig			+0.001	-2.18	-0.041						+0.286						+0.591
Rattus sikkimensis	Sikkim Rat					+0.011	+0.001		-0.085			+0.058						

4.7.3 Generalized Additive Model (GAM)

Table 4.24 shows the summary statistics of GAM and Table 4.25 lists the predictors selected by AIC for GAM models of the four mammal species. Among the four species, Chestnut Spiny Rat (*N. fulvescens*) *and* Sikkim Rat (*R. sikkimensis*) employ six predictors while East Asian Porcupine (*H. brachyuran*) and Eurasian Wild Pig (*S. scrofa*) have four. The bareland (BARE) is selected by three species and with the negative response to the predictor, the mammal species tend to live away from bare soil.

Statistics show that Eurasian Wild Pig (*S. scrofa*) has the highest deviance reduction (100%) while Sikkim Rat (*R. sikkimensis*) has the lowest (79%) and the average deviance reduction is 93%±9%. The overall large deviance reduction suggests that the logistic models fit the species data well. Except Eurasian Wild Pig (*S. scrofa*), the overall LOOCV classification accuracies with 0.5 as cutoff-threshold are all over 90% with an average of 86.3%±24.3%. As for the threshold-independent ROC, the simple one has mean AUC of 0.997±0.006 while that of the cross-validated one is 0.907±0.007. Referring to the two statistics, the discriminatory ability of models is quite high.

Table 4.24 Summary statistics of GAM for the four mammal species

Species Scientific name	Common English name	No. of points from Bd. Survey	No. of predictors	Extracted Model Summary				
				% Deviance Reduction	Residual DF	cvROC	ROC	LOOCV - Classification Accuracy (%)
Niviventer fulvescens	Chestnut Spiny Rat	64 (63)	13 (6)	93%	102.78	0.910	1.000	99.2
Hystrix brachyura	East Asian Porcupine	41 (41)	13 (4)	98%	67.96	0.899	1.000	100.0
Sus scrofa	Eurasian Wild Pig	53 (53)	11 (4)	100%	91.44	0.914	1.000	50.0
Rattus sikkimensis	Sikkim Rat	66 (63)	11 (6)	79%	101.76	0.904	0.988	96.0

Table 4.25 Predictors selected by AIC for GAM models of four mammal species

Species Scientific name	Common English name	AUTU	BLDG	COAST	EAST	ELEV	MAIN ROAD	BARE	GRASS	MSHRUB	SH-GRASS	WOOD	PLAN	PRO-FILE	RAIL	RIVER	SLOPE	STREAM 100
Niviventer fulvescens	Chestnut Spiny Rat		√			√		√	√	√						√		
Hystrix brachyura	East Asian Porcupine	√		√				√										√
Sus scrofa	Eurasian Wild Pig						√	√		√	√							
Rattus sikkimensis	Sikkim Rat	√		√	√		√		√									√

4.8 Model Selection

Table 4.27 shows the statistical comparison of two regression models – binary logistic regression model (BLRM) and generalized additive model (GAM) based on their percentage of deviance reduction (R); leave-one-out cross-validated percentage of classification accuracy (LOOCV); and area under curve (AUC) derived from ROC. For all the fifty models, the deviance reduction (R) of GAM is generally higher than that of BLRM. The mean deviance reduction are 87%±11% and 61%±14% for GAM and BLRM respectively. The maximum R for GAM and BLRM are 99% and 80% respectively. This implies that the reliability of GAM is higher than that of BLRM. The LOOCV and AUC are used for comparison of discriminatory ability. Judging from the LOOCV, all the species, except *S. scrofa*, receive high classification accuracy in GAM. The mean accuracy from LOOCV are 95.9±7.4 and 89.0±5.0 for GAM and BLRM respectively. The AUC reflects similar scenario as that from LOOCV. With the exception of two species – Yellow Orange Tip (*I. pyrene pyrene*) and Eurasian Wild Pig (*S. scrofa*), all species modeled with GAM receive higher AUC than those modeled with BLRM. The mean AUC are 0.988±0.022 and 0.946±0.035 for GAM and BLRM respectively. According to the three statistics, the GAM is better in terms of model reliability and discriminatory ability. As a result, the GAM is used for computation of taxonomic-grouped richness maps as well as species richness map in the following analyses.

Table 4.26 Comparison of models – Logistic Regression Model, Generalized Additive Model and ENFA in terms of percentage of deviance reduction (R); Leave-one-out cross validation (LOOCV); and Area under curve (AUC) from ROC

	Amphibian		Bird		Butterfly		Dragonfly		Mammal		Overall	
	GAM	**LR**	**GAM**	**LR**	**GAM**	**LR**	**GAM**	**LR**	**GAM**	**LR**	**GAM**	**LR**
Deviance Reduction												
Average	87%	64%	89%	57%	86%	59%	83%	62%	93%	72%	88%	63%
SD	9%	15%	9%	12%	10%	16%	14%	15%	9%	3%	10%	12%
Maximum	97%	84%	99%	76%	100%	83%	100%	80%	100%	76%	99%	80%
Minimum	70%	49%	73%	29%	69%	27%	46%	38%	79%	69%	68%	43%
LOOCV - Classification Accuracy (%)												
Average	95.5	89.1	97.6	88.1	97.2	88.2	96.4	89.4	86.3	93.4	94.6	89.6
SD	3.2	5.5	2.9	5.0	2.8	5.4	4.3	4.9	24.3	1.8	7.5	4.5
Maximum	100.0	95.8	100.0	95.8	100.0	93.9	100.0	94.7	100.0	95.3	100.0	95.1
Minimum	91.5	80.0	91.3	76.3	91.6	79.2	85.9	80.9	50.0	91.3	82.1	81.5
Area Under Curve (AUC) from ROC												
Average	0.994	0.958	0.996	0.933	0.993	0.938	0.987	0.949	0.997	0.976	0.993	0.951
SD	0.009	0.028	0.008	0.035	0.009	0.041	0.024	0.035	0.006	0.006	0.011	0.029
Maximum	1.000	0.992	1.000	0.975	1.000	0.991	1.000	0.986	1.000	0.984	1.000	0.986
Minimum	0.975	0.924	0.973	0.848	0.976	0.851	0.914	0.881	0.988	0.972	0.965	0.895

4.9 Identification of Biodiversity Hotspots

The biodiversity hotspots are represented and identified by species richness based on the average probability of occurrence of the fifty species derived from GAM. The species richness map is shown in Figure 4.1. Areas with extremely high species richness are indicated in red. They are Tai Ho San Tsuen, Ngau Au, Tei Tong Tsai, Sham Shek Tsuen, Sha Lo Wan, Lung Mei Tsuen, Wang Tong, valley in Mau Yuen, San Shek Wan, Cheung Sha, north of Tong Fuk, Shui Hau and individual areas distributed in Keung Shan. Pink locates high species richness sites. They include Chi Ma Wan Peninsula, Nim Shue Wan Tsuen, New Tung Chung Hang, Tin Sum, Tai O, Yi O San Tsuen, Tai Long Wan Tsuen and Keung Shan.

A few observations can be drawn from the result. First, the majority of extremely species-rich sites fall outside the protection boundary of Country Park. The obvious ones are located at South Lantau, areas around Tung Chung, Tai Ho and Nim Shue Wan. The concordance between species richness and existing protection system are detailed examined in Gap Analysis in Section 4.11. Second, most of highly species-rich sites are related to the presence of villages. Third, all the sites with high species richness are below 300 meters and they are located at foothills and along valleys in-between the hilly landscapes in Lantau. The upland in Lantau Peak, Sunset Peak, Yi Tung Shan, Lin Fa Shan, Nei Lak Shan are shown in blue indicating low species richness.

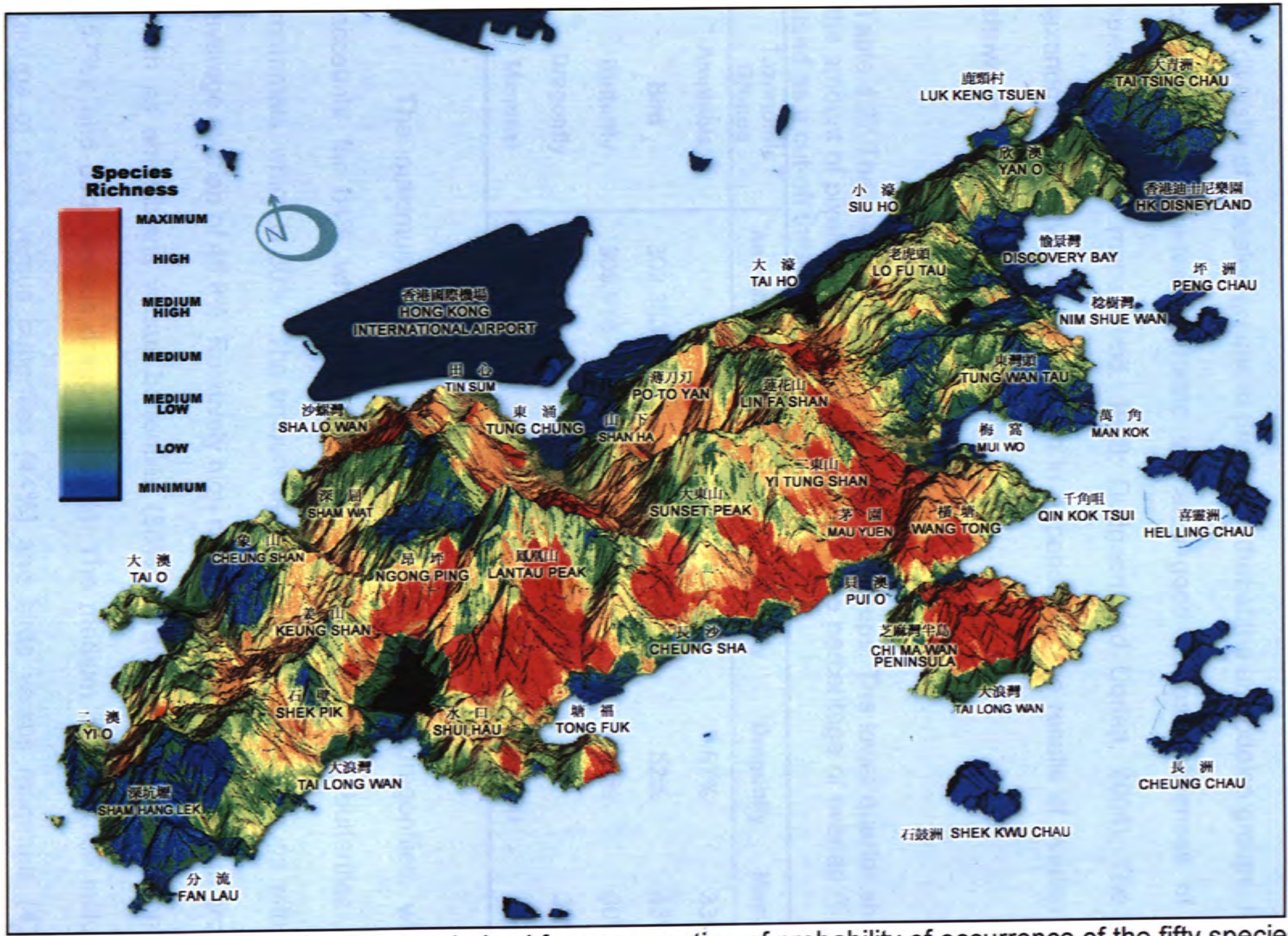


Figure 4.1 The species richness map derived from summation of probability of occurrence of the fifty species.

4.10 Correlations between Taxonomic Groups

The overlap between taxonomic groups indicates the possibility of using the diversity of modeled groups in predicting that of the unmodeled groups. High correspondence between groups indicates good representativeness of the species richness maps (Reid, 1998; Dudgeon and Corlett, 2004). The five taxonomic diversity maps are shown in Appendix 7. The results of overlap are shown in Table 4.27.

Table 4.27 The overlap among five taxonomic groups. The lower quarter shows the amount of pixels while the upper quarter is the percentage of overlap (0.7 is used as a cut-off threshold)

Taxonomic Groups	**Amphibian**	**Bird**	**Butterfly**	**Dragonfly**	**Mammal**
Amphibian	–	39%	58%	57%	33%
Bird	302,353	–	44%	52%	43%
Butterfly	305,918	354,341	–	64%	30%
Dragonfly	318,218	415,514	371,468	–	38%
Mammal	193,332	337,189	197,557	252,109	–

The maximum overlap is between butterflies and dragonflies, which accounts for 64% while the minimum overlap is between butterflies and mammals, which is 30%. The amount of overlap varies across groups with the average overlap of 45.8%. Relatively high concordance is found between groups such as amphibians versus butterflies (58%); amphibians versus dragonflies (57%); and birds versus dragonfly (52%). The medium concordance includes groups of birds versus butterflies (44%) and birds versus mammals (43%). Relatively low correspondence of patterns is found between groups including amphibians versus birds (39%); mammals versus dragonflies (38%); and mammals versus amphibians (33%). Since the patterns of species richness do not show distinctive correlations across taxonomic groups, it is less likely that the hotspots of one taxon can be used to represent and predict hotspots of other taxa (Reid, 1998). The non-concordance simply explains that the habitat requirements of the five taxa are different. In other words, sites suitable for a particular taxon, for example, amphibians, might not be desirable for another, mammals. The result further implies the incapability of these biodiversity hotpots in coinciding with the habitats of those rare, threatened or endangered species (Reid, 1998). The result is simply because the species richness map identifies sites with conditions that are suitable and favour the majority of species, but without taking into account the specific requirements of the rare species (Dudgeon and Corlett, 2004). The result is complementary with other studies which also show low correlation between species diversity and rare species (Williams *et al.*, 1996).

4.11 Gap Analysis

Although the species richness map alone fails to represent biodiversity hotpots in Lantau, its relationship with the current protection network is examined through Gap Analysis. Table 4.28 shows the relationship between species richness on three different cutoff points and existing protection system including the Lantau North and South Country Parks and eight SSSIs. The upper part of the table shows the results in number of pixel while the lower part indicates the results in proportion to the total number of species-rich pixels under the corresponding cut-off threshold.

Table 4.28 Identification of gaps through comparison of species richness (three thresholds) with existing protection system

	Lantau North CP	Lantau South CP	SSSIs	Subtotal	***Gap***	Total
Species Richness (0.9)	3,849	29,761	447	34,057	***27,996***	62,053
Species Richness (0.7)	33,536	192,698	4,394	230,628	***179,236***	409,864
Species Richness (0.5)	86,181	322,130	6,143	414,454	***342,172***	756,626
Species Richness (0.9)	6%	48%	1%	55%	***45%***	100%
Species Richness (0.7)	8%	47%	1%	56%	***44%***	100%
Species Richness (0.5)	11%	43%	1%	55%	***45%***	100%

When species richness being represented by 0.9 or above, 6%, 48% and 1% of species-rich areas fall within the Lantau North Country Park; the Lantau South Country Park and the SSSIs respectively. A total of 34,057 pixels or 55% of species-rich sites falls into existing protection system in Lantau. The remaining 45% of species-rich sites are identified as gaps which drop outside the protection boundary. The results from the other two thresholds show slight variability. There is a minor increase on the species-rich sites in the Lantau North Country Park; however, the majority of species-rich sites (over 40%) fall within the Lantau South Country Park. The eight SSSIs composed of mainly rare species, constitute constantly at 1%. The low contribution of SSSIs advocates the inability of species richness map in capturing the rare or threatened species. In other words, the species-rich sites do not coincide with the existing designated high ecological value areas. The gaps stay consistently around 45% which implies that the present protection network can only protect around 55% of species-rich sites with 45% being under-protected. Figures 4.2 – 4 represent the results in diagrams. Regions in dark green show the gaps. The species-rich sites fall within the Country Parks and SSSIs are represented in light yellow and red respectively. The remaining Country Parks and SSSIs are illustrated in green and orange respectively.

The results from the overlap analysis as well as the Gap Analysis indicate the possibility of under-representation of potential hotspots of other taxa, especially the rare, threatened or endangered species in the species richness map. As a result, the species richness map cannot be used as the sole indicator of hotspots as well as the only guide for conservation site selection in the later stage of the study.

