Analysis of Climate Change Impacts on Malaysian Biodiversity:
Projecting Species Distribution Changes and
Identifying Priority Areas for Conservation in Malaysia

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factual or interpretative correctness of the dissertation.
Projected climate change presents new challenges in biodiversity conservation as evidenced by shifts in species range in various ecosystems. This paper investigated the impacts of climate change on the distributions of the biodiversity in Malaysia to assist in shaping effective conservation policies. The Wallace Initiative, an existing harmonised analysis of climate and biodiversity models, was used to identify potential refugia and areas of concern for every taxa thus demonstrating the climate-induced shift in the species distributions. These areas are then compared to the location of the existing national reserves in Malaysia to validate its locations’ suitability. The findings of this paper agrees that climate change have impacted on the shifts of the species distributions in Malaysia. Decisions such as whether to continue conservation efforts at current reserve, expand or to shift to the reserve to a potential refugia and avoiding areas of concern are some questions to which this study has raised. The findings of this study will have some implications on how the policymakers in Malaysia will proceed with future conservation plans. The lack of knowledge and major research gaps on the biodiversity in Malaysia have been highlighted by this study. More information and better understanding on both climatic and ecological as well as an increase of the quantity of data on species of Malaysia and also on its keystone species will aid the efforts to adapt to the species range shifts. This paper could yet be the most thorough predictions of climate change effects on Malaysia’s biodiversity distribution shifts conducted to help policymakers and conservation managers in Malaysia to formulate effective strategies.
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“Alone we can do so little; together we can do so much.”

Helen Keller
1. INTRODUCTION

1.1 Overview and Significance of Research

The Working Group I contribution to Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) (2013) warned that the warming of the climate system is indisputable and numerous of the detected changes are unprecedented (IPCC, 2013). Subsequently, in the Working Group II (WGII) contribution to IPCC AR5, it was affirmed these changes in climate change, in recent decades, have instigated impacts on human and natural systems on all continents. However, there is substantiation that impacts from climate change is the greatest and most comprehensive for natural systems (IPCC, 2014). Additionally, Heller and Zavaleta (2009) acknowledges that climate change generates new challenges for biodiversity conservation.

Conservation strategies in general have been developed under a conjecture of a stationary climate (Warren et al., 2010). Similarly, conservation efforts in Malaysia have yet to take into account climate change impacts. As such, current conservation approaches may not succeed with changing climates, especially given existing anthropogenic pressures such as agricultural expansion, logging, habitat fragmentation and urbanization (Sodhi et al., 2010). Ecological dynamics and species ranges are already reacting to recent climate shifts and existing reserves will not continue to sustain all the species they were devised to protect (Heller and Zavaleta, 2009).

This paper seeks to assess potential climate change impacts on the distribution of the species that make up the biodiversity in Malaysia. Areas of concern and refugia for the biodiversity in Malaysia are mapped out. For this study, areas which are climate refugia in the future are defined as areas that remain climatically suitable for more than 75% of the species included in the study which are currently present. Similarly, areas of concern are defined as areas which become climatically unsuitable for more than 75% of the species studied that are currently present. Refugia and areas of concern will be identified for each of the five taxa: plants, mammals, birds, amphibians, reptiles.

Maps displaying refugia, areas of concern and adaptation efforts are produced for each taxa in this research. Adaptation is generally distinguished as modification in natural or human systems, processes and practices (IPCC, 2007). In the context of biodiversity conservation in the face of climate change, adaptation signifies to efforts by human with the intention of reducing the adverse impacts of climate change on the ecological environment (IPCC, 2007).
Heller and Zavaleta (2009) noted that advances in adaptation have grown slowly even though scientists have researched this area with higher frequency. An adaptation process involves numerous stages such as from methods and research needs for impact assessment to governmental, non-governmental or intellectual policies changes (Heller and Zavaleta, 2009).

Refugia and areas of concern maps are constructed for each taxa for three different timeframes, specifically 2020s, 2050s and 2080s, under the SRES A1B baseline emission scenario. In addition to these maps, figures of refugia for all five taxa are merged. Subsequently, locations of existing national park and wildlife reserve as well as oil palm plantations are overlaid on these maps to assess the refugia in relation to these landuses. The analyses deliberated herein, despite some limitations, could be the most thorough predictions of climate change effects on Malaysia’s biodiversity yet conducted. The paper concludes with considerations of restrictions, research needs and approaches for conserving Malaysia’s biodiversity to ensure it copes with potential future climate change.

