ASSESSING THE CONSERVATION VALUE OF PROTECTED AREAS OF SABAH IN RELATION TO THE DIVERSITY OF BUTTERFLIES

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INSTITUTE FOR TROPICAL BIOLOGY AND CONSERVATION
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ABSTRACT

ASSESSING THE CONSERVATION VALUE OF PROTECTED AREAS OF SABAH IN RELATION TO THE DIVERSITY OF BUTTERFLIES

Biodiversity is declining as a result of many environmental factors, including habitat loss and global climate change. Some areas of natural habitats that remain are protected in order to conserve biodiversity, but the effectiveness of these Protected Areas (PAs) to protect sites of high conservation value has received little consideration. The main aims of this study were: (1) to investigate the potential impacts of climate warming on species' distribution on Borneo and (2) to assess the current conservation value of PAs in Sabah based on species distribution data and land cover. A total of 22,274 records from 314 butterfly species (Papilionidae Pieridae, Nymphalidae) were included in the database. 'Maxent' ecological niche modelling was used to predict the potential distributions of butterflies (5 km grid cell resolution) based on 10 climate variables (temperature and precipitation) and forest cover. Model outputs showed that precipitation was the most important environmental variable in determining butterfly distributions for most species (>70% of species). Inclusion of forest cover into Maxent models improved model fitting, although it was rarely the most important variable in models (<8% of species). Butterfly distribution data (n = 176 species) were then incorporated into reserve-design software ('Zonation'), together with forest availability, to assess the conservation value of PAs of Sabah (5 km grid cell resolution) in relation to forest connectivity and butterfly species richness and complementarity. There are 50 PAs in Sabah that cover 10.5% of the land area. Zonation output showed that PAs were more highly ranked than non-PAs. However, analysis of 'high conservation priority areas' (i.e. cells with Zonation rank score ≥ 0.7) showed that < 15% of these grid cells were in PAs. The Zonation score of PAs was positively related to their size, showing that large PAs have higher conservation value. However, the Zonation scores of some small PAs were as high as those for large PAs, suggesting that some small forest fragments are important for conservation. In conclusion, these results show that climate (particularly precipitation) exerts an important role in determining the distribution of butterflies of Borneo. PAs have higher conservation value than non-PAs, but only a small proportion of high conservation priority sites are currently protected, and deserve higher protection. Areas with high habitat connectivity are likely to be more effective at conserving biodiversity in the long term, and future work should investigate methods of improving and preserving habitat connectivity in order to conserve biodiversity.