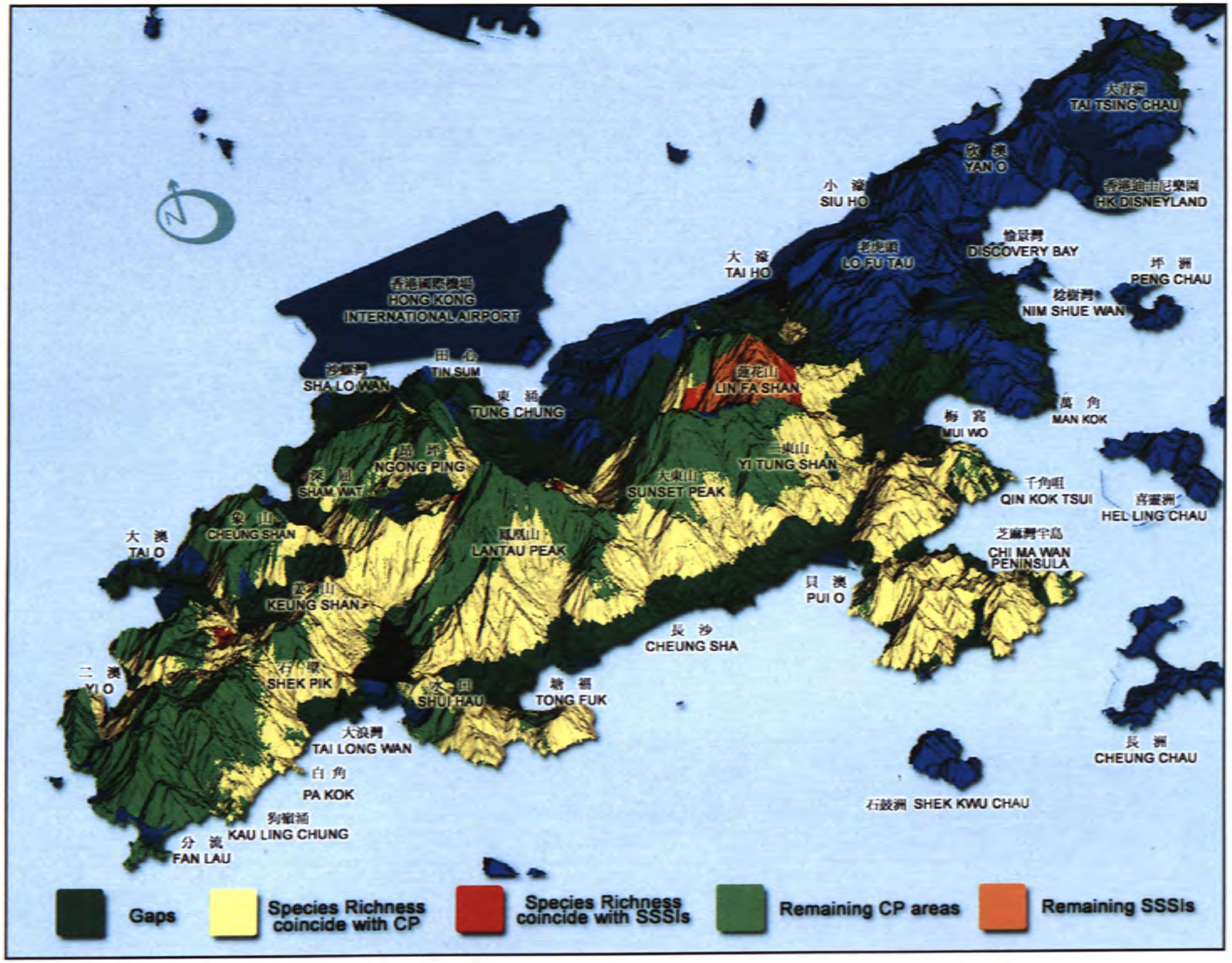


Figure 4.2 Result of Gap Analysis with 0.5 as cutoff threshold

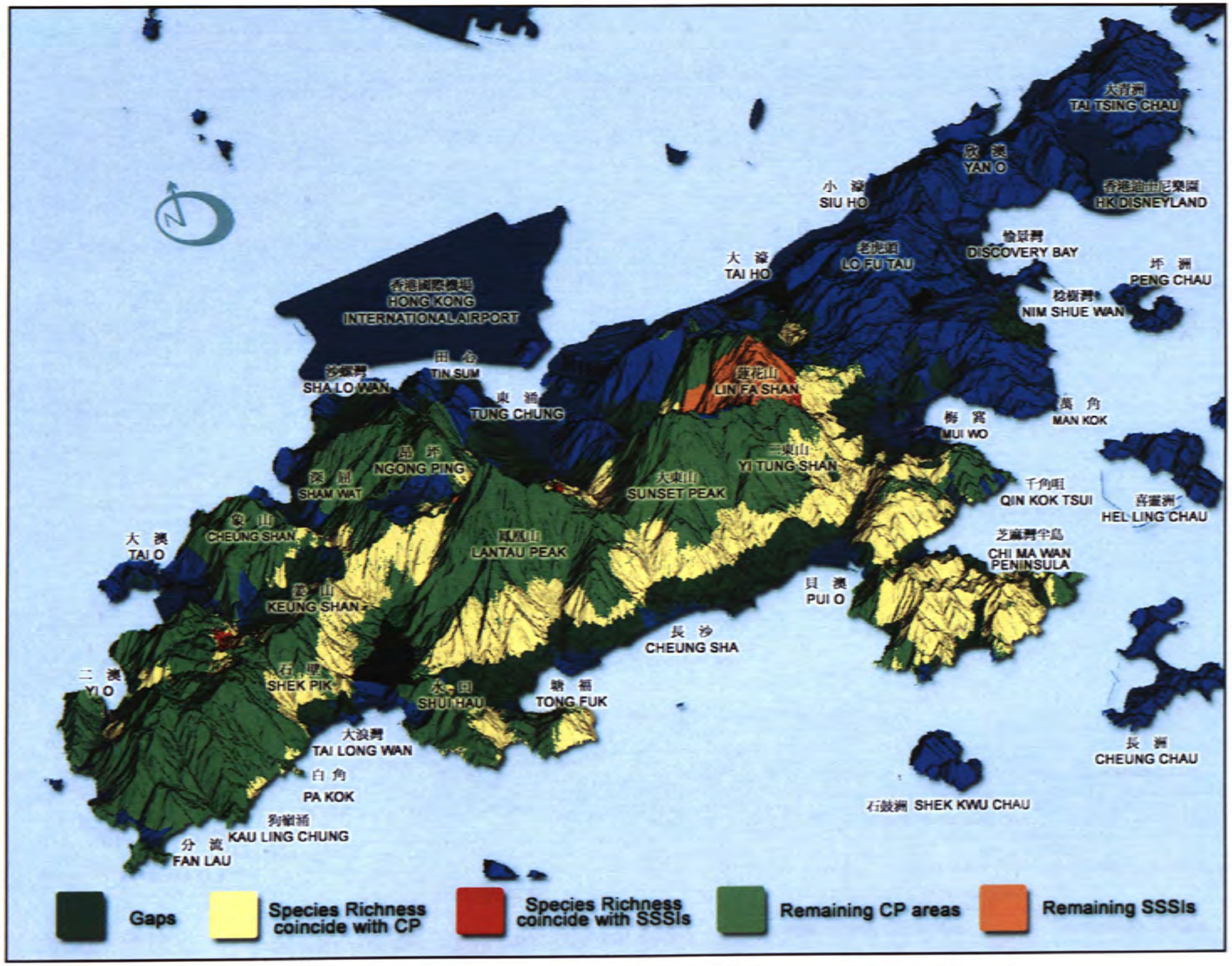


Figure 4.3 Result of Gap Analysis (with 0.7 as cutoff threshold)

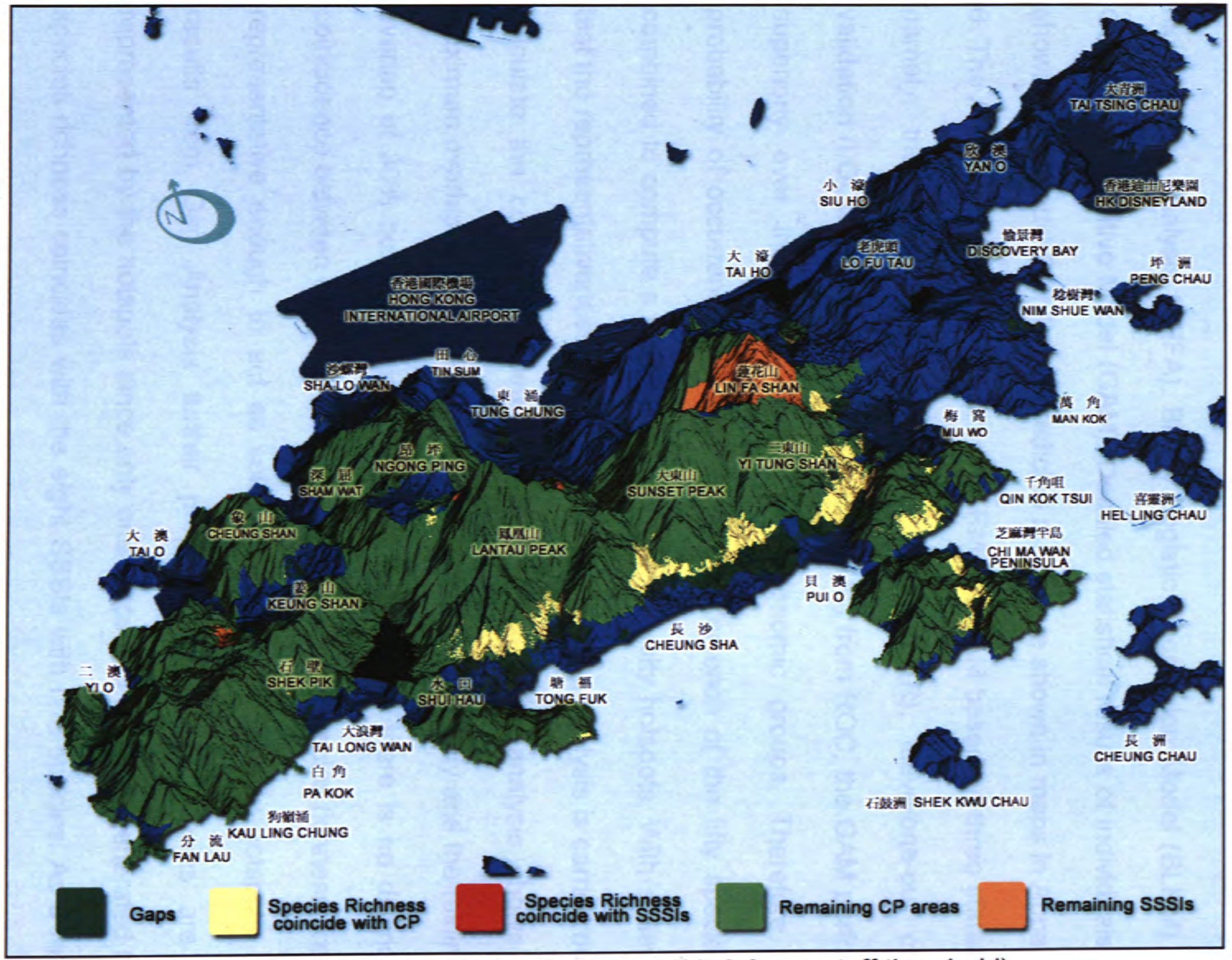


Figure 4.4 Result of Gap Analysis (with 0.9 as cutoff threshold)

4.12 Summary

To summarize, this chapter shows the summarized habitat mapping results for the fifty species from three statistical modeling methods – Ecological-niche Factor Analysis (ENFA), Binary Logistic Regression Model (BLRM) and Generalized Additive Model (GAM). Detailed statistical results of individuals are shown in Appendix 5 while the predicted results are shown in maps in Appendix 6. The After comparing the results of BLRM and GAM based on three statistics, namely, the percentage of deviance reduction (R), leave-one-out cross validation (LOOCV) and area under curve (AUC) from ROC, the GAM performs superiorly over the BLRM in the five taxonomic groups. Therefore, the probability of occurrence predicted from GAM for each of the fifty species is combined to compute a map representing biodiversity hotspots. With a view to test the representativeness of the hotspots, the overlap analysis is carried out to calculate the correlations between the five taxa. The analysis shows the maximum overlap of 64% between the butterfly and dragonfly and the minimum overlap of 30% between butterfly and mammal. Since there is no distinctive coincidence between taxa, the hotspots computed from species richness are not representative enough to act as sole indicator of biodiversity hotspots. The results from Gap Analysis further prove that the rare species are not represented by the hotspots since only one percent of hotspots generated from species richness coincides with the eight SSSIs with rare species. As a result, the biodiversity hotspots map cannot be used as the only guide in selecting conservation areas in the subsequent analyses. The Gap Analysis also indicates there are about 45% of species-rich sites being under-protected by the existing protection network, which suggests the extension of protection areas is needed.

CHAPTER 5 RESULTS AND DISCUSSION (II) – TOURISM PLANNING AND ZONE ALLOCATION

5.1 Introduction

This chapter discusses the results from multiple criteria analysis (MCA) and multi-objective land allocation (MOLA). The MCA is used to select sites for four ecotourism and tourism activities including (1) camping; (2) hiking; (3) cycling and picnicking; and (4) tourism development. Prior to the results, the evaluation factors, standardization processes as well as the analytic hierarchy process (AHP) in generating different weighting schemes for each activity are discussed. The results are used to evaluate proposals suggested in the Concept Plan for Lantau. By combining the species richness map in the previous section; the results from MCA, together with data regarding the existing conservation areas (SSSIs and Country Parks), four objective maps are developed through which the MOLA is used to classify Lantau into four different zones – (1) Sanctuary; (2) Nature Conservation; (3) Outdoor Recreation; and (4) Tourism Development. Regarding the four objectives, the possible conflicting sites are identified first. This is followed by the generation of two extreme scenarios, the conservation-oriented and recreation-and-tourism-oriented, as well as a balanced scenario. These scenarios are simulated with different weight combinations and areas allocated to the four objectives. The results are compared with the Concept Plan for Lantau.

5.2 Site Selection for Compatible Tourism Activities in Lantau Island

The Concept Plan proposes a number of recreational and tourism activities as listed in Table 3.12. Multiple criteria analysis (MCA) is used to select sites for three recreational activities including camping, hiking and cycling, as well as sites for tourism development. For each activity, evaluation factors are generated based on site attributes, tourism facilities and tourism interests. Fuzzy shape membership function combined with control points are selected to standardize each individual factor into a range of 0-255, i.e. from totally unsuitable to extremely suitable regarding the factor. Preferences are represented in the form of weight assigned to factors. Equal weighting (EW) and weighting with Analytic Hierarchy Process (AHP) are used with the later one simulating situations with specific interests or concerns. Suitability maps are produced by combining the factors and weights with weighted linear combination (WLC) decision rule. The recreational activities and tourism development are compared with the Concept Plan.

5.2.1 Potential Campsite selection

"Camping is an outdoor recreational activity involving the spending of one or more nights in a tent, a primitive structure, a travel trailer or a recreational vehicle at a campsite with the purpose of getting away from civilization and enjoying the nature (Wikipedia Encyclopedia Online, 2006a, para. 1)." In this study, the selection of campsites is mainly for tent camping activity. There are twelve existing campsites in Lantau, which cluster primarily in South Lantau. An extra tent campsite is proposed around Fan Lau Tung Wan in the Concept Plan.

5.2.1.1 Evaluation factors

According to the camping expert advice (2006), seven factors are chosen to govern the suitability of camp site within the Lantau boundary. The seven factors together with the chosen fuzzy shape membership functions and their corresponding control points are shown in Table 5.1. The slope steepness governs the safety of campsites. The flat and smooth areas are most preferable. The factor is standardized using a sigmoidal monotonically decreasing fuzzy membership function with two control points indicating that 0 degree of slope is the best while slope greater than 30 degree is totally unsuitable. Recommended by the experts, a suitable campsite should be as least 200 to 300 feet away from water and trails in order to avoid obstructing both hikers and wildlife. The factor can be represented by using a sigmoidal symmetric membership function. With distances from footpaths and rivers shorter than 3 meters or longer than 12 meters, the sites are no longer suitable. The maximum suitability is achieved if a site is between 6 and 9 meters from water and trails. Many campers favour the selection of east-facing slope in order to watch sunrise and catch the sun's early morning rays. The monotonically increasing function suggests that the west-facing slope (-1) is not preferable and the membership reaches one until the aspect has turned to east (1). Elevation also determines the suitability of a camp site. Too low or too high an altitude is not preferable in terms of temperature comfort and the possibility of flooding. The sigmoidal symmetric membership function is used to regard sites as unsuitable when they are either 0 meters or higher than 150 meters. In reverse, the site is considered as the most suitable with altitude between 50 and 100 meters. The last two factors, distance from the main roads and reservoirs are to keep the campsites away from traffic and the boundary of reservoirs. The monotonically increasing membership function is applied. With a distance of 300 meters or below from main roads and 500 meters or below from reservoirs, the sites are considered as unsuitable while the most favourable sites are situated at a distance of 500 meters or further from main roads and 800 meters or further from reservoirs.

Table 5.1 The seven factors governing potential campsite selection with their corresponding fuzzy membership functions and control points.

Factor	Abbrev.	Fuzzy Shape Membership Function	Control Points			
			a	b	c	d
Slope	S	Sigmoidal monotonically decreasing	-	-	0	30
Distance from Footpaths	FP_DIST	Sigmoidal symmetric	3	6	9	12
Distance from Rivers	RIV_DIST	Sigmoidal symmetric	3	6	9	12
East-facing Aspect	EAST	Sigmoidal monotonically increasing	-1	1	-	-
Elevation	ELEV	Sigmoidal symmetric	0	50	100	150
Distance from Main Roads	RD_DIST	Sigmoidal monotonically increasing	300	500	-	-
Distance from Reservoirs	RES_DIST	Sigmoidal monotonically increasing	500	800	-	-

5.2.1.2 Factor weights from the AHP

Apart from equal weighting of factors (0.1429), the AHP is used to develop a different weighting scheme by emphasizing on several factors including slope, elevation, and distance from footpaths and rivers. Table 5.2 shows the pairwise comparison matrix within which factors are compared based on a nine-point scale. The weights calculated for the seven factors are also shown in the table. The consistency ratio is 0.05 suggesting that the comparison is consistent. A strong emphasis is stressed on landscape factors, slope and altitude as well as distance from footpaths and rivers. The east-facing aspect and distance from main roads and reservoirs are considered as minor factors affecting the selection.

Table 5.2 Pairwise comparison matrix and the consistent weights for the seven factors of potential campsite selection.

	S	**FP_DIST**	**RIV_DIST**	**EAST**	**ELEV**	**RD_DIST**	**RES_DIST**	**WEIGHT**
S	1							0.4059
FP_DIST	1/5	1						0.1106
RIV_DIST	1/5	1	1					0.1199
EAST	1/7	1/3	1/5	1				0.0344
ELEV	1/3	3	3	7	1			0.2184
RD_DIST	1/5	1/3	1/3	1	1/3	1		0.0507
RES_DIST	1/5	1/3	1/3	3	1/3	1	1	0.0600

5.2.1.3 Results

The result of equal weighting and AHP-weighting are shown in Figures 5.1 and 5.2 respectively. The result from AHP-weighting is more distinguishing with higher contrasts than the equal weighting. In Figure 5.2, the emphases on slope and elevation sorted out sites with steep hill slopes and high altitudes. Individual sites at high altitudes and with medium or above suitability are owing to their proximity to footpaths and rivers. Since the weights of distance from main roads and reservoirs are immaterial, the main roads, such as the Tung Chung Road as well as the edges of reservoirs, with an originally low suitability in the equal weighting scenario are identified as sites of medium-high or high suitability for tent camping. The relatively high suitability of these sites is also a result of low altitude and relatively gentle slope which are stressed in the AHP-weighting scenario.

The existing twelve campsites clustering in South Lantau seem to have a range of medium to high suitability. Apart from Fan Lau Tung Wan proposed in the Concept Plan, the result also suggests some potentially high-quality campsites including the foothills of Keung Shan, Nei Lak Shan, Po To Yan; areas near Tai Ho, Siu Ho, Cheung Sha and Tong Fuk; Luk Keng Tsuen; Tai Shui Hang; Wong Kung Tin; and the northern tip of Shek Pik Reservoir. The eleven potential campsites are all located on flat and low lands and with suitable distance from footpaths and rivers. They also stay away from noise disturbances from traffic, as well as some unsuitable areas like reservoirs. Although the suitability level of these sites is high, their viability should be evaluated and examined on site before the formulation of the plan.

Figure 5.1 Map showing the suitability for camping in Lantau Island with equal weighting of factors.

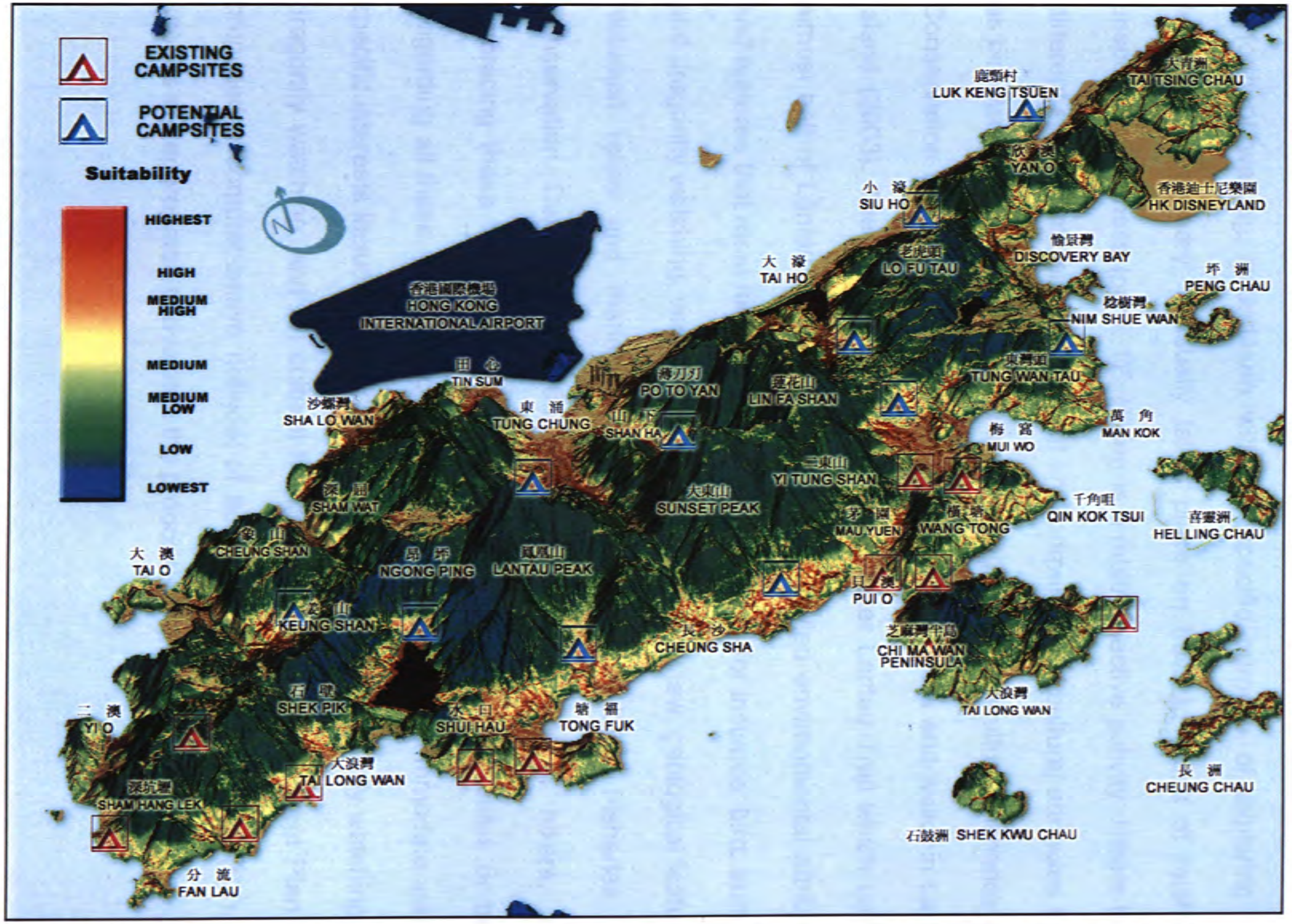


Figure 5.2 Map showing the suitability for camping in Lantau Island with AHP-weighting of factors.