1.2 Overall Objective

The ultimate objective of this research is to establish the effects of climate change on the distribution of biodiversity in Malaysia and to distinguish refugia as well as area of concern. It is hoped that this research will aid in shaping the appropriate effective conservation efforts and adaptation actions to minimize likely climate change impacts on the species which form the biodiversity in Malaysia.

1.3 Research Questions

The following questions guide this research and are used to focus the findings of this study.

1. What distribution changes may be expected for the biodiversity in Malaysia under future climate change scenarios? What are the potential climatic range losses? Where are the areas that may become climatically unsuitable, namely areas of concern, for the animals and plants?

2. Are the refugia collocated for the different taxonomies (plants, mammals, birds, amphibians, reptiles)?

3. Is there any connectivity between the current climatically suitable areas to the projected climatically suitable areas in the future? Are the terrains appropriate for migration? How much has land transformation constrained the potential migration of species (along ‘corridors’ for example) in response to climate change? Has the corridor already been
developed, for example, into oil palm plantations or housing areas? How will this affect the migration of the taxa?

4. What are the implications of these patterns have for conservation planning and how might the conservation efforts differ from those currently being undertaken? What level of adaptation effort is needed in different areas?

By answering these questions, it is hoped these systematic predictions of effects of climate change on range shift will assist Malaysia in its efforts to conserve its biodiversity and cope with potential future climate change. Required adaptation measures and the significance of conserving the species endemic to Malaysia is also considered.

2. BACKGROUND

2.1 Climate Change and Biodiversity

Loss of biodiversity or loss of the existence, abundance and genetic variant of organisms in an ecosystem has been a global concern for centuries (Krauss et al., 2010). The provision of environmental, ecological, economic and social goods and services are underpinned by biodiversity. Biodiversity is substantively accountable for the resilience of these goods and services under environmental and anthropogenic stressors (McMahon et al., 2011). The primary drivers of species loss are anthropogenic stressors such as overexploitation, extinction cascades, invasion by alien and non-native species, habitat deterioration and climate change (Thomas et al., 2004; Brook et al., 2008; Dunn et al., 2009). Studies are proving that key processes crucial to the productivity and sustainability of our Earth’s ecosystems are being altered by extinction of species (for example, Loreau et al., 2002; Hooper et al., 2005).

Heller and Zavaleta (2009) noted that climate change poses major new challenges to biodiversity conservation. Recent studies indicated that it has become indisputable that within the past decade the global climate is changing and is having extensive effects on biodiversity (for example, IPCC, 2013; Bellard et al., 2012; Staudinger et al., 2013). Even though there are few supported cases of extinction due to climate change (Monzón et al., 2011), a majority of studies are finding support for and predicting negative impacts of climate change on biodiversity (Barnosky et al., 2011; Mantyka-Pringle et al., 2011; Bellard et al., 2012; Staudt et al., 2013). Staudt et al. (2013) discerned that climate change also interacts with other environmental and stressors, such as exploitation of animals, land-use change, pollution, non-native invasive species and disease, to affect species and ecosystems. In various cases, the
primary drivers of biodiversity loss are these anthropogenic stressors (Master et al., 2009) and will interact with climate change to influence the vulnerability of species (Barnosky et al., 2011; Mantyka-Pringle et al., 2011).

In the Summary for Policymakers (IPCC, 2014), there is high confidence that many terrestrial, marine and freshwater species have altered their geographic ranges, migration patterns, seasonal activities, abundances and species interactions in response to climate change. It has been observed with high confidence that considerable species extinctions and ecosystem shifts during the past millions of years due to natural global climate change whose rates are slower than present anthropogenic climate change (IPCC, 2014). Fossil records (Davis & Shaw, 2001) and newly observed trends (Root et al., 2003; Walther et al., 2002) revealed that species’ range expansion and contraction are profoundly influenced by the changing climate.