ABSTRAK

Biodiversiti telah menyusut sebagai kesan daripada pelbagai faktor persekitaran, termasuk kemusnahan habitat dan perubahan iklim global. Sesetengah kawasan habitat semulajadi yang masih wujud telah dilindungi untuk memulihara biodiversiti, tetapi keberkesanan Kawasan Terlindung (PAs) ini untuk melindungi kawasan-kawasan yang mempunyai nilai pemuliharaan yang tinggi kurang mendapat perhatian. Matlamat utama kajian ini adalah i) menyiasat potensi kesan pemanasan iklim terhadap taburan spesies di Borneo dan ii) untuk menaksir nilai pemuliharaan Pas semasa berdasarkan taburan spesies dan litupan tanah. Sejumlah 22,274 rekod dari 314 spesies kupu-kupu (Papilionidae, Pieridae, Nymphalidae) telah dikumpulkan di dalam pangkalan data. Permodelan taburan spesies 'Maxent' telah digunakan untuk meramal potensi taburan kupu-kupu (5 km resolusi sel grid) berdasarkan 10 pembolehubah-pembolehubah iklim (suhu dan taburan hujan) dan litupan hutan. Keputusan dari model menunjukkan taburan hujan adalah pembolehubah iklim terpenting dalam menentukan taburan kupu-kupu dan pensertaan litupan hutan ke dalam model Maxent telah menambah baik penyuaian model. Data taburan kupu-kupu (n = 176 spesies) kemudiaannya digabungkan ke dalam perisian reka bentuk rizab ('Zonation'), berserta dengan ketersediaan hutan, untuk menaksir nilai pemuliharaan kawasan terlindung di Sabah (5 km resolusi sel grid) yang berkait rapat dengan kesinambungan hutan, kekayaan spesies kupu-kupu dan kesalinglengkapannya. Terdapat 50 PAs di Sabah yang merangkumi 10.5% keseluruhan kawasan daratan. Keputusan dari Zonation menunjukkan PAs bernilai lebih tinggi berbanding bukan PAs. Walau bagaimanapun, analisis 'kawasan keutamaan pemuliharaan tertinggi' (iaitu sel-sel dengan peringkat skor Zonation ≥ 0.7) menunjukkan ≤ 15% daripada sel-sel grid berada dalam PAs. Skor Zonation PAs adalah berkait secara positif dengan saiznya, menunjukkan PAs yang besar memiliki nilai pemuliharaan yang tinggi. Walau bagaimanapun, skor Zonation untuk sesetengah PAs kecil adalah lebih tinggi daripada PAs yang besar, mencadangkan serpihan-serpihan hutan kecil penting untuk pemuliharaan. Kesimpulannya, hasil kajian ini menunjukkan iklim (terutama taburan hujan) memainkan peranan penting dalam menentukan taburan kupu-kupu di Borneo. PAs mempunyai nilai pemuliharaan yang tinggi berbanding bukan PAs, namun hanya sebahagian kecil daripada kawasan keutamaan pemuliharaan tertinggi masa kini terlindung dan memerlukan perlindungan yang lebih lagi. Kawasan-kawasan dengan kesinambungan habitat yang tinggi akan lebih berkesan untuk melindungi biodiversiti dalam jangka masa panjang dan pada masa akan datang, kajian harus menyiasat kaedah-kaedah meningkatkan dan memelihara kesinambungan habitat dalam usaha melindungi biodiversiti.

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LIST OF SYMBOLS

$>$	More than
$<$	Less than
$\geq$	More than and equals to
$\leq$	Less than and equals to
$\bar{x}$	Mean
%	Percent
^{O}C	Degree Celsius
^{O}N	Degree North
^{O}S	Degree South
^{O}E	Degree East
^{O}W	Degree West
χ^2	Chi square
df	Degree of freedom
C	Carbon
CO_2	Carbon dioxide
CH_4	Methane
CO	Carbon monoxide
km^2	Kilometer square
m	Meter
mm	Millimeter
n	Sample size
N	Nitrogen
N_2O	Nitrous oxide
p-value	The probability of hypothesis being tested is true
r_S	correlation coefficient value
X,Y	Latitude, Longitude coordinate

LIST OF ABBREVATIONS

a.s.l	Above sea level
ArcGIS	Arc Geographical Informatin System software
ASCII	American Standard Code for Information Interchange
AUC	Area under Receiver Operating Characteristic curves
BIOCLIM	Bioclimate Envelope Model
BM	Brunei Museum
BORNEENSIS	ITBC, UMS specimen museum
CD-ROM	Compact disc read-only memory
COR	Correlation
DNA	Deoxyribonucleic acid
DOMAIN	Distance modeling method
ENFA	Ecological Niche Factor Analysis
ENSO	El Niño Southern Oscillation
ESRI	Environmental Systems Research Institute
FRC	Forest Research Centre
GAM	Generalized Additive Model
GARP	Genetic Algorithm for Rule-set Prediction
GDM	Generalized Dissimilarity Model
GIS	Geographical Information System
GLC2000	Global Land Cover 2000
GLM	Generalized Linear Model
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KP	Kinabalu Park
Lepindex	Lepidoptera Index
LIVES	Limiting Variable and Environmental Suitability
Maxent	Maximum Entropy Model
NASA	National Aeronautics and Space Administration
Naturalis	National Museum of Natural History
NHM	Natural History Museum
NMS	National Museum of Scotland
NNP	Net primary productivity
PAs	Protected Areas

PhD	Philosophy of Doctor
ROC	Receiver Operating Characteristic
SARs	Species-Area Relationships
SD	Standard deviation
SDMs	Species Distributions Models
SLOSS	Single Large or Several Small
SPSS	Statistical Package for Social Science
SRES	Special Reports on Emission Scenarios
WorldWind	NASA Global Geographical software
UK	United Kingdom
UKM	Universiti Kebangsaan Malaysia
WDPA	World Database of Protected Area
Zonation	Large-scale spatial conservation planning tools
ZMA	Zoological Museum of Amsterdam