5.2.2 Potential Hiking Route Selection

According to Wikipedia Encyclopedia Online definition (2006b), "hiking is a form of walking, undertaken with the specific purpose of exploring and enjoying the scenery. It usually takes place on trails in areas of relatively unspoiled wilderness (para. 1)". Hiking is a multi-objective activity. Hikers have different specific interests on different environmental and cultural attributes such as bird watching or, visitation of cultural heritage. The Agriculture, Fisheries and Conservation Department (AFCD) has provided nine trails and walks in Lantau Island (2003). The longest one is the 70-kilometer Lantau Trail which covers almost half of Lantau. The AFCD has also identified environmental attributes and features that most hikers seek for in their hiking, for instance, bird, butterfly and dragonfly watching, vegetation, woodland, coastal view, geological features, historical relics and marine life (Hong Kong Agriculture, Fisheries and Conservation Department, 2005). From the perspective of hikers, sites embracing these features are regarded as favourable hiking routes or trails. Regarding all these, different scenarios are generated to accommodate various specific interests including hiking for (1) bird watching; (2) butterfly watching; (3) dragonfly watching; and (4) cultural heritage visitation. The Concept Plan has proposed a comprehensive network of eco-trails and heritage trails (C1), the scenes are aggregated to evaluate the proposals.

5.2.2.1 Evaluation factors

The evaluation factors for hiking are shown in Table 5.3. Footpaths and trails use the Boolean factor regarding the accessibility or availability of roads connecting the potential sites. Since most of the precious and significant features are associated with dense vegetation, Boolean maps of woodland and mixed shrubland achieved in the result of image classification are extracted and summed. The species richness of taxonomic groups including bird, butterfly and dragonfly resulted from habitat modeling are used to represent the potential presence of these creatures. These potential habitat maps are standardized with the sigmoidal monotonically increasing membership function. Sites with probability of occurrence of 0.5 or below are unsuitable for observation or visitation of creature of particular interests. Afterwards, the fuzzy set membership is increased progressively until 0.7 and beyond with the suitability reaches the maximum. The cultural resources such as declared monuments, temples, ancestral halls and churches are all related and within a distance of the villages in Lantau after overlay analysis of various attributes. As a result, the distance from villages is used as a single factor governing the heritage location. The sigmoidal monotonically decreasing fuzzy membership function is applied with distance from villages of 200 meters or below regarded as the most favourable sites receiving the highest value of 255. The fuzzy set membership decreases progressively until a distance of 800 meters is reached and beyond which the membership drops to zero.

Table 5.3 The six factors governing potential hiking route selection with their corresponding fuzzy membership functions and control points.

Factor	Abbrev.	Fuzzy Shape Membership Function (Sigmoidal)	Control Points			
			a	b	c	d
Potential Habitat of birds	BIRD	monotonically increasing	0.5	0.7	-	-
Potential Habitat of Butterfly	BUTT	monotonically increasing	0.5	0.7	-	-
Potential Habitat of Dragonfly	DRAG	monotonically increasing	0.5	0.7	-	-
Woodland and Mixed Shrubland	WMS_BL	Boolean Map	-	-	-	-
Footpaths and Trails	FP_BL	Boolean Map	-	-	-	-
Distance from Villages	VILL_DIST	monotonically decreasing	-	-	200	800

The factors chosen for specific hiking interests are different. For natural hiking purpose, five factors are used including the potential habitats of birds, butterfly, dragonfly; woodland and mixed shrubland; and footpaths and trails. As for hiking for cultural heritages, three factors are used, namely, distance from villages; woodland and mixed shrubland; and footpaths and trails.

5.2.2.2 Factor weights from the AHP

Apart from the equal weighting of factors (0.25), The AHP is applied to develop weighting schemes through which various hiking interests are represented by adjusting the weights of different factors. Tables 5.4a – d show the pairwise comparison matrix and the corresponding factor weights for the four AHP models in order to assess the suitability of four hiking interests. With reference to the first three interests, the weights for the two Boolean maps, woodland and mixed shrubland; and footpaths and trails are of no difference, which are 0.3856 and 0.2424 respectively. The weight of emphasis switches among the three creatures of interest. The accentuated creature has a weight of

0.2427 while the other two have equal weights of 0.0647. The consistency ratio of 0.04 has fallen within the acceptable range. As for hiking for cultural heritage visitation, distance from villages receives the strongest weight of 0.6370, followed by woodland and mixed shrubland (0.2583) and footpaths and trails (0.1047). The weighting is reasonably consistent with a consistency ratio of 0.03.

Table 5.4 Pairwise comparison matrix and the consistent weights for four scenarios of potential hiking route selection.

a. Bird watching

	BIRD	BUTT	DRAG	WMS_BL	FP_BL	WEIGHT
BIRD	1					0.2427
BUTT	1/5	1				0.0647
DRAG	1/5	1	1			0.0647
WMS_BL	3	5	5	1		0.3856
FP_BL	1	3	3	1	1	0.2424

b. Butterfly watching

	BIRD	BUTT	DRAG	WMS_BL	FP_BL	WEIGHT
BIRD	1					0.0647
BUTT	5	1				0.2427
DRAG	1	1/5	1			0.0647
WMS_BL	5	3	5	1		0.3856
FP_BL	3	1	3	1	1	0.2424

c. Dragonfly watching

	BIRD	BUTT	DRAG	WMS_BL	FP_BL	WEIGHT
BIRD	1					0.0647
BUTT	1	1				0.0647
DRAG	5	5	1			0.2427
WMS_BL	5	5	3	1		0.3856
FP_BL	3	3	1	1	1	0.2424

d. Cultural Heritage Visitation

	WMS_BL	FP_BL	VILL_DIST	WEIGHT
WMS_BL	1			0.2583
FP_BL	1/3	1		0.1047
VILL_DIST	3	5	1	0.6370

5.2.2.3 Results

The results of equal weighting and AHP-weighting are shown in Figures 5.3 and 5.8 respectively. The result from equal weighting is less distinguishable than that from AHP-weighting in terms of the contrast level of suitability. Figures 5.4 – 5.6 show the hiking trails for natural hiking purposes. They are all concentrated in low to medium high altitudes and are seldom found in the upper portions of the hills. This is mainly due to the concentration of woodland, mixed shrubland and high species diversity of bird, butterfly and dragonfly all in sites of relatively low altitude. Suitability of sites varies according to different interests (Figures 5.4 – 5.7). Figure 5.8 shows the aggregation of the four AHP-results. When compared with the equal weighting scenario, they almost identify the same locations. The higher contrast in the aggregated-AHP result is mainly due to high suitability in the heritage-visiting scenario.

Around the whole island, the trails from Keung Shan in the west of the island passing through the southern aspect of the Lantau Peak, Sunset Peak, Yi Tung Shan, Lin Fa Shan and Po To Yan and all the way to the east of the island, as well as the Chi Ma Wan Peninsula are recommended for observing and contacting with a high diversity of bird, butterfly and dragonfly species. Individual sites including Shek Pik, Tai O, Yi O, Tai Ho, Tung Wan Tau, Nim Shue Wan and Luk Keng Tsuen are also preferable. Man Kok Tsui is favorable for butterfly and dragonfly watching. Tai Tsing Chau is specifically for birds and butterflies. Figure 5.7 shows the potential sites for cultural heritage exploration and in which the clusters and connection between villages form the routes. The villages coincide with a number of unique cultural entities such as declared monuments, temples, mosques, ancestral halls and churches. These are the main attractions for hikers.

When comparing the results with the existing 70-kilometre Lantau Trail which is shown in white in Figures 5.3 and 5.8, the trail covers both high and low suitability regions. Since the results are biased towards the relative low altitude sites, the portion in South Lantau is regarded as highly favourable while the part covering the highest peak of Lantau Peak, Sunset Peak and Yi Tung Shan are of low suitability. As for the proposed eco- and heritage trails (C1) in the Concept Plan, which are shown in red in Figure 5.3 and 5.8, they are rich and abundant in both natural and cultural attributes, especially for the two trails in North Lantau, with one linking Tai O, Sha Lo Wan, Tin Sum to Tung Chung and another one linking up Tung Chung, Tai Ho to Mui Wo.

However, it is arguable that the analysis considers only some of the attributes of interest which can be quantified and represented in the form of maps. For other attributes, such as scenic beauty, and visibility of the sea which are not quantifiable, they are difficult if not impossible to take into consideration.

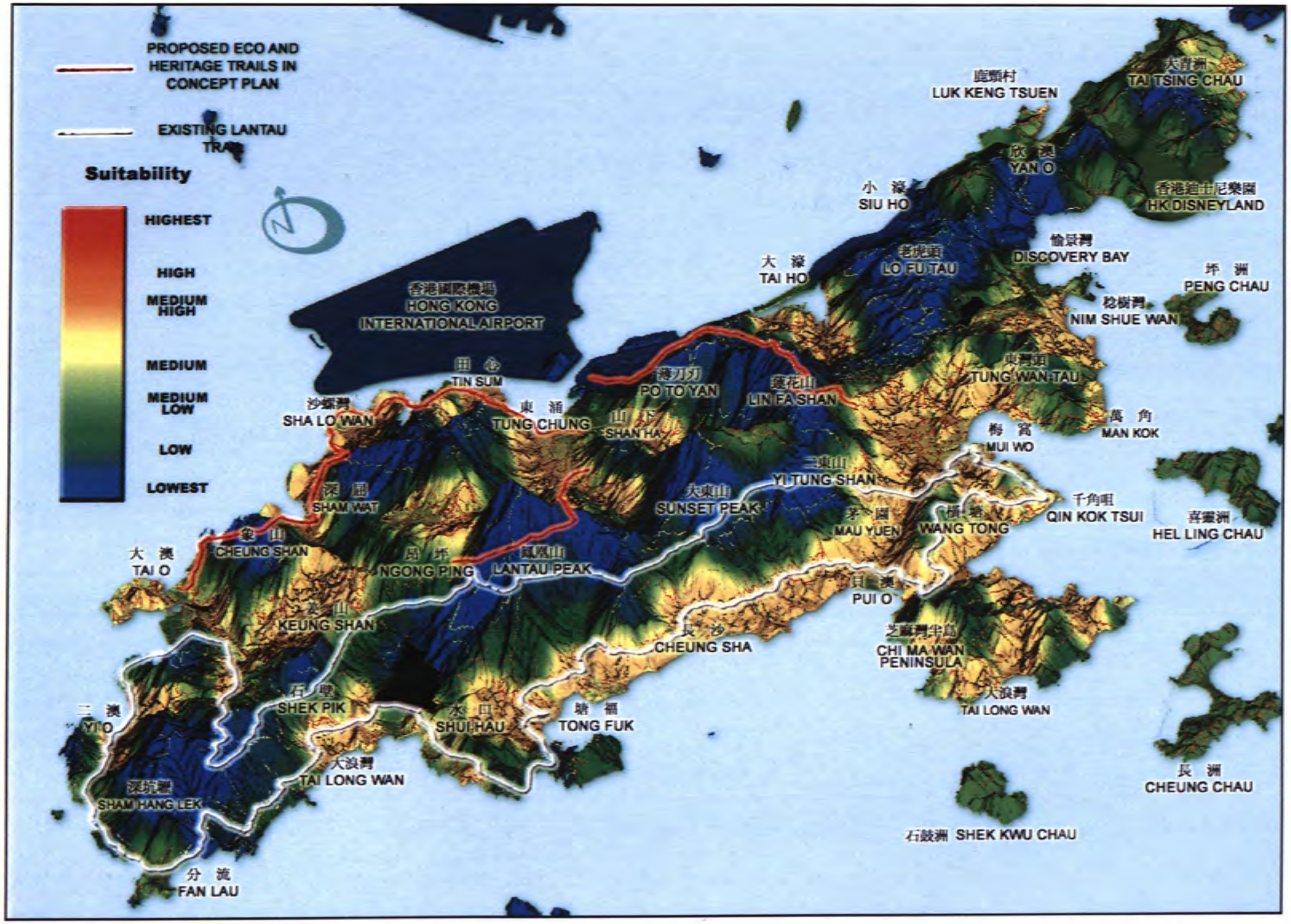


Figure 5.3 Map showing the suitability for hiking in Lantau Island with equal weighting of factors.

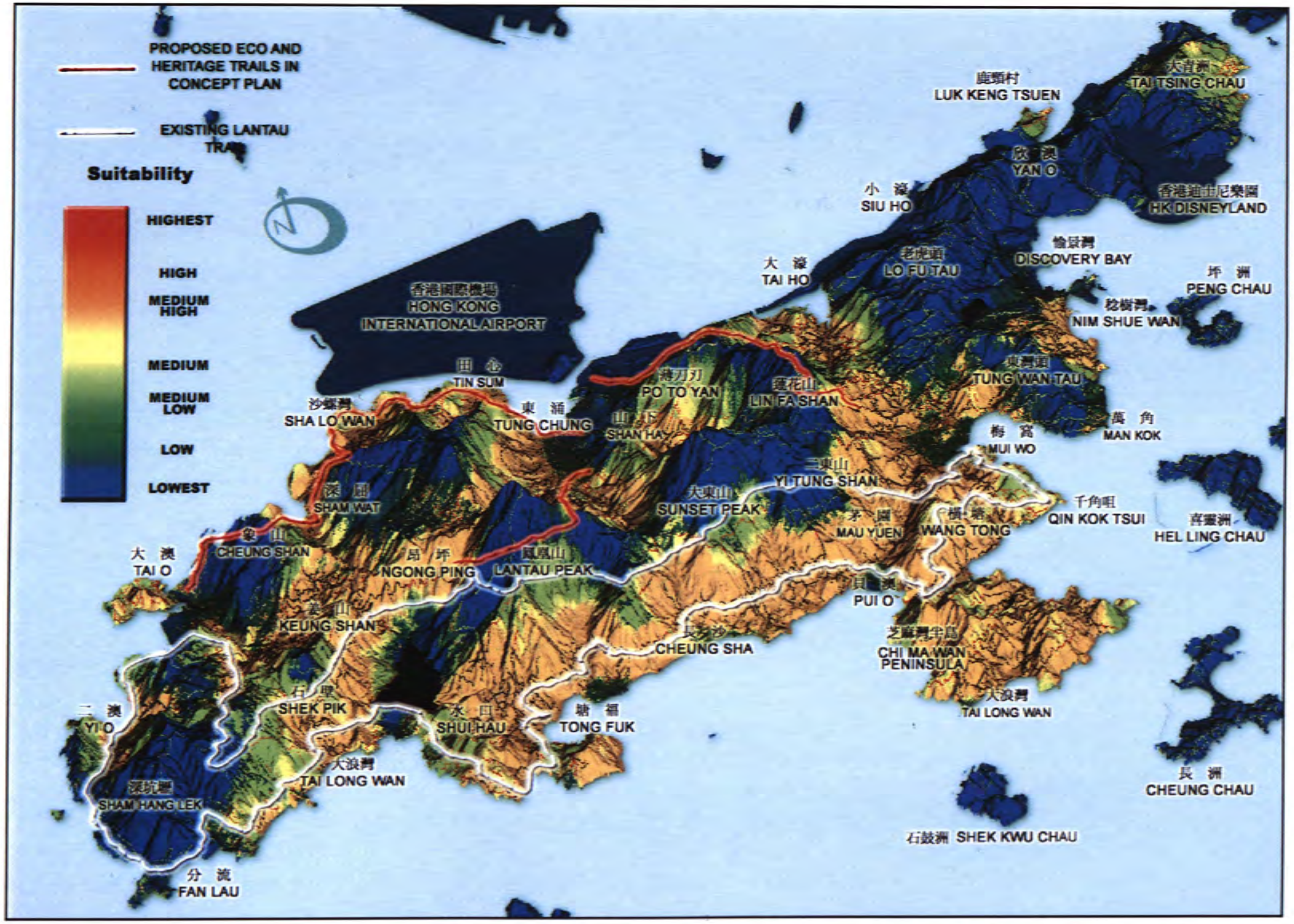


Figure 5.4 Map showing the suitability for hiking with the purpose of bird watching in Lantau Island.

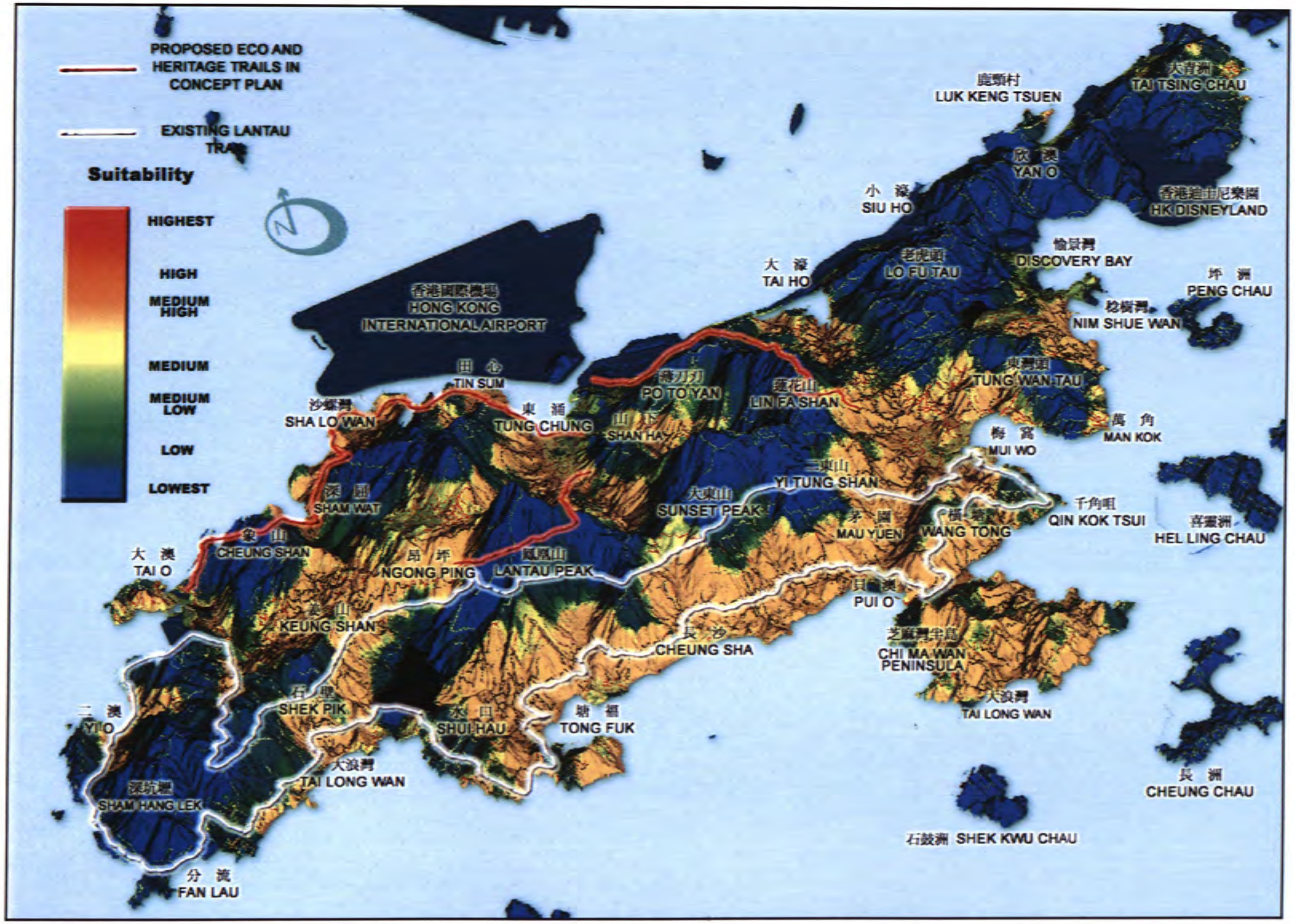


Figure 5.5 Map showing the suitability for hiking with the purpose of butterfly watching in Lantau Island.