Pearson and Dawson (2003) expected that projected future climate change will have a substantial impacts on the distribution of species. Evidence of shifts in species range has already been observed for a variety of ecosystems (Root et al., 2003; Walther et al., 2005). Brooker et al. (2007) indicated that this is not surprising since species have temperature optima and dispersal processes facilitate species to track suitable environmental settings through space. Staudinger et al. (2013) noticed that climate change is causing many species to shift their geographic ranges and distributions at faster rates than were previously documented. Even though these range shifts may increase the prospect of persistence for some species and populations, the competence to migrate or disperse to new areas does not ensure survival. There are barriers to movement such as human activities and species interactions (Staudinger et al., 2013). Furthermore, interactions between species could potentially be disrupted by variations in phenologies and affect population dynamics (Yang and Rudolf, 2010). Martinez-Meyer (2005) noted that one of the element of the effects climate change on the environment which has been analysed is in understanding its repercussions for potential geographic distributions of species.

Forecasting climate change impacts on biodiversity has grown into an extremely dynamic field of study (for example, Guisan and Thuiller, 2005; Williams et al., 2007; Pereira et al., 2010; Dawson et al., 2011; Bellard et al., 2012). Pereira et al. (2010) acknowledged these studies are crucial in warning decision makers and scientists to likely future risks, offer a measure to strengthen attribution of biological changes to climate change and can encourage the growth of proactive approaches to lessen climate change impacts on biodiversity. Clark et al. (2001) noted that climate is a key constraint on ecosystem function.
and species distributions, and predicting species range shifts, biome shifts, extinction risks, changed disturbance regimes, biogeochemical cycling, and additional ecological reactions to climate change is a challenge faced by ecologists. Williams et al. (2007) highlighted the complexity of forecasting ecological responses to environmental conditions beyond the range of existing experience.

Bellard et al. (2012) asserted that climate can cause variations in vegetation communities which have high abundance of biodiversity and these changes are predicted to be considerable enough to affect biome integrity. Their study pointed out that there could be strong repercussions for ecosystem services from the implications of climate change on genetic and specific diversity. Identifying possible changes in species distribution is essential to protect biodiversity and to enhance persistence of rare species so that reserve systems can be planned to accommodate species range shifts, including movement of species to new suitable habitats (Araújo et al., 2004; Williams et al., 2007). Species, due to climate change, might no longer be adapted to the set of environmental conditions in a given area and consequently could fall beyond its usual climatic niche (Bellard et al., 2012).

Biodiversity’s potential distributional zones will likely move to higher latitudes (Martinez-Meyer, 2005; Wilson et al., 2005) and upward in elevation (Martinez-Meyer, 2005). Others species will retract and could likely face extinction (Sekercioglu et al., 2008). However, studies have also indicated that species could shift downhill as a result of changes in precipitation for example, Pounds et al., 1999; Crimmins et al., 2011). Precipitation are also crucial niche axes for biodiversity (Crimmins et al., 2011). Nonetheless, the proof for these documented shifts mostly comes from the dispersals of a few well-researched taxonomic groups (Sekercioglu et al., 2008). Chen et al. (2011) also noted that evidence has failed to validate that greater range shifts have been demonstrated at the areas with the highest levels of warming. In order to ensure that reserve systems can be deliberated to accommodate species range shifts incorporating movement of species to new appropriate habitats to protect biodiversity and improve perseverance of rare species, identification of potential changes in species distributions is critical (Guisan et al., 2006). Schut et al. (2014) acknowledged that in conservation planning, it is becoming more important to identify refugia as part of a critical climate change adaptation strategy. Game et al. (2011) stated that it is crucial for in-situ survival for many species that refugia are preserved.
2.2 **Southeast Asia and Malaysia**

As atmospheric CO\(_2\) increases over the next century, climate change is expected to become the first or second greatest driver of global biodiversity loss (Sala *et al.*, 2000 and Thomas *et al.*, 2004). In the Working Group II Contribution to the IPCC 5\(^{th}\) Assessment Report, it has been stated that it is very likely that over the past century the mean annual temperature has risen over most of the Asia region. It has been observed at the country scale in East and South Asia, during the 20\(^{th}\) century that annual mean temperature has shown an increasing trend (IPCC, 2014). The IPCC report also stated that across Southeast Asia, not only is there a decline in cooler weather and a growing number of hot days as well as warm nights, it has been noted that since the 1960s, temperature has also been rising at a rate of 0.14°C to 0.20°C per decade.