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Biodiversity

The Convention on Biological Diversity (1992) defined biological diversity as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". Generally, biodiversity can be divided into three components; genetic diversity, organismal diversity and ecological diversity (Gaston and Spicer, 1998). Genetic diversity reflects the variation in genes within species and individuals, organismal diversity refers to the variety of living species, and ecological diversity reflects the diversity of natural habitats (Harper and Hawksworth, 1994; Gaston, 2000). There are global estimates of between 3-30 million species on Earth, of which approximately 60% are estimated to be insects (May, 2002; Speight *et al.*, 2009). However, only approximately 1.8 million species have been described to date (Cox and Moore, 2005; Speight *et al.*, 2009). A large proportion of living organisms still remains undescribed, particularly cryptic taxa such as microorganisms (Odegaard, 2000), and organisms in hard to study areas such as tropical and marine habitats (Wilson, 2000). Thus, more studies are required on global biodiversity, especially in tropical regions.

Biodiversity is distributed heterogeneously across the Earth (Hannah *et al.*, 2005) and diversity increases from the poles to the equator, and from high elevations to low elevations. Diversity is also higher on continents compared with islands, and is relatively low in habitats with extreme environmental conditions, such as deserts (Gaston, 2000). One of the most well-studied patterns in biogeography is the relationship between species richness and latitude (Groombridge and Jenkins, 2000; Clarke and Gaston, 2006). Increased diversity from low to high latitudes is evident in many taxa including vertebrates and plants, as well as insects (Eggleton *et al.*, 1999; Cox and Moore, 2005) and other invertebrates (Speight *et al.*, 2009). These patterns of latitudinal variation are evident not only in terrestrial environments but also in marine ecosystems (Connell, 1978; Tokeshi, 1999).

Tropical regions support high biodiversity (Myers *et al.*, 2000; Olson *et al.*, 2001), but the effects of increasing human disturbance on natural habitats (e.g. through habitat destruction, pollution, and anthropogenic climate warming (Millennium Ecosystem Assessment, 2005) have resulted in many species becoming threatened by extinction. This has led conservationists to identify priority sites that are “biodiversity hotspots” (Prendergast *et al.*, 1993; Reid, 1998; Myers *et al.*, 2000; Olson *et al.*, 2001). Biodiversity hotspots have been defined as “an area particularly high in the number of species present, rich in rare species, high in threatened species or some combination of these attributes” (Reid, 1998). Many biodiversity hotspots are located in tropical regions including Southeast Asia. The Southeast Asian region overlaps four biological hotspots, which are Indo-Burma, Sundaland, Wallacea, and The Philippines. These hotspots contain particularly high levels of within-country endemism for bird and mammal species (Sodhi *et al.,* 2010). Human population growth presents a serious threat to these hotspots because 20% of human populations live within or close to these hotspots (Myers *et al.*, 2000; Willis *et al.*, 2006).

1.2 Global Climate Warming

Global climate warming is of current concern for ecologists and conservationists because of its effects on biodiversity. Climate is usually considered as a primary factor affecting biodiversity within ecosystems (Bailey, 2009). Changes in climate can alter the composition of species within ecosystems and thus alter the functioning of ecosystems (Thuiller *et al.,* 2005; Bailey, 2009; Slik *et al.,* 2009). There are numerous published examples of the ecological impacts of recent climate warming (Easterling *et al.,* 2000; McCarty, 2001; Walther *et al.,* 2002; Parmesan and Yohe, 2003; Root *et al.,* 2003; Parmesan, 2006). Based on current scientific consensus, recent climate warming is resulting from the increasing production of anthropogenic carbon dioxide (CO_2) and other greenhouse gasses such as nitrous oxide (N_2O), methane (CH_4), and carbon monoxide (CO) (IPCC, 2000, 2001, 2007). The consequences of these greenhouse gas emissions is the warming of the biosphere by 0.74^{o}C over the past 100 years (IPCC, 2007) and changes in precipitation rates, which in turn affect physiological and ecological processes (McCarty, 2001; Jenkins *et al.,* 2005; Hansen *et al.,* 2006; Rosenzweig *et al.,* 2008).