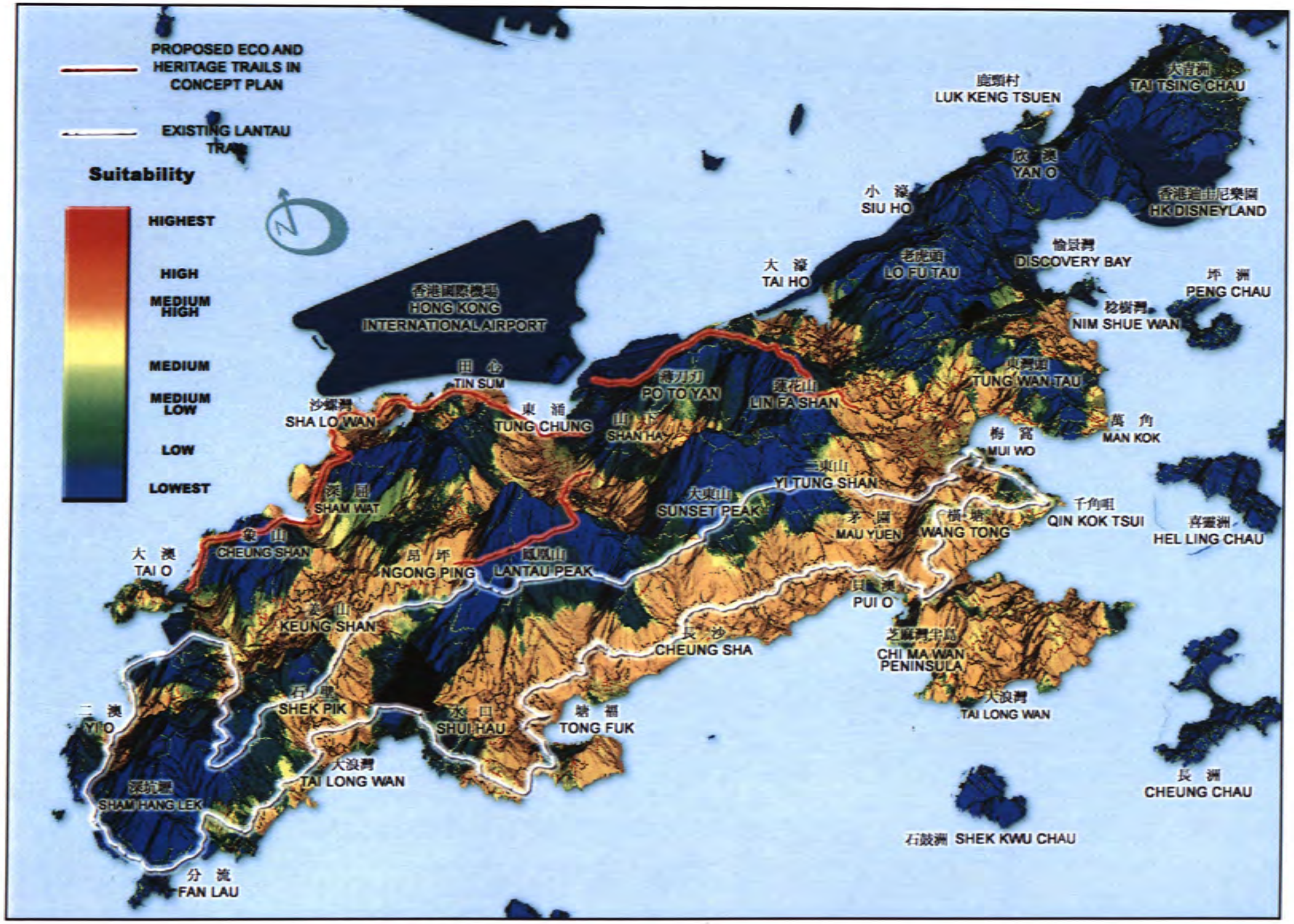


Figure 5.6 Map showing the suitability for hiking with the purpose of dragonfly watching in Lantau Island.

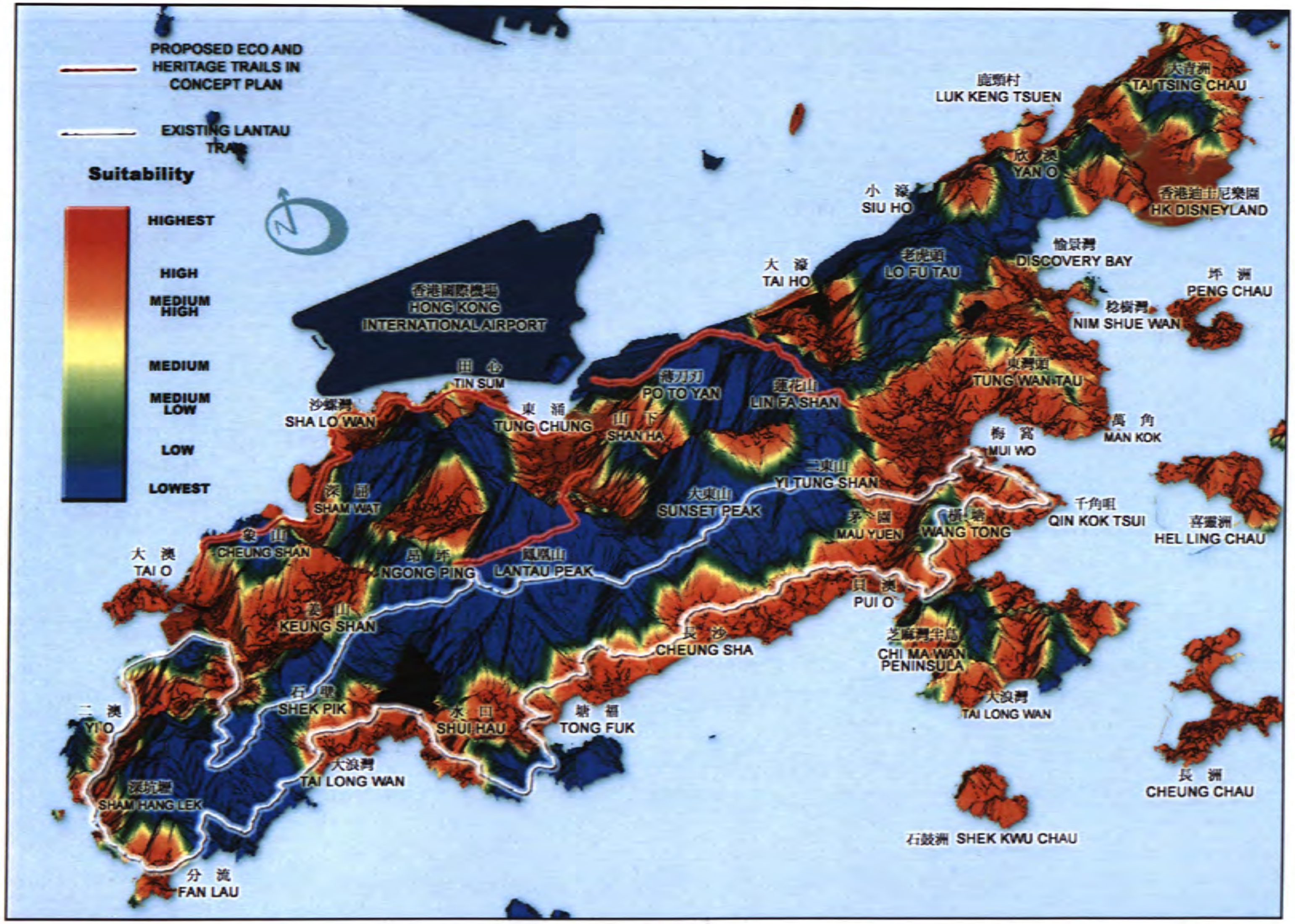


Figure 5.7 Map showing the suitability for hiking with the purpose of heritage-visiting in Lantau Island.

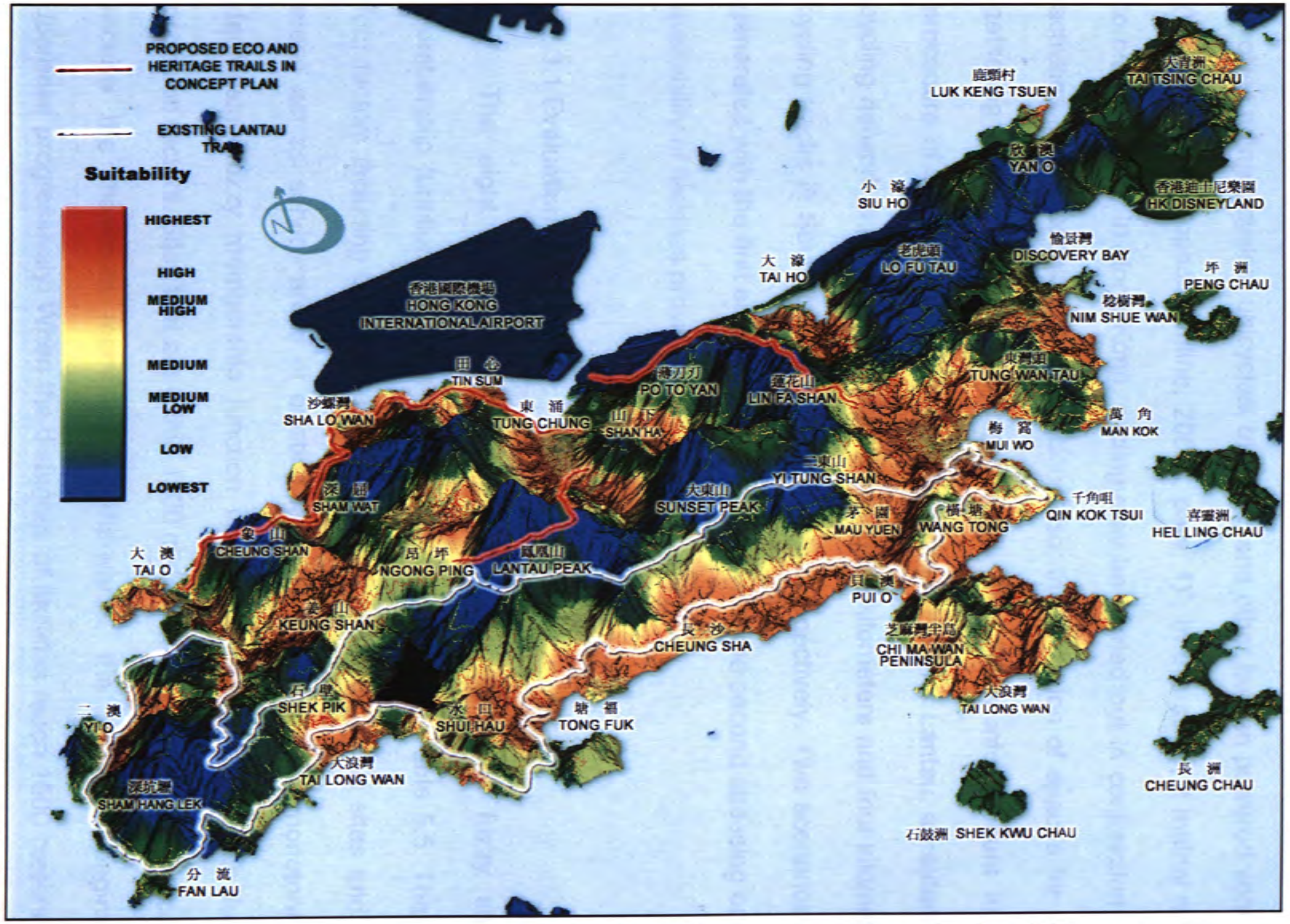


Figure 5.8 Map showing the overall suitability for hiking combined from the four hiking purposes.

5.2.3 Potential Cycling and Picnic Site Selection

"Cycling is a recreation, a sport, and a means of transport across land. It involves riding bicycles, unicycles, tricycles, and other human powered vehicles (Wikipedia Encyclopedia Online, 2006c, para. 1)". In this study, it mainly refers to bicycle riding. In Hong Kong, cycling may be carried out in conjunction with activities like barbecuing, and picnicking. So, the provision of spaces for such gathering activities along a cycling track is also taken into account in the procedure of selection of factors. In the Concept Plan for Lantau, an extensive cycling network is proposed to include an eleven kilometers and four kilometers cycling tracks in South Lantau and in Mui Wo respectively. Two scenarios are generated with the first emphasizing on safety while the second stressing on the availability of facilities provision.

5.2.3.1 Evaluation factors

The eight evaluation factors with their corresponding fuzzy shape membership functions and control points are as shown in Table 5.5. The first four factors including distances from toilets, playgrounds, picnic sites and rest areas act as service areas of existing facilities. The sigmoidal monotonically decreasing fuzzy membership function is used to standardize these facility provision factors. Sites that are within 1000 meters of servicing areas of facilities receive the maximum membership. Afterwards, the suitability begins to decrease progressively. When the distances of facilities reach 1500 meters and beyond, the suitability reduces to zero. The Boolean footpaths and trails map indicate the accessibility to the sites. Distance from the coast is a factor governing the availability of high-quality scenic view. Monotonically decreasing membership function indicates areas with distance of 500 meters or below contributes the maximum suitability to the factors while distance of 1000 meters or above receives zero suitability. The slope steepness is used to ensure safety for the activity. The monotonically decreasing fuzzy membership function with control point of 10 degrees or below indicates maximum suitability. The suitability diminishes progressively until 20 degrees and beyond which it drops to zero. The final factor is distance from non-villages. Non-villages mainly refer to two extensively built-up areas in Lantau, namely, Tung Chung New Town and Discovery Bay. This factor governs the selection of sites that are remote from urban areas. The monotonically increasing fuzzy membership with control point of 500 meters limits the areas within the 500-meter distance under consideration. The suitability increases progressively until 1000 meters at and above which the suitability reaches maximum.

Table 5.5 The eight factors governing potential cycling and picnicking site selection with their corresponding fuzzy membership functions and control points.

Factor	Abbrev.	Fuzzy Shape Membership Function (Sigmoidal)	Control Points			
			a	b	c	d
Distance from Toilets	T_DIST	monotonically decreasing	-	-	1000	1500
Distance from Playgrounds	PG_DIST	monotonically decreasing	-	-	1000	1500
Distance from Picnic Sites	PS_DIST	monotonically decreasing	-	-	1000	1500
Distance from Rest Areas	P_DIST	monotonically decreasing	-	-	1000	1500
Footpaths and Trails	FP_BL	Boolean Map	-	-	-	-
Distance from Coast	CO_DIST	monotonically decreasing	-	-	500	1000
Slope	S	monotonically decreasing	-	-	10	20
Distance from Non-villages	NV_DIST	monotonically increasing	500	1000	-	-

5.2.3.2 Factor weights from the AHP

Apart from equal weighting of factors (0.125), the manipulation of weights of different factors through AHP is used to generate two scenarios. Tables 5.6a and b show the pairwise comparison matrix and the corresponding factor weights for the two scenarios. The weights of the eight factors are also shown in the table. The first scenario has greater emphasis on safety factor, and slope steepness (0.3360). The second scenario emphasizes on facility availability with the highest weight going to distance from toilets and rest areas (0.2663). The consistency ratios are 0.04 and 0.03 for the two scenarios respectively, which fall within the acceptable range.

Table 5.6 Pairwise comparison matrix and the consistent weights for two scenarios of potential cycling and picnicking site selection.

a. Emphasis on safety (CR = 0.04)

	T_DIST	PG_DIST	PS_DIST	P_DIST	FP_BL	CO_DIST	S	NV_DIST	WEIGHT
T_DIST	1								0.0640
PG_DIST	1/3	1							0.0266
PS_DIST	1/3	3	1						0.0357
P_DIST	1	3	3	1					0.0640
FP_BL	3	5	5	3	1				0.1519
CO_DIST	3	5	5	3	1	1			0.1845
S	5	7	7	5	3	3	1		0.3360
NV_DIST	3	5	5	3	1	1/3	1/3	1	0.1373

b. Emphasis on facilities provision (CR = 0.03)

	T_DIST	PG_DIST	PS_DIST	P_DIST	FP_BL	CO_DIST	S	NV_DIST	WEIGHT
T_DIST	1								0.2663
PG_DIST	1/3	1							0.1117
PS_DIST	1/3	1	1						0.1117
P_DIST	1	3	3	1					0.2663
FP_BL	1/5	1/3	1/3	1/5	1				0.0466
CO_DIST	1/5	1/3	1/3	1/5	1	1			0.0502
S	1/3	1	1	1/3	3	5	1		0.1238
NV_DIST	1/7	1/5	1/5	1/7	1/3	1/5	1/5	1	0.0233

5.2.3.3 Results

The results of equal weighting and AHP-weighting are shown in Figures 5.9 – 5.11 respectively. The scenario with a heavy emphasis on safety measure (Figure 5.10) has sorted out the steep slope sites. Together with the factor of distance from the coast, highly suitable alternatives are scattered along the coastal flat land around the edge of the island. Individual sites with medium high or high suitability in the upper portion of the hills, especially Ngong Ping are mainly because of gentle slope, high accessibility by footpaths as well as remoteness. This scenario is considered as the most conservative one among the three.

As for the scenario with an emphasis on facilities provision (Figure 5.11), although the sites with high suitability for cycling and picnicking are almost the same as the previous scenario, this scenario provides a greater flexibility for site selection. Since heavier weights are assigned to land areas that are within the service areas of facilities including toilets and rest areas, sites that have overlapping service areas of different facilities receive high suitability. Instead of identifying discrete sites with high suitability as in the previous scenario especially in South Lantau, the result is much smoother in highlighting the suitable regions for the activity. Besides, since slope is still playing an important role (though not the most important one), gentle sloping sites in high grounds such as Ngong Ping are still regarded as highly suitability. Moreover, disconnected sites along the hillsides disappear in this scenario owing to two reasons. First, when facilities provision is stressed, the lack of facilities along hillsides lowers their suitability level. Second, although these sites are regarded as highly accessible, the relatively low weight on footpaths further lessen their suitability in this scenario. This scenario resembles the equal weighting one in Figure 5.9.

Although there are slight discrepancies among the three scenarios, they all suggest South Lantau, starting from Chi Ma Wan, passing through Pui O, Cheung Sha, Tong Fuk, Shui Hau, Shek Pik and all the way to Tai Long Wan form a continuous waterfront belt which is highly suitable for cycling and picnicking purposes. Besides, individual sites such as Mui Wo, Tai O, Ngong Ping, Sha Lo Wan, Tai Ho, Tung Chung and Discovery Bay all have suitability level ranging from medium to high. These highly suitable sites except Tung Chung and Discovery Bay are all staying away from urban disturbance but highly accessible by footpaths and trails. Besides, they are located on flat lands and stayed close to the coastal front. Moreover, they contain infrastructures such as toilets, rest areas, playground and picnic gathering sites within a reasonable distance, which can accommodate the needs of different visitors.