IPCC report (2014) observed that in many parts of Asia, terrestrial systems have reacted to current climate change with shifts in the distributions of plant species, phenologies and growth rates. It further predicted with high confidence that the projected changes in climate during the 21\(^{st}\) century will increase these impacts. Alterations in animal distributions have also been predicted, in response to both direct and indirect impacts of climate change though variations in the availability of appropriate habitats (IPCC, 2014). Despite these findings, the relative significance and long term repercussions of these drivers of biodiversity threats and, more crucially, their synergistic impacts on the biodiversity of Southeast Asia, remain inadequately understood (Sodhi *et al.*, 2004).

The IPCC report (2014) also acknowledges that understanding of climate change impacts on Asia’s ecosystems is presently constrained by the inaccessibility and incompleteness of biodiversity information. In addition to the poor understanding of interactions between the direct impacts of rising CO\(_2\) and climate change on natural ecosystems, there are major research gaps in the tropics such as the thermal tolerances and acclimation capacities of both plants and animals as well as temperature dependence of carbon fixation by tropical trees (IPCC, 2014).

Worldwide biodiversity loss is driven by the conversion of natural habitat to other land uses (Sala *et al.*, 2000). The unique and rich biodiversity in Southeast Asia has been severely impacted by deforestation, forest fire, untenable wildlife hunting and unsustainable wildlife trade ((Sodhi *et al.*, 2004; Nijman, 2010). Nearly the whole Southeast Asia is regarded as a biodiversity hotspot as it harbours a remarkably high amount of endemic species which are
endangered by the loss of original habitats (Myers et al., 2000). In the study (Myers et al., 2000), 25 biodiversity hotspots, areas comprising high concentrations of endemic species but experiencing massive habitat loss, were identified and Southeast Asia overlays with four of these hotspots. Due to heavy losses of its native habitats, Southeast Asia is a region of conservation concern and this is not helped by the fact that Southeast Asia’s annual deforestation rate is not only the greatest in the tropics, but it has also intensified between the period 1990 to 2005 (Sodhi et al., 2010). Sodhi et al. (2010) projected that this could result in losses of 13% to 85% of biodiversity in the region by the year 2100. In an earlier study, Sodhi et al. (2004) indicated that the outlook for the biodiversity of Southeast Asia looks bleak due to some key scientific, social and logistical conservation challenges encountered by the region. It was noted that in contrast with other tropical regions, studies on Southeast Asia’s biodiversity have been quite neglected over the past 20 years (Sodhi et al., 2004).

Tropical forest landscapes are altering rapidly mainly due to deforestation, invasive species and local landuse cover change (Wright, 2005). Thus far, protecting vast whole tropical forest reserves is the most common conservation approaches for tropical biodiversity and this method is proving to be increasingly challenging (Melo et al., 2013). Brodie (2012) noted that tropical ectotherms have narrower ranges of thermal tolerance than temperate zone area and as such temperature increases are critical. Huntingford et al. (2013) highlighted that situations in the tropic will swiftly deviate from historical baseline variability even with reasonably minor warming. Conservation implications need to take this into consideration for tropical species with narrow thermal tolerance (Tewksbury et al., 2008).

Tan et al. (2009) confirmed that the necessity to create a dedicated climate change policy is gradually more recognized. Hence, the Ministry of Natural Resources and Environment Malaysia collaborated with the Institute for Environment and Development (LESTARI) of Universiti Kebangsaan Malaysia and formulated Malaysia’s National Policy on Climate Change which was sanctioned by the Cabinet in 2009 (Tan et al., 2009). One of its principles includes conservation of the natural resources and environment. Among its targets is to promote development which is climate-proof through implementation of mitigation and adaptation methods, intensify environmental conservation and encourage sustainable use of natural resources. Malaysia hosts some of the world’s uniquely richest and diverse flora and fauna, namely an approximated 12,500 species of flowering plants and 185,000 species of fauna, many of which are endemic to tropical forestry in the region (Noor et al., 2010). Malaysia is acknowledged as one of the world’s twelve mega diversity countries, considering its exceptional species diversity and richness, requiring particular attention to halt swift habitat loss (Myers, 1988).
In Malaysia’s Second National Communication (NC2) to the United Nations Framework Convention on Climate Change (UNFCCC) (2011), it was reported that 40 years of documentation from years 1969 to 2009 showed that the rate of mean temperature rise for Malaysia spans from 0.6°C to 1.2°C per 50 years. In the report, it was stated that the annual mean surface temperature as whole for the country ranges approximately from 26°C to 28°C. The Malaysian Second National Communication to the UNFCC (2011) highlighted a number of species which could be susceptible to climate change. Biodiversity requires substantial habitat to adapt to variations in their ecosystem (Malaysia Second National Communication to the UNFCC, 2011). Thus, it was subsequently admitted that there is a necessity to institute more totally protected areas (TPAs) which capture the diversity and variation of what is found in Malaysia. The report acknowledged that currently the information and data on the impact of climate change on biodiversity and how they respond to altering climate conditions is very sparse and inadequate. It was also recognized that additional research must be undertaken to collect more information to enable decision making in the future.