At a global scale, phenomena associated with climate change such as increasing global temperatures, increasing intensity of hurricanes and typhoons, melting of glaciers, extreme precipitation, and more severe El Niño Southern Oscillation (ENSO) events are evident (Easterling *et al.,* 2000; Walther *et al.,* 2002; IPCC, 2007; Parmesan, 2007). These phenomena have altered the physical characteristics of ecosystems in terms of abiotic factors such as water, relative humidity and soil carbon fluxes (Root, 2003; Harper *et al.,* 2005), leading to unsuitable conditions for some species. Studies have demonstrated the ecological impacts of anthropogenic climate change, including shifts in species' distributions, and local extinctions of populations (Easterling *et al.,* 2000; Thomas *et al.,* 2004; Parmesan, 2006; Reading, 2007), and altered phenology (Walther *et al.,* 2002; Hughes *et al.,* 2003; Pounds *et al.,* 2006).

In tropical regions, investigations of the impacts of climate change on species are lacking. However, the effects of climate warming on species in tropical regions may be as strong as those observed in temperate and boreal regions (Parmesan, 2006; Pounds *et al.,* 2006; Wright *et al.,* 2009). These effects include declines in species diversity (Deutsch *et al*., 2008), shifts in species ranges to higher latitudes, invasion of non-native species and diseases (Pounds *et al*., 2006), shifts in species ranges up-hill to higher altitudes (Colwell *et al.,* 2008; Chen *et al*., 2009). These impacts of climate change may alter community composition and ecosystem functioning within Protected Areas (PAs). Thus, PAs may change in their effectiveness for supporting biodiversity under future climate change, and more information is required to help conservation planning and management.

1.3 Conservation Planning

The current biodiversity crisis derived from human-induced climate warming and habitat destruction has attracted the attention of conservationists, ecologists, and policy makers keen to preserve natural ecosystems and the species they support. Some areas of natural and semi-natural habitats have been preserved in the form of Protected Areas (PAs) in order to promote conservation of biodiversity in natural conditions (i.e. *in situ* conservation). Thus, an important feature of PAs is their ability to maintain existing populations and to reduce extinction rates. To achieve this, the sizes, number, characteristics, and connectivity of PAs need to be considered (Shafer, 1999; Williams *et al.,* 2005; Lindenmayer *et al.,* 2006; Primack, 2006). However, human-induced climate change may alter the effectiveness of PAs to protect biodiversity, and PAs need to take account of shifts in species' ranges as a consequence of current and future climate changes (Hannah and Salm, 2005; Lee and Jetz, 2008).

Species diversity in tropical regions may decline under future climate warming if species shift polewards and disappear from tropical regions. These declines in species diversity may decrease the resistance and recovery of ecosystem functions within PAs (Shafer, 1999; Hooper *et al.,* 2005; Hannah, 2008). Not only may species disappear from PAs, but also new species may colonise PAs from habitats outside PAs. This may further reduce forest-dependent species within PAs if, for example, these colonists include predators, and species that are better competitors than resident species (Hartley and Jones, 2003). However, information is lacking and more data are needed for tropical regions in order to examine how species may respond to climate changes, and the effectiveness of PAs in preserving biodiversity in future (Hannah, 2008).

1.4 Biodiversity Monitoring

Assessment of biodiversity within PAs is very important for measuring the conservation value of PAs but may be very costly in time, effort and resources. This is especially true in highly diverse tropical areas, which support ~60% of terrestrial species (Myers *et al.,* 2000; Gaston and Spicer, 2004). There are also taxonomic difficulties in identifying species in tropical regions (Gotelli, 2004), and the rapidity with which habitats are being lost and climate is warming makes it unlikely that full biodiversity inventories can be carried out in the near future. The use of biodiversity indicators has been suggested as a quick way of assessing overall biological diversity in an area (McGeoch, 1998; Pereira and Cooper, 2006), and the impacts of disturbance in these areas. Biodiversity indicators are a species or group of species that reflect the abiotic or biotic environment, and can represent the impact of environmental changes on a habitat, community or ecosystem. Biodiversity indicators should ideally reflect the diversity of other taxa within an area (McGeoch, 1998; Hodkinson, 2005), have a well-studied taxonomy, and be easy to sample and identify (Pearson, 1994; McGeoch, 1998; Nelson, 2007).