The Concept Plan has identified two types of cycling tracks, the general cycle track and mountain bike trail. The former is indicated with light blue while the latter one is shown in pink in the Figures. The cycle tracks proposed in South Lantau and Mui Wo are generally high in safety. Facilities of different purposes are adequately provided throughout the two regions. Although this analysis focuses on the former activity, the results provide some implications on the mountain bike trail. The majority of mountain bike trails are existing network and the parts in Pui O and near Mui Wo are proposed new extensions (Lantau development task force, 2004). Judging from the safety scenario (Figure 5.10), the suitability of the cycle track network is always higher than that of the mountain bike network in general. This reveals the challenging nature of mountain biking which can be carried out in undulating landscapes. The low suitability level for general cycling purposes in Chi Ma Wan Peninsula can be suitable for mountain biking. Besides, judging from the facilities provision scenario (Figure 5.11), insufficient facilities provision is observed for the mountain bike network in Qin Kok Tsui and Chi Ma Wan Peninsula.

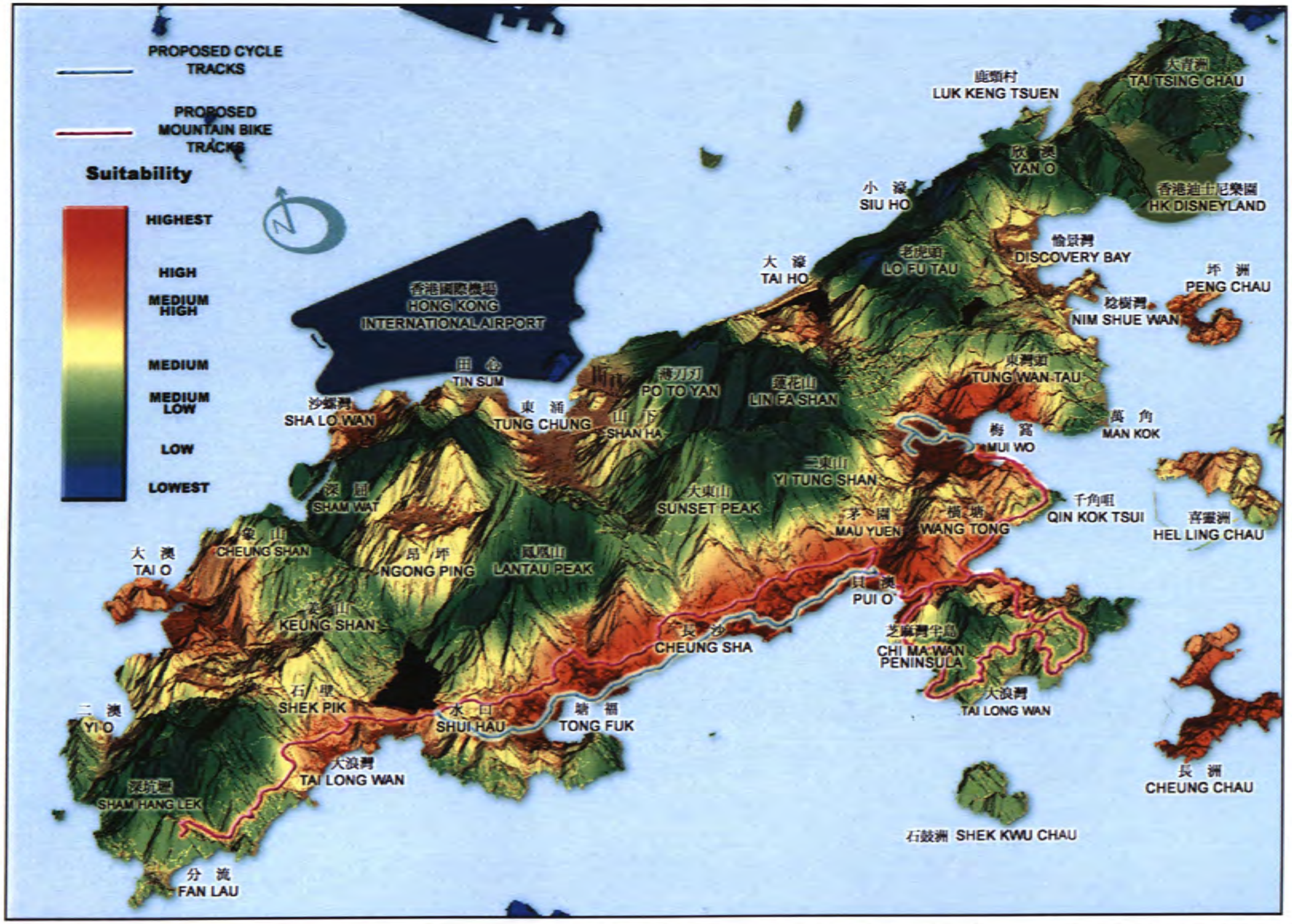


Figure 5.9 Map showing the suitability for cycling and picnicking in Lantau Island with equal weighting of factors.

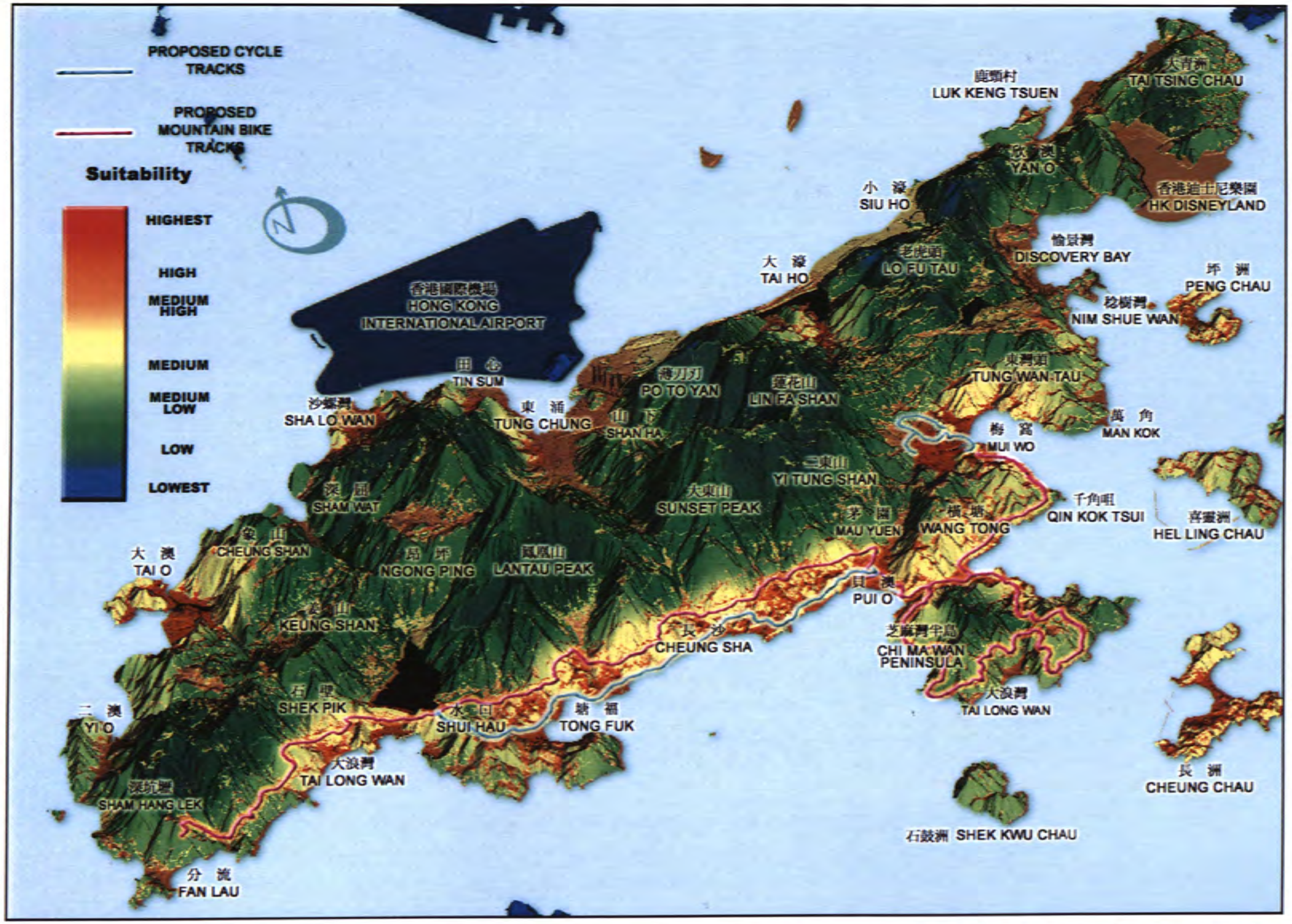


Figure 5.10 Map showing the suitability for cycling and picnicking in Lantau Island with emphasis on safety

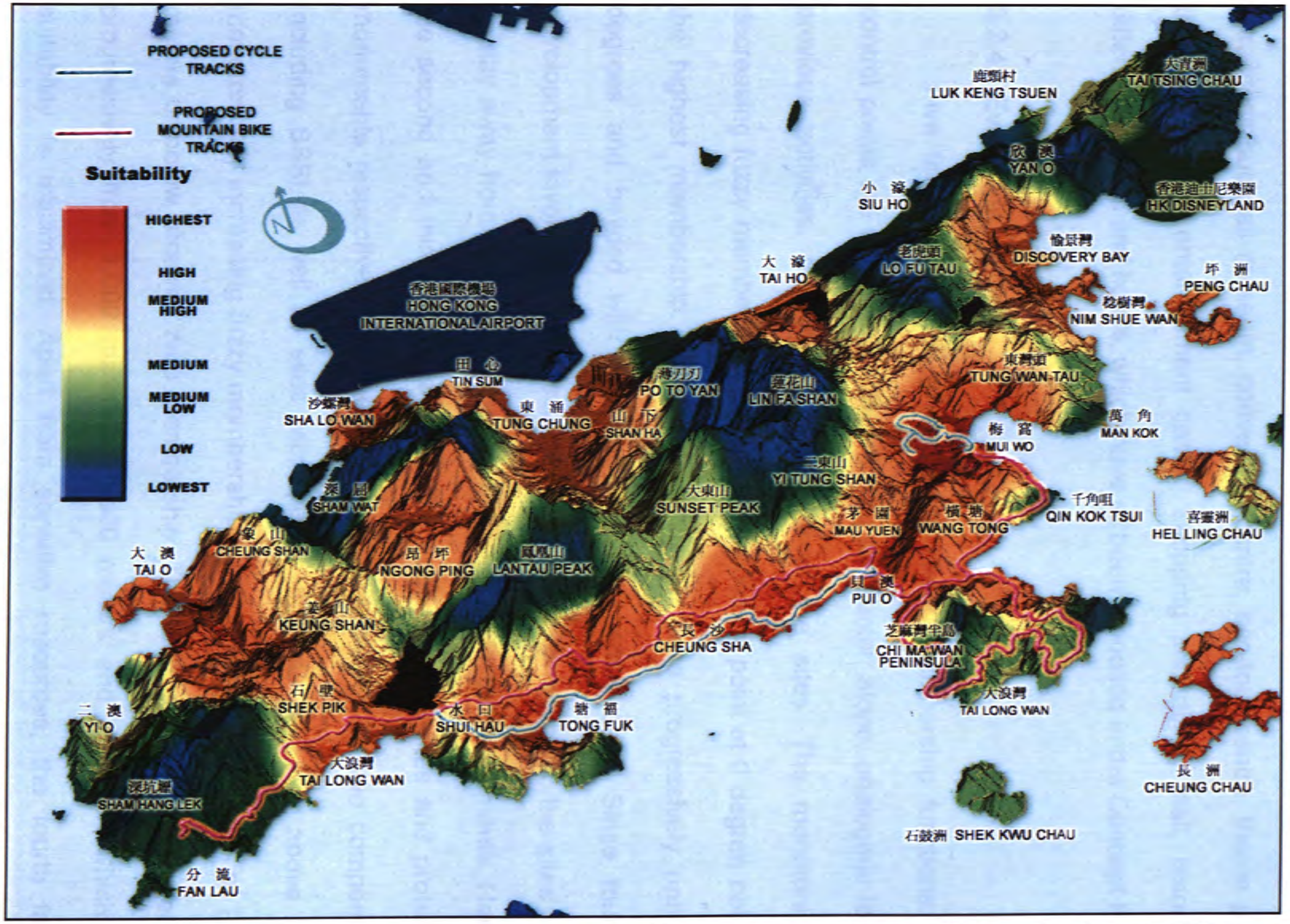


Figure 5.11 Map showing the suitability for cycling and picnicking in Lantau Island with emphasis on facilities provision

5.2.4 Potential Tourism Development Site Selection

Site for tourism development refers to small areas of concentrated attractions such as museum, convention centre, eco-tour centre, theme park, theatre complex, entertainment center, shopping and dining mall, resort of different varieties and hotels, which have all been proposed in the Concept Plan.

5.2.4.1 Evaluation factors

Five factors with their related fuzzy shape membership functions and control points are shown in Table 5.7. The first factor, slope, analogous to the previous activities, determines the safety of the sites. The monotonically decreasing fuzzy membership function with a control point at 0 degree obtains the highest membership. The membership decrease progressively until 20 degrees and beyond with the membership becomes zero. Since tourism development involves different scales and levels of construction, the sites have to stay away from ecological sensitive sites and protected monuments. Hence, the second and third factors are distance from sensitive sites and protected monuments respectively. The sensitive sites are defined by two components including SSSI as well as sites with species richness of 0.9 or above. The monotonically increasing fuzzy membership function with control points of 1,000 meters or below receives zero membership. The fuzzy membership increases progressively from 1,000 meters to 1,500 meters and above in which the suitability is maximized. Apart from sensitive resources, the fourth factor concerns the Lantau North and South Country Parks. A binary map is used for this factor with zero assigned to areas within the Country Park boundary while one for non-Country Park areas. This factor governs the unsuitability of tourism development to be carried out within the Country Park boundary. The fifth and final factor concerns accessibility to the sites. The same notion is applied to protected monuments. Sites with a distance of 50 meters or below from these monuments are classified as totally unsuitable while 100 meters or beyond are regarded as the most suitable. Areas that can be accessed via existing road networks receive a higher priority. The monotonically decreasing membership function is used. Sites with a distance of 20m or less are regarded as the most suitable while 200 meters or beyond are classified as unsuitable.

Table 5.7 The five factors governing potential tourism development site selection with their corresponding fuzzy membership functions and control points.

Factor	**Abbrev.**	**Fuzzy Shape Membership Function (Sigmoidal)**	**Control Points**			
			a	**b**	**c**	**d**
Slope	S	monotonically decreasing	-	-	0	20
Distance from sensitive sites (SSSI and Species Richness over 0.9)	SS_DIST	monotonically increasing	1000	1500	-	-
Distance from Protected Monuments	PM_DIST	monotonically increasing	50	100	-	-
Lantau North and South Country Parks	CPs_BL	Binary without Fuzziness	-	-	-	-
Distance from Main Roads	RD_DIST	monotonically decreasing	-	-	20	200

5.2.4.2 Factor weights from the AHP

Apart from equal weighting of factors (0.2), the pairwise comparison matrix and the resultant weights are shown in Table 5.8. A heavier emphasis has been put on the distance from ecological sensitive sites and protected monuments (0.3899), which show the significance of protecting these areas from disturbance. The distance from main roads and the unsuitability of Country Park areas have equal weights of 0.1524 while slope has 0.0679. The consistency ratio is 0.01 suggesting that the AHP-weighting is reasonably consistent.

Table 5.8 Pairwise comparison matrix and the consistent weights of potential tourism development site selection.

	S	SS_DIST	PM_DIST	CPs_BL	RD_DIST	WEIGHT
S	1					0.0679
SS_DIST	5	1				0.3899
PM_DIST	5	1	1			0.3899
CPs_BL	3	1/3	1/3	1		0.1000
RD_DIST	3	1/3	1/3	1	1	0.1000

5.2.4.3 Results

The result of equal-weighting and AHP-weighting are shown in Figures 5.12 and 5.13 respectively. When the ecological and cultural attributes are stressed in Figure 5.13, the further the sites are away from these two factors, the higher are the suitability they received. Generally, the sites with a high suitability level for tourism development are distinctively clustered in two areas – (1) the north-eastern Lantau including Tai Tsing Chau, Yan O, Siu Ho and Lo Fu Tau) and (2) south-western Lantau including Tai O, Nga Ying Kok, Yi O, Fan Lau and Kau Ling Chung. When compared with the equal-weighting scenario, the suitability levels of the two clusters are raised from medium high to high and highest because these clusters stay relatively far away from the ecological and cultural sensitive sites including the SSSIs, sites with high species richness.

Besides, the suitability levels in South Lantau and Tung Chung are slightly reduced. Firstly, it can be explained by their short distances from the ecological sensitive sites. Secondly, the relatively lower weights in accessibility of roads also reduce the attractiveness of the sites. On the other hand, since areas within the Country Parks are weighted relatively lower, it is also observed that the general suitability with the boundaries of the Country Parks is increased. Besides, areas around Tai Hom Sham and Sham Hang Lek in southwestern Lantau which are under the protection of the Lantau South Country Park are being classified as highly suitable for tourism development.

When comparing with the tourism development proposals in the Concept Plan, the entertainment complex in Sunny Bay is extremely suitable. The eco-tour center, museum of Lantau and theme park clustering around Tung Chung receive an average of medium high to high suitability levels. The resorts and watersports centers in South Lantau have high suitability in the equal weighting scenario, but the suitability lowers to around medium and medium high with the specificity of high species richness in South Lantau. Finally, the Golf Course cum Resort at Tsing Chau Tsai East shows the greatest discrepancy between the two scenarios. The equal-weighting suggests the site has only a medium level of suitability while the result from AHP-weighting indicates a very high suitability because of its long distance away from ecological sensitive sites. The development of these sites should be under further scrutiny and careful consideration.

Figure 5.12 Map showing the suitability for tourism development in Lantau Island with equal weighting of factors.