2.3 Biodiversity Habitat Range Models

Bioclimatic or climate envelope models can be applied to predict the location of habitat for species under future climate to explore the potential consequences of climate change for individual species and biodiversity (Lawler et al., 2006; Pearson et al., 2006). Guisan and Thuiller (2005) noted that predictive modelling of species distribution are increasingly being used to address various concerns in ecology, evolution, biogeography, and, more recently, in conservation biology and climate change research. Species distribution models which generate habitat suitability maps have been applied with reasonably good success to explore a variety of scientific issues (Guisan and Thuiller, 2005).

Lawler et al. (2006) highlighted that various modelling approaches with different levels of model accuracy are relied on for predictions of future range shifts. These existing climate projections have its weaknesses and strengths. Harris et al. (2014) noted the ambiguity associated with future projections at various temporal and spatial scales, the differences between diverse downscaling methods such as simple scaling of universal circulation model output as well as the implications these ambiguities have for ecological models. The conviction of the projecting power of these models continues to be undermined by biotic, algorithmic and conceptual flaws such as impractical model conjectures (Dormann, 2007), ambiguity pertaining to variable selection (Austin & Van Niel, 2011) and absence of accord over the classification of basic conceptions (Austin, 2007).
Lawler *et al.* (2006) established that the types of models utilized in a research can have dramatic effects on forecasted range shifts and concluded that model-averaging methods appear to have the highest potential for predicting range changes in the challenge of climate change. Araújo and New (2007) opined that the usage of ensemble forecasting is a promising approach for dealing with these uncertainties. Ensemble predictions are a form of model averaging or multimodel inference which are constructed using different data sets, models or future climate conditions and then combined (Dormann *et al.*, 2008). For this study, the Wallace Initiative, using the MaxEnt bioclimatic model, is employed. MaxEnt is a programme which uses records of presence-only species to model species distributions (Elith *et al.*, 2011). Studies have concurred that MaxEnt is one of the best performing programme presently available to project distribution of species (for example, Phillips *et al.*, 2008; Elith *et al.*, 2010).

### 2.4 Wallace Initiative

The Wallace Initiative is chosen as the methodology for this study as it is an existing harmonised analysis of climate and biodiversity models. Prior to the creation of Wallace Initiative, studies carried out were based on ad-hoc selection of scenarios and species of the researcher’s own choosing. Wallace Initiative is a rigorous approach of cohesive climate and biodiversity modelling with climate estimates across 19 climate variables for four timelines, six emission scenarios and seven GCMs as well as biodiversity data for 50,000 species, through four timelines (James Cook University, 2014). The Wallace Initiative provides a harmonized conservation framework that allows for data to be exchanged with the adequate conservation of biodiversity. This method also incorporates uncertainties in both the climate change projections and in the probable capability of species to move to areas which have become newly climatically suitable (Warren *et al.*, 2013).

The Wallace Initiative is a global endeavour to appraise the likely impacts of climate change on distribution of plant and animal species using biodiversity data from the Global Biodiversity Information Facility (GBIF) and the maximum entropy (MaxEnt) algorithm (Price *et al.*, 2013). Primary biodiversity data was provided by the GBIF which facilitates discovery of data from various worldwide datasets (Yesson *et al.*, 2007). The Wallace Initiative was constructed to provide predictions on potential species changes, including natural resources species and some crops, to those working on adaptation as well as to provide key policy insights for mitigation efforts. Currently, approximately 50,000 species (plants, birds, animals, reptiles, amphibians) have enough occurrence data to be analysed using seven climate models, four dispersal scenarios, and both business-as-usual (BAU) as well as AVOID mitigation emission...
scenarios (Price et al., 2013). AVOID is a research programme which gives key advice to the United Kingdom Government on avoiding dangerous climate change caused by greenhouse gas emissions (AVOID, 2013).