Insects are often used as a bioindicator in measuring the impact of environmental changes in natural ecosystems. For example, butterflies have several benefits as an indicator taxon because their taxonomic status is clear and stable (Koh, 2007). They are also relatively easily to sample in the field, and butterfly richness has been shown to relate to the species richness of some taxa (Lawton *et al.,* 1998; Kerr *et al.,* 2000; Schulze *et al.,* 2004; Thomas, 2005) but not others (Lawton *et al.,* 1998; Barlow *et al.,* 2007; Gardner *et al.,* 2008). Butterflies have been shown to be sensitive to habitat changes and changes in climate (Roy *et al.,* 2001; Warren *et al.,* 2001; Franco *et* *al.,* 2006; Nelson, 2007) because they are cold-blooded, have short generation times, and are relatively mobile. Thus, butterflies may be a good indicator taxon for quick biodiversity assessments and studies of ecological impacts of climate change in tropical regions.

However, obtaining data on species distribution and abundance necessary for monitoring biodiversity changes is often problematic and long-term, fine-scale information is usually limited in tropical regions. However, species distribution models (SDMs) offer a potential solution to these problems by predicting species distributions across large areas based on a relatively small number of observation records e.g. based on museum and herbarium collections (Raxworthy *et al.*, 2003; Graham *et al.*, 2004; Moilanen *et al.*, 2005; Phillips *et al.*, 2006). Furthermore, the development of GIS and remote sensing techniques have enabled researchers to incorporate information such as land cover, climate, topography, hydrology and other biodiversity attributes into the design of protected area networks (Raxworthy *et al.*, 2003). There has also been an increase in software tools for predictive modelling of species distributions based on environmental conditions (Phillips *et al.*, 2006) which have been widely used in predicting the potential impact of climate change on biodiversity (Hannah *et al.*, 2002; Peterson *et al.*, 2002; Thomas *et al.*, 2004; Araújo *et al.*, 2006) as well as for conservation prioritization (Araújo and Williams, 2000; Moilanen *et al.*, 2005; Williams *et al.*, 2005).

1.5 Research Objectives

Investigation on the effects of climate warming in tropical regions is lacking, and more information is required. Furthermore, conservation management and planning for maintaining the effectiveness of PAs to support biodiversity in the long-term is needed. Thus, the aims of this thesis are:

1. To investigate the potential impacts of climate warming on species' distributions on Borneo, and
2. To assess the current conservation value of PAs in Sabah based on species distribution data and land cover.

This thesis focused on butterflies in Borneo and addressed these main aims by:

- Collating information from museum specimens and existing records of butterfly distributions on Borneo.

- Using ecological niche models to model butterfly distributions in relation to environmental variables.
- Using reserve design software to examine the conservation value of PAs in Sabah.

1.6 Research Questions and Hypotheses

The research will address the following questions:

1. Are butterfly distributions on Borneo limited by climate?
2. Which environmental variables are most important in determining the current distributions of butterflies on Borneo?
3. Do species with different distribution extents differ in the role of climate in limiting their distributions?
4. Can species distribution models be used to predict species distributions based on data from museum collections?

To answer these questions, butterfly distribution data were analysed using existing niche modelling techniques ('Maxent', see Chapter 3), with climate and land cover data as environmental predictors of species distributions. Two species distribution models were developed, which were based on only climate information (Model I), or on a combination of climate and land cover information (Model II). The following hypothesis was tested:

Hypothesis 1

To test whether or not climate variables affect the distribution of butterflies on Borneo.

H_O: Maxent models fitting species distributions to climate variables are not significantly better than random predictions (i.e. model training AUC values ≤ 0.5 if models are no better than random projections)

H_I: Maxent models fitting species distributions to climate are significantly better than random (i.e model training AUC ≥ 0.5)

The final question of this thesis is:

5. Can outputs from distribution models be used to determine the conservation value of PAs in Sabah?

To tackle this last question involved analysing outputs from butterfly distribution models (Maxent model I) and incorporating these data into conservation prioritization software