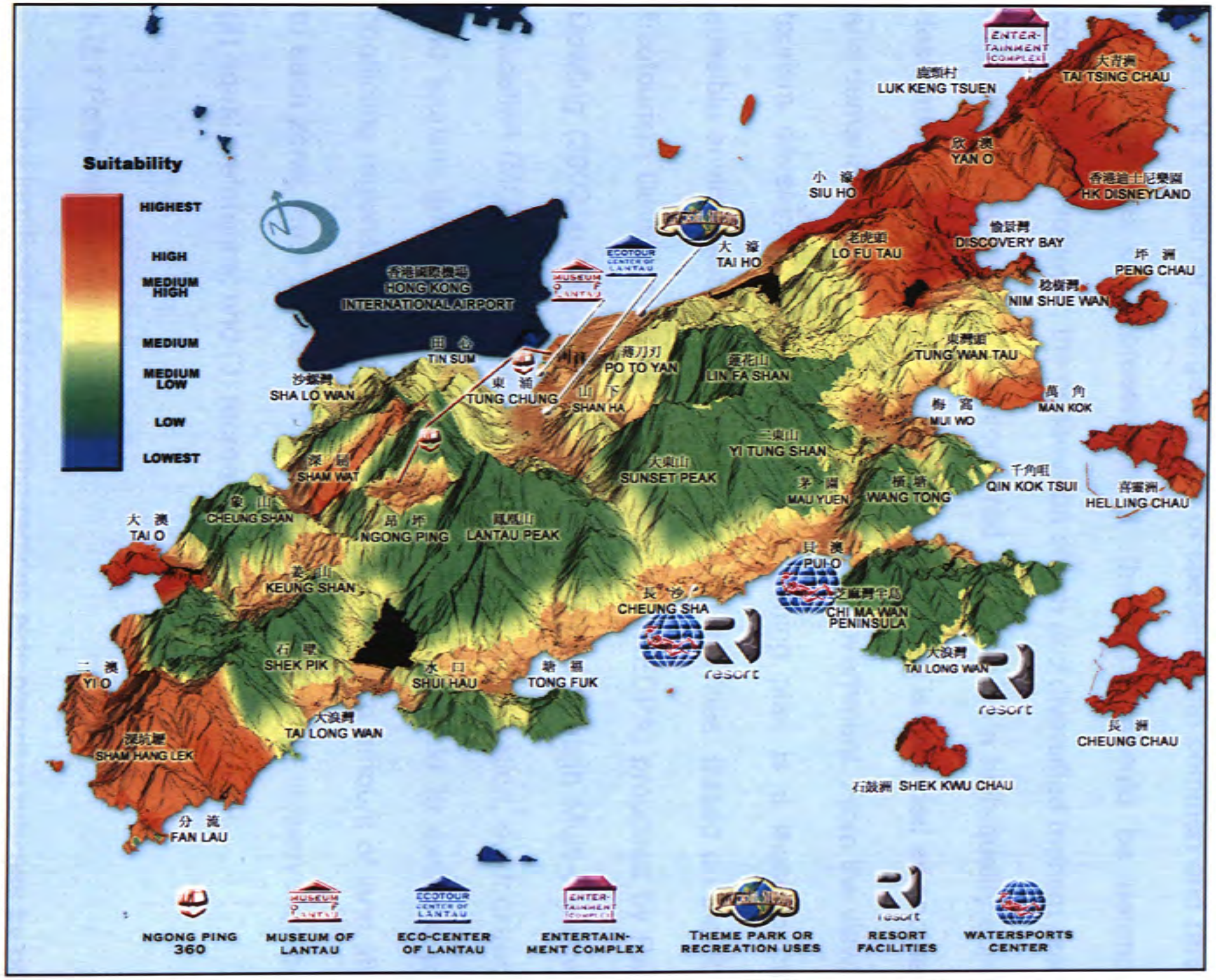


Figure 5.13 Map showing the suitability for tourism development in Lantau Island with emphasis on significant natural and cultural attributes protection

5.3 Zone Allocation and Zoning Plans

Lantau Island is one of last pieces of remaining lands of conservation value in Hong Kong. She owns many ecologically valuable resources and is home and shelter for a large number of species, both common and rare. From the perspective of a preservationist, the island should be defended for conservation. However, the possession of rich and diversified tourism resources, both natural and cultural, has conferred it the role as a high-quality ecotourism destination. Recreational and tourism development is regarded as another focus and demand requested by the public and the government. From the viewpoint of tourism development, a comprehensive zoning plan is a must to minimize possible environmental impacts from tourism activities. Based on the Regional Ecotourism Development Planning Approach (REDPA) proposed by Page and Dowling (2002, p.214), four zones are developed through Multi-objective Land Allocation (MOLA) including sanctuary, nature conservation, outdoor recreation and tourism development. The four zones are overlaid to examine potential conflicting regions. Then, by adjusting the weight and amount of land allocation to each zone, three scenarios are generated, namely, (1) conservation-oriented; (2) equal preference; and (3) recreation-and-tourism-oriented.

5.3.1 Potential Conflicting Sites

The identification of conflicting regions aids planning process by providing further understanding of the site characteristics. Among the four objectives, the sanctuary and nature conservation objectives are grouped to represent conservation initiative and compared with the recreation and development objectives. Regarding each particular objective, sites are reclassified to only two categories – suitable and unsuitable. By using simply overlay analysis of the three layers, the results are shown in Figure 5.14. Dark green, light green and light brown represent conflicts between conservation and recreation; conservation and tourism development; and recreation and tourism development respectively. The regions highlighted in red are conflict involving all the three objectives.

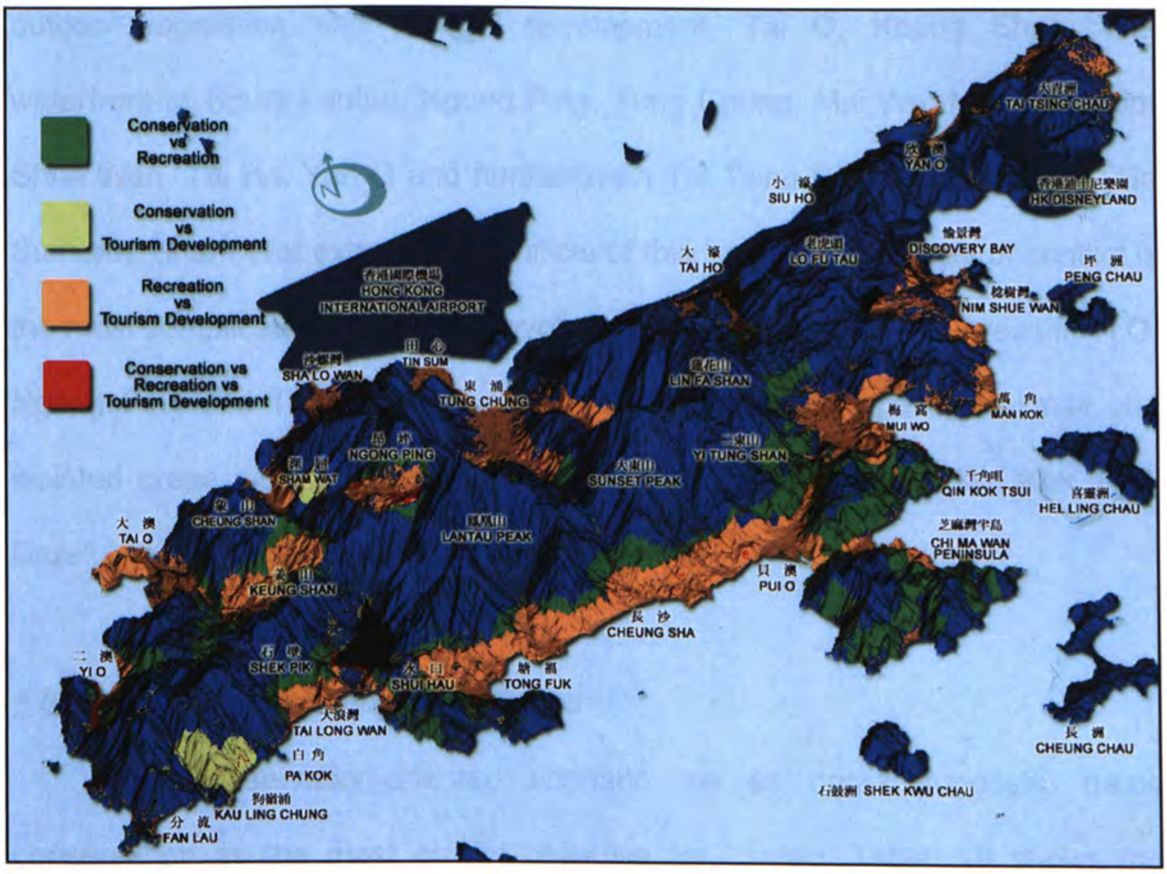


Figure 5.14 Conflicting regions between conservation, recreation and tourism development objectives

The existence of conflict between conservation and recreation is located mainly in South Lantau, Chi Ma Wan Peninsula, Keung Shan, Yi O, Tai Ho and areas around Ngong Ping. This kind of conflict is regarded as the least vital and conflicting one since in most of the cases, conservation and recreation are symbiotic. The more prominent one is the conflict between conservation and tourism development. Only two areas fall into this category including the areas between Kau Ling Chung and Pa Kok as well as areas next to Sham Wat. The third kind of conflict is the most abundant one which is the conflict between outdoor recreation and tourism development. Tai O, Keung Shan, The waterfront of South Lantau, Ngong Ping, Tung Chung, Mui Wo, Man Kok, Nim Shue Wan, Tai Ho, Yan O and northeastern Tai Tsing Chau, Sha Lo Wan, Tin Sum and Sham Wat experience conflicts of this kind. The final type of conflict is the most complicated one since it involves all the three objectives. Areas in Yi O, Ngong Ping and Tai Ho are obviously identified as this type while small and isolated areas includes Fan Lau, foothill of Yi Tung Shan and Qin Kok Tsui. Careful consideration for these sites is essential.

5.3.2 Scenario 1: Conservation-oriented

The conservation-oriented scenario, as its name suggests, treats conservation as the most crucial objective for Lantau. Table 5.9 shows the weights and amounts of areas assigned to this objective. The significance of conservation is emphasized through assigning a heavier weight and more areas to the first two objectives. Sanctuary receives the heaviest weight of 0.4 and at least 15% of land areas should be allocated to the objective. Nature conservation has the second highest weight 0.3 and the minimum land allocated has to be 50% of Lantau's total land areas. The two objectives have a total weight of 0.7 out of 1 as well as total areas required of 65%. With a view to separate the protected zones from the possible impacts of tourism development, a 100-meter buffer zone is constructed around the two zones. The last two objectives are minimized in terms of weights and areal allocation. Outdoor recreation and tourism development objective has a weight of 0.2 and 0.1 and minimum required area of 10% and 5% respectively. The zoning plan is shown in Figure 5.15.

Table 5.9 The weight and areal assignment to the four zoning objectives with emphasis on conservation

Objective/ zone	Weight	Areal Requirement	% of area in Lantau
Sanctuary	0.4	219,000	15%
Nature Conservation	0.3	730,000	50%
Outdoor Recreation	0.2	146,000	10%
Tourism Development	0.1	73,000	5%

In Figure 5.15, the whole of Lantau is almost classified into sanctuary and nature conservation zones. Apart from the eight SSSIs, the sanctuary zone has extended to the southern Lantau, Tai Long, Cheung Sha Wan, northern Mui Wo, western Tung Chung, Yi O, around Keung Shan, Wang Tong, Mong Tung Wan, Shan Ha, Nim Shue Wan, Tai Shui Hang, and western valleys in Nei Lak Shan owing to their high species richness. Together with the nature conservation zone, the areas reserved for conservation have exceeded the original Country Parks boundary. Limited recreational activities are clustered around the south Lantau including Pui O, Cheung Sha, Tong Fuk, Shui Hau and Tai Long Wan. Separate, individual and large recreational sites are located in Mui Wo, Tung Chung south to Tei Tong Tsai, Tin Sum, Sha Lo Wan and Tung Wan Tau while small sites includes areas in Tai Ho, Tai O and Keung Shan. Tourism development sites are restricted to areas around Discovery Bay, Hong Kong Disneyland, Tai Yam, Yan O, Siu Ho, Tung Chung and Tai O.

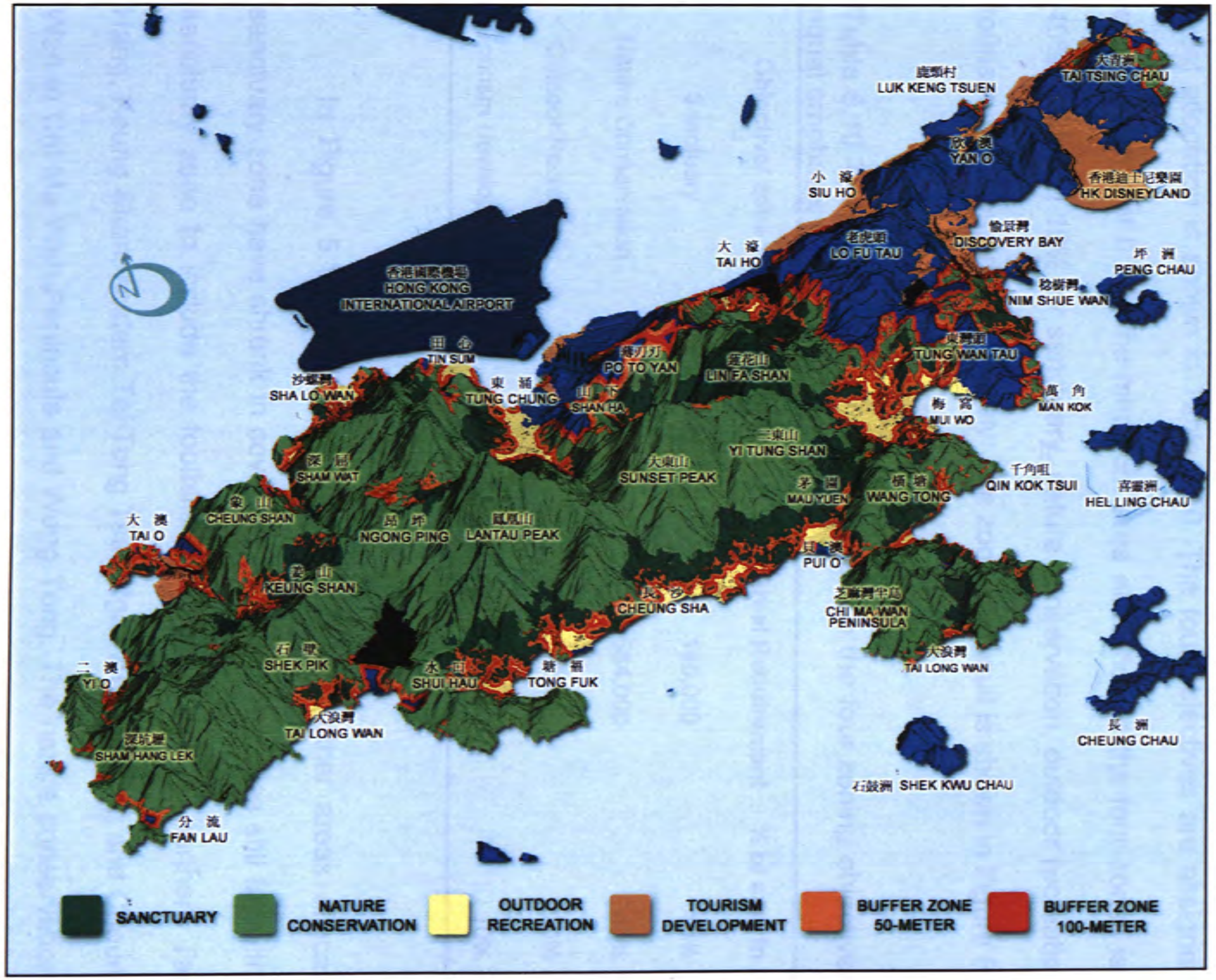


Figure 5.15 Zoning Plan of the conservation-oriented scenario

5.3.3 Scenario 2: Equal-preference

The equal preference scenario simulates a balanced development approach with no specific emphasis on particular objective. The weight and areal allocation is shown in Table 5.10. The four objectives are assigned with equal weights of 0.25. The minimum area allocation to the four zones is 10%, 40%, 20% and 10% for sanctuary, nature conservation, outdoor recreation and tourism development respectively. The zonation result is shown in Figure 5.16.

Table 5.10 The weight and areal assignment to the four zoning objectives with equal emphasis

Objective/ zone	**Weight**	**Areal Requirement**	**% of area in Lantau**
Sanctuary	0.25	146,000	10%
Nature Conservation	0.25	584,000	40%
Outdoor Recreation	0.25	292,000	20%
Tourism Development	0.25	146,000	10%

In Figure 5.16, apart from the eight SSSIs, other areas allocated to sanctuary zone have shrunk in coverage and size. The sites still fall within the sanctuary zone to include the foothills of southern Lantau, northern Tai Shui Hang, Keung Shan, eastern Tei Tong Tsai, Ngau Au, Tai Long and Cheung Sha Wan in Chi Ma Wan Peninsula and Wang Tong. The nature conservation zone covers more or less the same areas as that of Lantau North and South Country Parks. However, the previously covered areas, Tai Hom Sham and Sham Hang Lek in south-western Lantau as well as Cheung Shan are released with no specific zonation. The recreational zone which is located in the previous conservation-oriented scenario has expanded. They include the southern Lantau, Tai Long Wan, Mui O, Tung Wan Tau, Tai Ho, southern Tung Chung, Tin Sum, Sha Lo Wan, and western Keung Shan. New recreational sites include western Tai Tsing Chau, Luk Keng Tsuen, Qin Kok Tsui, Man Kok, Tai Shui Hang, Nim Shue Wan, Ngong Ping, Shan Ha, Fan Lau, Tai O, Yi O and Sham Wat. The tourism development sites clustered in the north-eastern Lantau including sites of Tsing Chau Tsai, Yan O, Siu Ho, Tung Chung, areas around Discovery Bay and Hong Kong Disneyland as well as Tai O are expanded. Extra tourism development sites are mainly found in Ngong Ping, Fan Lau, Shek Pik, Tong Fuk, Pui O, Mui Wo and Man Kok.

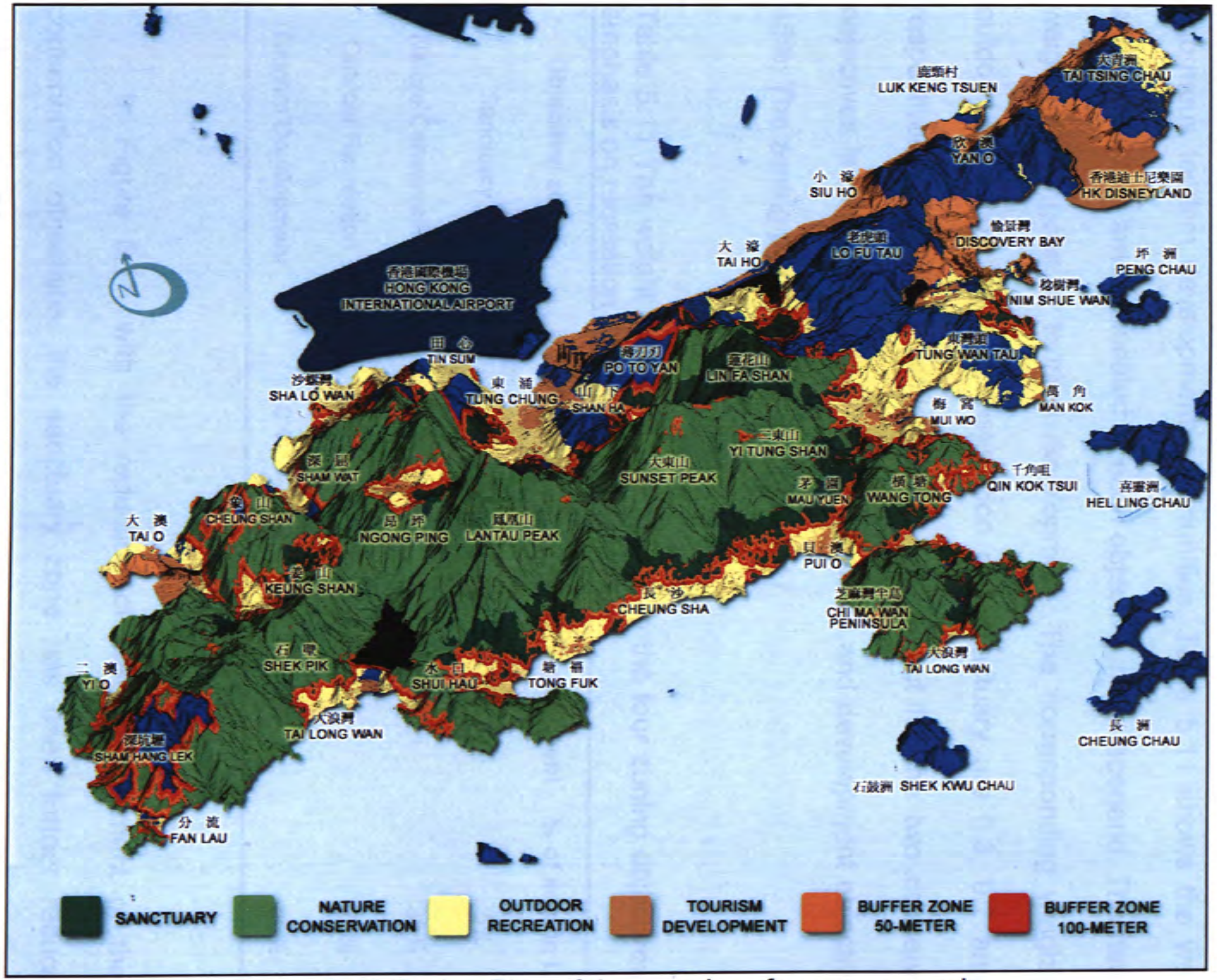


Figure 5.16 Zoning Plan of the equal-preference scenario

5.3.4 Scenario 3: Recreation-and-tourism-development-oriented

The tourism development and recreation oriented scenario put emphasis on turning and shaping Lantau into a site into a tourism destination with enormous tourism development opportunities. Table 5.11 shows the weights and amounts of areas allocated to each objective in this scenario. The heaviest weight of 0.4 goes to tourism development. The corresponding weights for outdoor recreation, nature conservation and sanctuary are 0.3, 0.2 and 0.1 respectively. The total minimum areal requirement for the two conservation objectives is 35% while that for the recreational and development objectives is 45%. The zoning plan is shown in Figure 5.17.