Under the Wallace Initiative, a web portal has been created to give any interested parties from the public some model results for individual species and access to the climate data to enable any scientists to run their own models (Price et al., 2013). The data is displayed graphically as an overlay on google maps and is also available for download from the site. There are approximately 350,000 datasets on the site. As it currently stands, the website is a prototype of a concept demonstration site. It shows climate predictions across 19 climate variables for four timelines (Current, Year 2030, Year 2050 and Year 2080), seven General Circulation Models (GCMs) and six emission scenarios as well as biodiversity densities for approximately 50,000 species.

Two studies namely, “Quantifying the Benefit of Early Mitigation in Avoiding Biodiversity Loss” (Warren et al., 2013) and “The Role of Mitigation in AVOIDing Potential Climate Change Impacts on Biodiversity” (Price et al., 2013), were carried out using the Wallace Initiative. Both these papers analysed global future climatic range change of widespread species. There is still a huge amount of data in the Wallace Initiative which have not been analysed. This study will build on the findings of the global scale studies by refining the analysis to a specific country, namely Malaysia, and species found within Malaysia, as well as relating it to existing on the ground conservation planning in Malaysia.

3. MATERIALS AND METHODS

3.1 Study Area

The study area is the country of Malaysia which is located in South East Asia. It lies between 1ºN and 7ºN of the equator, and 99.5ºE and 120ºE. It covers an area of approximately 329,750 km². Malaysia comprises Peninsular Malaysia and East Malaysia. Eleven states and two federal territories (Kuala Lumpur and Putrajaya) are located in Peninsular Malaysia while East Malaysia consist of the states of Sarawak and Sabah (Figure 1). The two regions are separated by the South China Sea. Malaysia has a coastline of over 4,800 km. The weather in Malaysia is affected by convective rain of which distribution is prominently influenced by the monsoon winds and topography (Malaysia’s NC2 to the UNFCCC, 2011).
Peninsular Malaysia’s topography is varying as it ranges from mountainous regions to coastal areas (Malaysia’s NC2 to the UNFCCC, 2011). The Titiwangsa Range, a central mountainous spine which is 900 to 2,100 m in height above sea level and extends approximately 480 km in length, dominates the peninsular topography. Sabah is mountainous, particularly in the western part while the eastern part is generally undulating lowland basins. Sabah houses the highest mountain in Malaysia, Mount Kinabalu, which stands at approximately 4,100m above sea level. Mount Kinabalu is located on the Crocker Range which divides the rest of Sabah from the western part. United Nations Educational, Scientific and Cultural Organisation (UNESCO) inscribed Kinabalu National Park as a World Heritage Site due to its unique topographical, geological and climatic conditions combined with its richness plant diversity (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2013). Sarawak has a narrow belt of hills with an abrupt rise of mountainous area ranging the full length of the state followed by a flat coastal plain (Malaysia’s NC2 to the UNFCCC, 2011). Mount Mulu, which is the second highest peak in Sarawak, boasts the largest natural limestone cave system in the world (Malaysia’s NC2 to the UNFCCC, 2011).

3.2 Wallace Initiative

The Wallace Initiative was created to be a platform for a coordinated conservation framework to permit both the exchange of data between stakeholders and the sufficient preservation of biodiversity (Wallace Initiative, 2014). The Wallace Initiative comprises five main areas namely appraisal of impacts from climate change on species distributions for determining refugia and enhancing information on extinction risks, charting of possible corridors for species, utilizing
carbon distribution and prospective refugia to inform REDD policy mechanisms, guide protected zone designs in the 21st century as well as offer crucial advices to facilitate the growth of adaptation strategies (Wallace Initiative, 2014).

In the Wallace Initiative, the MAGICC4.1 climate model, driven by 21st century emissions time series, is utilised to carry out the global climate change modelling to project 21st century climate change. The projection is based on exploration of uncertainties in three key parameters explicitly ocean mixing rate, climate sensitivity and a climate-carbon cycle feedback factor that intensifies the temperature reliant on climate-carbon cycle feedbacks in MAGICC (Wigley and Raper, 2001).