Table 5.11 The weight and areal assignment to the four zoning objectives with emphasis on recreation and tourism development

Objective/ zone	**Weight**	**Areal Requirement**	**% of area in Lantau**
Sanctuary	0.1	73,000	5%
Nature Conservation	0.2	438,000	30%
Outdoor Recreation	0.3	365,000	25%
Tourism Development	0.4	292,000	20%

In Figure 5.17, with the reduction of areal requirement of the two conservation objectives, the sanctuary zone has been further reduced to embrace the SSSIs only with some small and disconnected sites located in southern Lantau. Mountain ranges of Lantau Peak, Sunset Peak, Yi Tung Shan western Lin Fa Shan as well as Cheung Shan, Tai Hom Sham, Sham Hang Lek and areas around Yi O in the western Lantau, which fall within the Lantau Country Park protection systems have been excluded and idle with no allocation to specific objectives. The outdoor recreational sites further spread out from the sites mentioned in both scenarios covering the entire South Lantau which start from Tai Long Wan and extend and connect to Mui Wo, Tung Wan Tau, Tai Shui Hang and Nim Shue Wan. Areas in Tai O, Keung Shan, Ngong Ping, Sha Lo Wan, Tin Sum, Tung Chung, Shan Ha, Sham Wat, Tai Ho and Tai Long also spread out further. Cheung Sha Wan in Chi Ma Wan Peninsula and Wang Tong are two newly adjoin sites. Finally, the tourism development sites are clustered mainly in the north and north-eastern part of Lantau extending from Tung Chung, passing through Tai Ho, Siu Ho, Lo Fu Tau, Discovery Bay, Yan O, Luk Keng Tsuen, and Hong Kong Disneyland to Tai Tsing Chau. South Lantau including Fan Lau, Shek Pik, Tong Fuk, Cheung Sha, Pui O as well as individual sites in Ngong Ping, Sham Wat, Tai O, Mui Wo and Man Kok are also sites designated as tourism development zone.

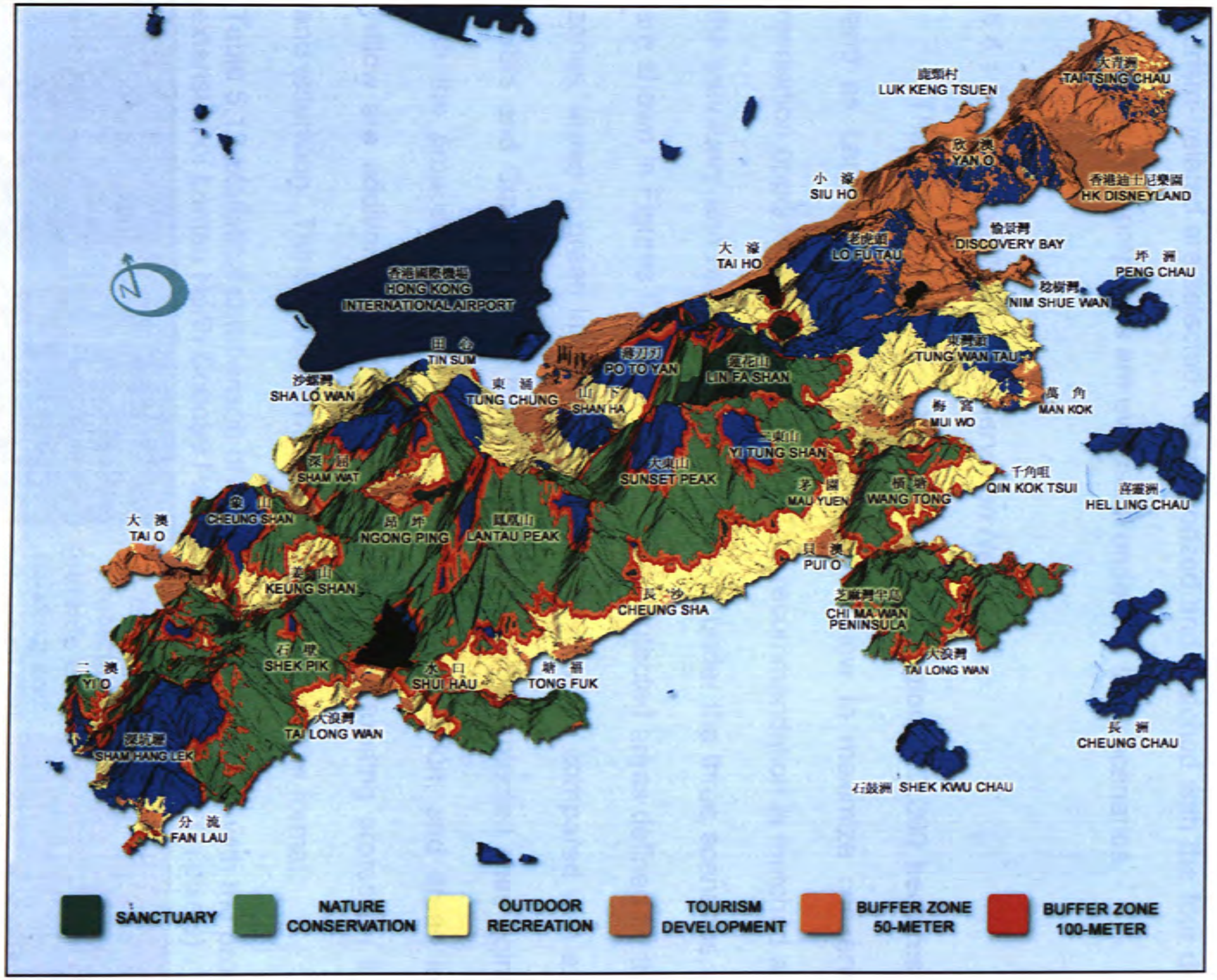


Figure 5.17 Zoning Plan of the recreation-and-tourism-development-oriented scenario

5.4 Evaluation and Recommendation for the Concept Plan

The Concept Plan for Lantau proposes a number of plans regarding the future development of the Island. The proposals which are conservation- or tourism- related are selected, re-categorized and matched with the four defined objectives. The proposals are evaluated under the three scenarios.

5.4.1 Exploring Additional Conservation Needs

The Concept Plan has proposed a designation of 2,360 hectares extra land as Lantau North Country Park with a view to maximize conservation, recreation opportunities for the island. This recommendation is matched against the sanctuary and nature conservation zones under the three scenarios, which are shown in Figures 5.18 – 5.20. Given the protected areas defined by the two zones, areas in green indicate unprotected areas when compared with existing SSSIs and Country Parks; those in red show extra protected sites coinciding with the proposed Lantau North Country Park extension; and areas in light yellow are additional protected areas outside both existing protection system and extension;. Table 5.12 shows the comparison in tabular format.

Table 5.12 Statistical comparison of nature conservation zone with the proposed extension of Lantau North Country Park under three scenarios (in pixels)

Scenario	MOLA - Nature Conservation zone	Unprotected (Compared with existing CP)	Extra Protected (outside both existing and proposed CP)	Extra protected (coincide with extended CP)	Proportion related to the total extension
1	Conservation-oriented	118,667	202,367	83,700	35.3%
2	Equal-Preference	59,324	41,123	13,665	5.8%
3	Recreation-oriented	237,284	549	11	0%

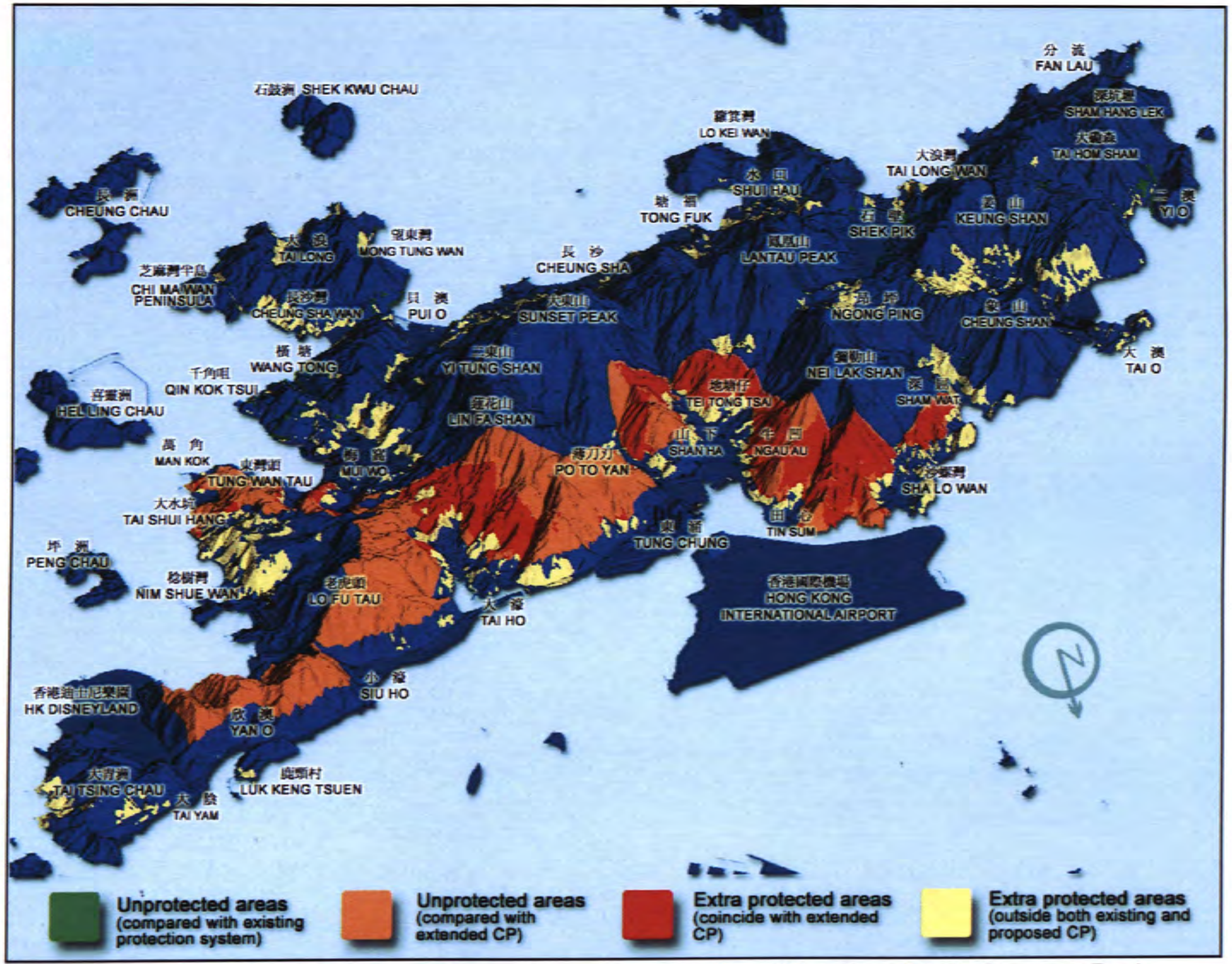


Figure 5.18 Comparison of the proposed extension of Lantau North Country Park with nature conservation zone defined by conservation-oriented scenario.

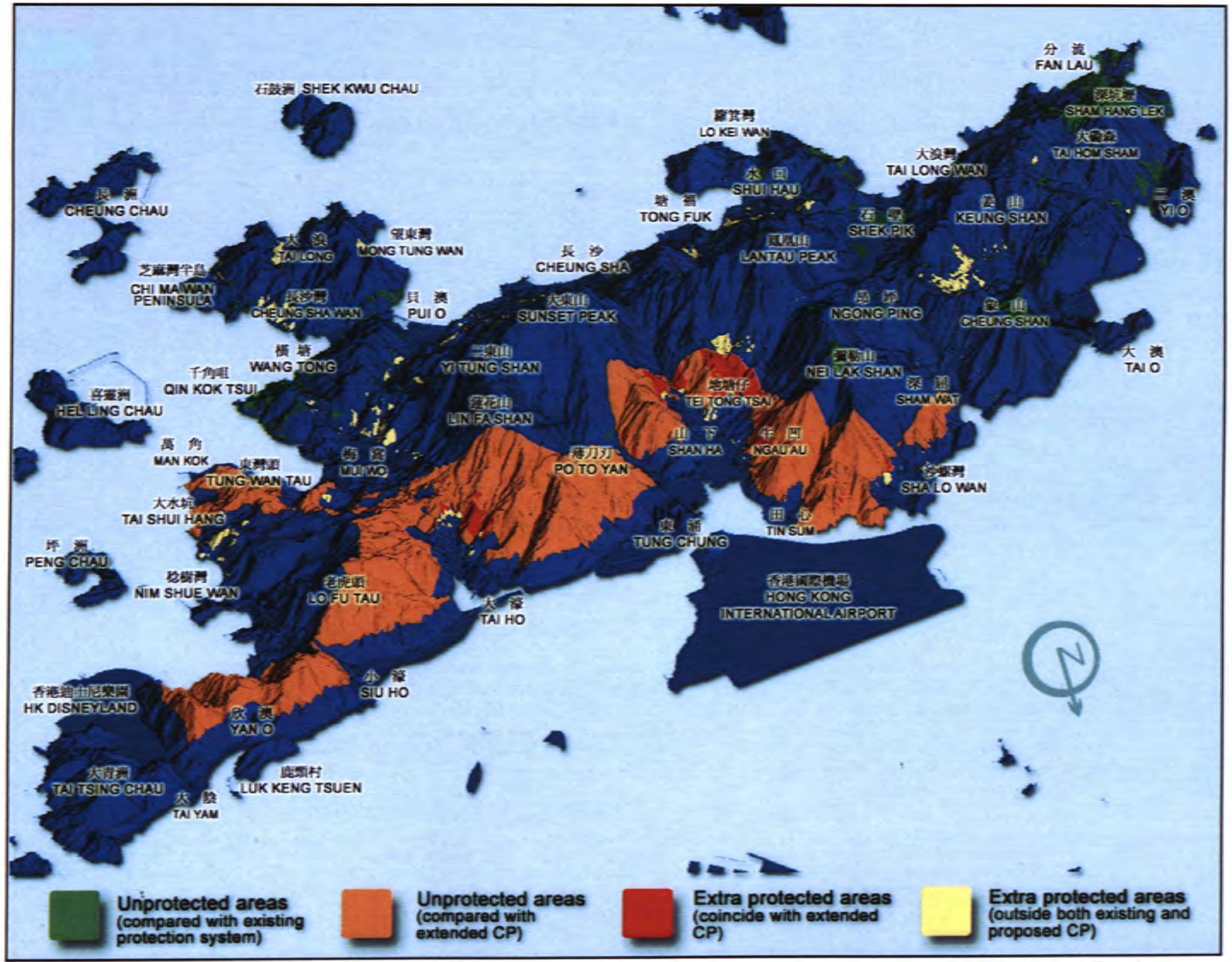


Figure 5.19 Comparison of the proposed extension of Lantau North Country Park with nature conservation zone defined by equal-preference scenario.

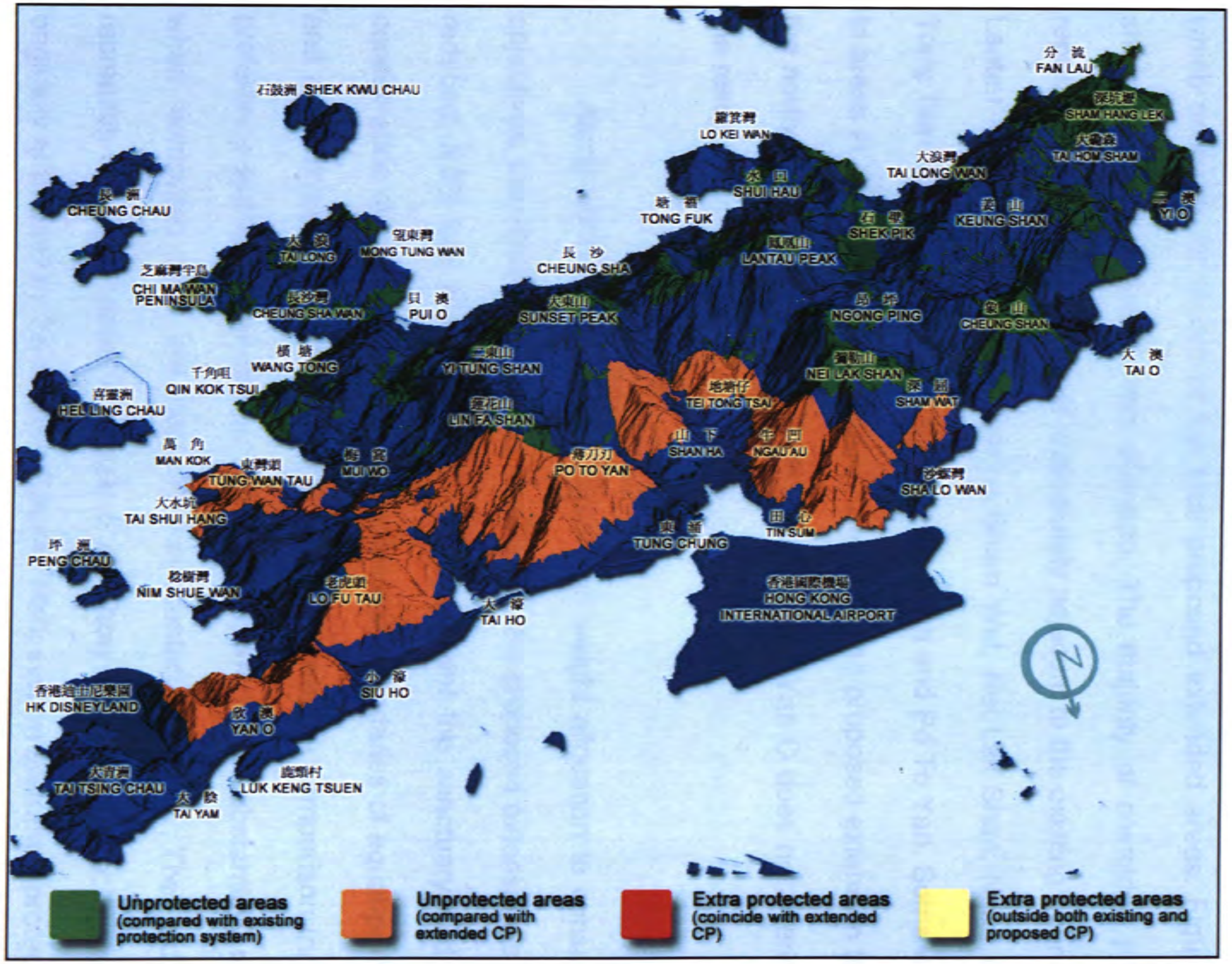


Figure 5.20 Comparison of the proposed extension of Lantau North Country Park with nature conservation zone defined by recreational-and-tourism oriented scenario.

Under the most optimistic scenario in terms of conservation, the additional protected areas, defined by sanctuary and nature conservation zones fall within the proposed extended Lantau North Country Park is 83,700 pixels which accounts for 35.3% of the total proposed extended areas. Figure 5.18 shows the comparison for this scenario. The majority of coincided portions, represented in red, are located immediately adjacent to the existing boundary of Lantau North Country Park including Sham Wat, Nei Lak Shan, Ngau Au, Tei Tong Tsai, foothills of Sunset Peak, Lin Fa Shan and Po To Yan. Some extends to areas in Tai Shui Hang and Tung Wan Tau. The proposed extension towards the northeast in areas around Lo Fu Tau, Siu Ho, Yan O does not overlap with the result.

Along with the shrinkage in areal and weight allocation to conservation objectives, the amount of sites that match with the proposed extension is largely reduced. 5.8% and 0% respectively of sites under the sanctuary and nature conservation objectives fall within the extension boundaries of equal-preference and recreation-oriented scenario. Figure 5.19 shows the comparison for equal-preference scenario in which the areas of concurrence is substantially reduced when compared with the conservation-oriented scenario. The picture of recreation-oriented, shown in Figure 5.20, show no coincidence. Many areas originally embraced by the existing Country Park system are under-protected.

Judging from the results, some additional sites fall outside the existing and proposed protection system boundaries (which are highlighted in light yellow). The areas includes Pui O, Cheung Sha, Tong Fuk, Shui Hau in the South Lantau, Mui Wo, northern Tai Shui Hang, Keung Shan, eastern Tei Tong Tsai, Ngong Ping, Ngau Au, Wang Tong, and Tai Long and Cheung Sha Wan in Chi Ma Wan Peninsula. These sites, defined by species richness, are worthy of further exploration of potential ecological values so as to demarcate extra protection areas.

5.4.2 Maximizing Recreational Opportunities

With Lantau's abundant natural and cultural resources, maximizing recreational opportunities is also another goal in the Concept Plan. The Concept Plan proposes a number of recreational activities including cycle tracks in South Lantau and Mui Wo; eco-trails and heritage trails; and high-quality camping sites. The three activities match against the results from MCA independently. The selection of recreational sites summarized from the three scenarios suggests South Lantau (Tai Long Wan, Shui Hau, Tong Fuk, Cheung Sha and Pui O), East Lantau (Mui Wo, Tai Shui Hang and Nim Shue Wan), sites near Tung Chung and individual sites such as Ngong Ping, Sham Wat, Keung Shan and Tai O are all suitable sites for the accommodation of compatible recreational activities.

Recreational activities are scale and purpose dependent. Activities with different levels of scales and purposes call for different site attributes and tend to pose various levels of impacts on the site. For instance, the extent and site characteristics of cycling and hiking are unlikely the same. Generally speaking, hiking is more flexible than cycling in terms of site requirement and facilities provision and the potential environmental impacts are likely to be lower for hiking. Therefore, hiking is not confined to outdoor recreation zone, the nature conservation zones and even the sanctuary zones are also possible sites for such activity.

5.4.3 Tourism Development

Hong Kong relies very much on tourism as one of her major income sources, but the potential sites for large-scale tourism or recreational development is very limited (Lantau Development Task Force, 2005). The Concept Plan for Lantau has placed major development proposal, such as second major theme parks, entertainment hub, museum and eco-center in North and North-eastern Lantau and has identified Tung Chung and Sunny Bay as two main focal points together with reclamation around them. Ngong Ping 360, originally named Tung Chung Cable Car as well as the Big Buddha in Ngong Ping are examples of the prior tourism developments. The South Lantau is another tourism development spot for facilities such as watersports centres, boardwalks and resorts.

Under the conservation-leaded scenario, tourism development has been restricted to the northeastern part of Lantau, clustering around Tung Chung, Disney amusement park, Discovery Bay, Yan O and Siu Ho. Tai O is another tourism development site. Areas have been expanded to Sham Wat, Ngong Ping, East Lantau (Tai Shui Hang, Man Kok and Mui Wo) and South Lantau (Pui O, Tong Fuk, Shek Pik and Fan Lau) when equal preference scenario is considered. These sites are regarded as pioneer sites for tourism development outside North Lantau. When tourism development objective is further increased and weighted in the recreation-and-tourism oriented, the existing sites expand outward but still with North and Northeast Lantau as more distinctive location for tourism development. Cheung Sha in South Lantau is the only additional site shifts from outdoor recreational zone into tourism development. Other than Pui O and Cheung Sha being proposed as resort and watersports centers in the Concept Plan, there are still many alternatives. For example, Tong Fuk and Fan Lau Tung Wan in South Lantau are also feasible options. However, almost the entire area has conflict with recreational use. Although the conflict is not a major one, detailed consideration should be raised to resolve it.

Although the result shows that South Lantau has potential in tourism development, much concern has been put on the scale and nature of development in the public consultation report. The scale of development should be relatively small when compared with that in North Lantau. Besides, potential impacts, for instance the destruction of landscape, natural coastline; and possible measures to increase harmony with the environment are taken into consideration with a view to preserve the natural beauty of the South Lantau (Lantau Development Task Force, 2005).

Finally, with respect to Tai O, the Concept Plan has largely stressed on the preservation of this old fishing village's cultural and natural attributes (Lantau Task Development Force, 2004). However, the results from the three scenarios all placed part or whole Tai O under the zone of outdoor recreation and tourism development. Only part of Tai O is classified as protection zone in the conservation-oriented scenario owing to its natural attributes such as mangroves which support a diversity of animal life. Apart from the natural elements, stilt house, disused salt pans, salted fish and shrimp paste are prominent cultural features live along with the history of Tai O (Hong Kong Planning Department, 2001b). The contradiction arouses from the failure of protecting Tai O's cultural entities by the Antiquities and Monuments Ordinance (Cap. 53), which in turn has been dropped out of consideration in the analysis. Revealed from the analysis, if Tai O really needed to be preserved as planned, more conservation measures are essential.

All in all, ecotourism makes use of both natural and cultural resources to support a wide variety of activities and through which a number of objectives are anticipated to be achieved. In this study, the activities and objectives chosen are just representative subsets from the variety. The range of activities cannot fully represent the whole set of ecotourism activities. Certainly, water-related activities and other variables such as pleasures from landscape admiration, tranquility and fresh air which are also essential elements have not been taken into account. The objectives focus on conservation and tourism related activities while other vital aims of ecotourism such as the generation of satisfaction, educative role, benefits of local community are assumed to be readily incorporated in the designed objectives.

Given the availability of essential geo-referenced data of site attributes, ecotourism planning can be carried out efficiently and effectively. Various combinations of areal and weight allocation to different objectives generate independent compromise solutions from different perspectives. It is not the purpose of this study in formulating a once-and-for-all solution, rather, the simulated zoning plans demonstrate MOLA as a potent decision support tool in allocating zones with different objectives. However, since the scenarios are simulated, the real compromise solution depends on collection of preference from interest groups and different parties in reality. Besides, through such exercise, the characteristics and value of each site, for instance, the potential conflicting sites can be scrutinized and thoroughly understood prior to the formulation of a more comprehensive zoning plan. Moreover, implications from the resultant plans serve as guides for future conservation and development. Although it is difficult if not impossible to verify the results, the resultant zoning plans provide insights for Lantau's future from different perspectives as well as render the position of the Concept Plan.

5.5 Summary

To summarize, the site identified for the three recreational activities including camping, hiking and cycling by multiple criteria analysis match with the proposals in the Concept Plan. When the importance of factors is considered in AHP-weighting, the results show higher contrast of suitability when compared with the equal-weighting scheme. The results reveal additional sites that can be considered as alternative of choice; however, their feasibility is subjected to further evaluation. Conflicts exist between different zones. By matching the Concept Plan with the zoning plans computed from Multi-objective Land Allocation, the Concept Plan has a tendency to fall in-between the equal-preference and recreation-and-tourism oriented scenarios. Regarding conservation objective, additional protected sites tend to be located in South Lantau and immediately adjacent to the Lantau North Country Park. However, it does not extend to the Northeastern portion of Lantau even in the conservation-led scenario. Although sites are identified for outdoor recreational activities, some activities such as hiking with less impacts and dependence on facility provision are not restricted within the zone. They are also compatible within the conservation areas. As for tourism development, they tend to cluster in North and Northeastern Lantau with some isolated sites distributed in South Lantau. The mode of development in South Lantau should be under thorough evaluation and planning so as to retain and match with its natural landscape. Tai O is a special case which requires more intensive studies.

CHAPTER 6 CONCLUSION

6.1 Summary of The Study

This study has seven objectives and can be divided into two parts. The first part embraces four objectives concerning the statistical modeling of habitats of fifty selected common species in Lantau Island. Two habitat regression models are statistically compared and the statistically sounded ones are selected to represent the probability distribution of the species. The distribution of the species are then combined to formulate the biodiversity hotspot map and based on which the possible conservation gaps are identified through matching with the existing protection system. The second part has three objectives regarding ecotourism planning in Lantau Island. Suitable sites for four tourism-related activities are identified through MCA. Based on these results as well as the results from the habitat modeling, zoning plans are generated concerning conservation, recreation and tourism development with different scenarios. The zoning plans are used to evaluate the Concept Plan for Lantau.

The habitat suitability of fifty species is firstly modeled with ENFA and based on the results, pseudo-absence data are generated. The pseudo-absence data are then input into the regression models to predict the probability of occurrence of the species. From the statistical perspective, the generalized additive models outperform the binary logistic regression models in terms of their reliability and discriminatory ability for the majority of species. The modeling results from GAM are used to represent the probability of occurrence of the species.

The species richness map combined from the probability of occurrence of the fifty species does not fulfill its task as a representation of biodiversity hotspots. The overall non-distinctive correlations between taxonomic groups imply that there is little opportunity for the modeled taxa to represent other un-modeled taxa. Besides, sites of high species diversity are also unlikely to represent the habitat of rare, threatened or endangered species. This is endorsed by a comparison of existing Sites of Special Scientific Interest which provide reliable location of rare species with the species diversified sites. The species richness map is therefore not used as a sole guide for conservation area selection.

The sites with a high suitability for camping, hiking, cycling and tourism development through multiple criteria analysis match quite closely with the proposals in the Concept Plan for Lantau. The results from AHP-weighting scheme provide a higher contrast of suitability than those from equal weighting. Apart from the proposed sites, alternative sites are identified for each specific recreational activities.

With reference to the zoning maps, the three scenarios provide some insights on the future planning issues for Lantau. Under the conservation-oriented scenario, almost the whole Lantau Island is under conservation with limited areas reserved for recreational activities and tourism development. This scenario indicates that sites in Tai O and northeastern Lantau including areas around the Disney amusement park, Siu Ho and Discovery Bay are the priority sites for tourism development. The equal-preference scenario provides a more balanced view between conservation and tourism-related activities. In contrast, the recreation-and-tourism-development-oriented scenario generates a plan that is dominated by recreation and tourism opportunities. On the other hand, it also reveals that the remaining conservation areas in this scenario are of extremely high protection values. The Concept Plan for Lantau falls in-between the equal-preference and recreation-and-tourism-development-oriented scenario.

Comparing the scenarios against the extension of Lantau North Country Park, the nature conservation is immediately adjacent to the existing boundaries of the Lantau North Country Park. However, its areas hardly expand to the northeast even under the conservation-oriented scenario. Species richness sites located outside the protected boundaries is worthy of further exploration to determine their conservation potential. Apart from the well-recognized recreational sites such as South Lantau, Mui Wo and Ngong Ping, alternative sites are identified for compatible recreational activities, for example, they include Sham Wat, Keung Shan and Tai O. Sites highly suitable for tourism development are found to cluster in north and northeastern Lantau, such as Tung Chung and Yan O. Isolated patches of small sites in South Lantau, such as Pui O, Tung Fong, Cheung Sha and Tai Long Wan are suitable for recreation and tourism development.

6.2 Limitations of The Study

The limitations of the study fall within three main areas – (1) data availability; (2) data uncertainty; (3) related issues of MCA; (4) areal and weight allocation; and (5) result validation.

The problem of data availability is inherent in both habitat modeling analysis and the multiple criteria analysis. In terms of habitat modeling analysis, the relatively small number of presence data points, totally lack of true- absence data points, and unavailability of validation dataset are the main constraints in data availability. The number of presence data points varies from 19 to 259 from the Biodiversity Survey. The amphibian group is on average the most well-sampled while birds are on average poorly-sampled. The small number of data samples limits the selection of environmental predictors in explaining the distribution of the species. The number of sample points is used as a reference to determine the number of predictors used to explain its distribution to prevent the problem of over-fitting. The general rule is 1 to 10 in the final model, i.e. 10 sample points with 1 predictor (Harrell *et al.*, 1996). The small number of sample points is likely to restrict the selection of environmental variables which are probably important to the distribution of species.

Regression modeling requires both the presence and absence data points. In this study, the true-absence data point is unavailable from the survey. Pseudo-absence data points are generated of for each species based on the habitat suitability resulted from ENFA. They are assumed to be reliable and valid since there is no way to prove their degree of credibility. The number of pseudo-absence point is another problem. In this study, the number of pseudo-absences is assumed to be equal to the number of valid presences to make the prevalence equal to 0.5. However, in reality, the two numbers can be different.

In usual practice, the computed habitat models have to be tested against an independent validation dataset in order to obtain an unprejudiced estimation of a model's predictive performance. An independent dataset can be attained by two ways – collection of independent field data or split the available data into separate datasets with one reserved for validation. The first method is unattainable because there is no additional field survey data. The second method is also unachievable due to their small dataset not suitable for further separation. Therefore, as the only data available, the training dataset is also used for validation. This is the only choice though it is regarded as a biased evaluation process.

The environmental predictors used for species modeling are assumed to provide sufficient representation in terms of species distribution. Certainly, other important factors which probably govern the species distribution are not taken into account because of two reasons. First, it is owing to time, resource and technical constraints. For examples, climatic data are only available in tabular format; topographic index which is a composite index of soil moisture, flow accumulation (Florinsky, 1998) cannot be computed due to technical reasons. Second concerns the availability of mapped features. Morrison *et al.* (1992) argue that species' present or absence is governed by certain microhabitat features which are too small to map. Therefore, the prediction of species occurrence based on such wildlife-habitat relationship can only be conducted in landscape scale rather than at the scale of an individual stand.

The situation is similar in the multiple criteria analysis when factors are chosen for the computation of suitability indices for the recreational activities. The criteria selected focus on safety, accessibility, facility provision and other perceived interests of tourists. Nevertheless, the set of criteria is not always comprehensive enough to incorporate all the essential elements which can satisfy the diversified needs of tourists. The reason is mainly due to the unquantifiable nature of some criteria. For example, hikers may want challenges such as undulating, sloping hiking trails; geologic landforms; excellent scenery and brilliant views from the paramount. The resultant suitability map is therefore limited by the availability of criteria.

The second limitation is data uncertainty. The possible data uncertainty in terms of habitat modeling arises from the species survey data, environmental predictors as well as modeling assumptions (Elith *et al.*, 2002). The species survey data from Biodiversity Survey is biased towards certain taxonomic groups such as amphibians and birds. Given that not all records are from the survey but with some from published sources and personal records, a great variability in the database is inevitable. As for the environmental data, possible errors may arise at pre-processing or analyses. The most apparent example is the computation of a land use classification map from satellite images. Since the classification result cannot be perfectly correct, errors embedded in such data tend to propagate to the later stages of the analysis. Finally, since any model is an abstract of the reality, assumptions are used to simplify the modeling process. Such simplifying assumptions are likely to cause uncertainty. For instance, equilibrium is assumed between the environment and observed species patterns (Lischke *et al.*, 1998) when static habitat modeling is concerned. Certainly, this assumption can be invalid in heavily disturbed or fragmented sites.

The third limitation involves the related procedure and results from MCA. Apart from economic and conservation perspectives, ecotourism also concerns the social aspect. This study pays little attention on incorporating the views of local residents who are one of major stakeholders in the planning processes. Although MCA allows the integration of different opinions, the function is not fully utilized. Moreover, this study focuses on the assessment of individual proposal in the Concept Plan against the results of MCA. Although there is a high coincidence between the two, foreseeable impacts are limited to individual sites.

Planning is a process in which impacts are not considered separately. MCA may do well in individual project assessment, however, its does not have the ability of integrating all proposals. The effects of aggregated impacts are still unknown.

The fourth limitation is related to the areal and weight assignment in the generation of the zoning plans. Since no algorithm is available in determining the amount of areas as well as preference towards different objectives, the values of the two attributes can only be assigned arbitrarily. The results may not be objective enough.

The final limitation worthy of mentioning concerns the validation of results. As mentioned beforehand, independent datasets are unavailable for validation of the results of habitat modeling. Difficulties are also encountered in the evaluation of suitability maps created from MCA, as well as the zoning plan for Lantau. There are no objective validation methods for the results.

6.3 Recommendations

Recommendations are on two aspects. The first concerns the technical aspect regarding the refinement of the methodology in terms of both habitat mapping and multiple criteria analysis. The second concerns the policy implications and suggestions from the study.

Since habitat modeling is a spatial issue, spatial autocorrelation plays a role in the analysis. Cressie (1991) also observed the necessity to quantify the magnitude, intensity and extent of spatial autocorrelation using spatial statistics. By taking spatial autocorrelation into account, it is expected that the model can use fewer predictors, give better results and provide better indication on which predictors have a strong influence on the species occurrence and distribution (Augustin *et al.*, 1996). With the availability of statistical software incorporating spatial autocorrelation, it makes possible the comparison of autologistic models with the original models.

Habitat modeling techniques and field data act as complementary tools which can benefit from each other. The modeling results render further field surveys more effective by identifying possible occurrences of species in previously unknown or non-visit sites. Instead of using training datasets, newly collected data are used as validation for the models. By repeating the cycle, quality species distribution databases can be built, which can, in turn, reduce data uncertainty and provide more reliable results for subsequent studies. Expertise can also be input to facilitate the evaluation process. It would be ideal if an independent dataset can be collected and used for evaluation purposes.

Although this study does not focus on consensus building, the multiple criteria analysis can be a powerful tool in such areas. Ecotourism planning concerns not only the environmental protection and economic viability, but also pays attention to sustaining the local community. With the widespread use of computer technology and high accessibility to internets, opinions from the public, especially those from the local residents can be collected. Instead of selecting criteria and assigning weight hypothetically, genuine opinions can be incorporated into MCA to assist the evaluation of alternatives from different perspectives.

In terms of determination of the amount of areas and preferences assigned to different objectives in formulating the zoning plans, possible computerized algorithms can serve in coming up with a more objective and sound solution.

GIS and multiple criteria techniques are valuable decision supporting tools in conservation and planning. They provide assistance to decision makers to evaluate proposals through their capability in generating and visualizing of different opportunities built upon various objectives and interests. In terms of the conflicting nature of societal problems, policy makers can better explore and come up with compromising planning policies with the aids of these tools. This planning study demonstrates not only the methodology side in the generation of future plans, but also provides insights and directions for the tourism development policy of Lantau.

The three scenarios provide an objective base for evaluating the conservation, recreation and tourism development objectives. As far as conservation is concerned, although the Plan suggests a large portion of Country Park extension, the extension does not coincide much with the results. Since the proposed extension of Lantau North Country Park is established almost seven years until now, alteration of the habitats and environment is not unexpected. It is advised that a comprehensive review and probably revision of the conservation policy is required. On the other hand, the results identify alternative sites that are valuable for conservation based on their high species richness. These sites tend to fall outside the Country Park boundaries and cluster in South Lantau which is currently the proposed spots for recreation and tourism development. Therefore, careful and thorough assessment of the conservation value in South Lantau is essential. Finally, the extremely high conservation value sites include the eight SSSIs and some hotspots of species richness. The former should be continuously preserved and monitored while the later provides an opportunity for further exploration of potential and possible areas of high ecological.

As for tourism, a number of alternatives sites are identified for different kinds of recreational activities as well as tourism development. The availability of alternatives suggests that further opportunities can be explored. South Lantau is one of the sensitive areas that draw much concern. The zoning plans generally suggest that conservation and recreation are of high priority in South Lantau.

The limited area in the recreation-and-tourism-development scenario suggests that tourism development should be minimized. Even if development is going to take place, the scale should be as small as possible and with sensitive design in order to preserve the natural beauty of South Lantau. Besides, the priority sites from the conservation-oriented scenario are regarded as sites that should be developed first before other locations are selected. In particular, development involving lots of construction works and large-scale should cluster around the Disney amusement park in the northeastern part of Lantau to limit disturbances to other parts of Lantau. In order to formulate polices compromising with the principle of sustainable development, conservation, recreation and tourism development should balance with each other.

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