Patterns of seven GCMs derived from the Coupled Model Inter-comparison Project (CMIP3) archive were used, specifically UKMO-HadCM3, CCCMA-CGCM3.1, IPSL-CM4, MPI-ECHAM5, UKMO-HadGEM1, CSIRO-Mk3.0 and NCAR-CCSM3.0. GCMs are the most advanced tools presently accessible for modelling the response of the universal climate system to rising greenhouse gas concentrations. Scaled climate change patterns established from the seven alternative GCM simulations are combined with a baseline climate resulting in projections of global temperature change which led to a pattern-scaling module ClimGen (Osborn, 2009; Warren et al., 2008). To give a higher degree of certainty to the results of this research, refugia is modelled based on the concordance of at least five GCM models. This is achieved by reclassifying as 0 for less than 5 GCMs in agreement that the area is climatically suitable for more than 75% of the species currently present in the area, 1 for 5 GCMs, 2 for 6 GCMs and 3 for 7 GCMs. No reclassifying is carried out for the maps of areas of concern as analysis showed that not many cells are classified as areas of concern.

The Wallace initiative has six emissions scenarios. For this study, the SRES A1B baseline scenario is employed. The IPCC released a report in the Third Assessment Report on a new set of scenarios, which is the Special Report on Emissions Scenarios – SRES (Nakicenovic et al., 2000). The greenhouse gas emissions scenarios published in the report have been employed to make and explore projections of potential future climate change (Nakicenovic et al., 2000). The A1B scenario is characterized by rapid economic growth with a global population which peaks in 2050 with the usage of new and efficient technologies based on a balanced emphasis on all energy resources (Nakicenovic et al., 2000).

Primary biodiversity data for the Wallace Initiative was obtained from the Global Biodiversity Information Facility (GBIF) which expedites discovery of data from many datasets worldwide (Yesson et al., 2007). These data are released via the Internet after it has been indexed
centrally. GBIF offers a source which allows researchers to distinguish potential patterns of change across the broadest range of species and areas possible through an accessible common portal (GBIF, 2014).

### 3.3 Data

The greenhouse gas emission scenario with the greatest forcing, analysed in this study is the SRES A1B baseline scenario. The Wallace Initiative employed the AVOID mitigation scenarios to derive other potential climate futures from the global climate change model MAGICC 4.1 (Wigley and Raper, 2001). The baseline climate are combined with seven alternative general circulation models (GCM) simulations to generate scaled climate change patterns from the pattern-scaling model ClimGen which was inputted with the resultant predictions of global temperature change (Price et al., 2013). This create 42 spatially-explicit time series predictions of monthly minimum, maximum, mean temperatures and total precipitation which are downscaled to 0.5° x 0.5° and are consistent with IPCC. Only seven of the time series predictions are applied in this study. The modelling of species’ current and potential suitable climate space/niche models will have a standard suite of 19 bioclimatic indices which were generated after these information were post-processed (Price et al., 2013).

Biodiversity records sourced from the GBIF were utilized. In GBIF, Malaysia has 340, 269 records from 476 occurrence datasets. Occurrences are documentations which record a “collection event”, proof that a particular, named organism was located at a precise place and time (GBIF, 2014). Occurrences are primary biodiversity data which can be based on evidences such as labelled specimen in a herbarium or museum and observation in the field (GBIF, 2014). The Maximum entropy modelling (MaxEnt) generates a model of the extent of a given species by using a set of environmental variables and geo-referenced occurrence locations (GBIF, 2014). The geographic distributions of each species are cropped to the bio-geographic zones from which the species data was obtained and to a cautious 2000 km buffer around the species’ occurrence records (Price et al., 2013).

The results from these models were then employed to appraise the changes in suitable climatic ranges for each taxa, areas categorized as refugia (areas maintaining an appropriate climate for < 75% of the species in the 0.5° x 0.5° cell) and areas categorized as areas of concern (areas which become climatically unsuitable for more than 75% of the species in the 0.5° x 0.5° cell). Indicative maps of adaptation efforts were also modelled for each taxa to explore the potential adaptation measures required. These maps are created by merging refugia and AOC layers for each taxa. Rising amounts of adaptation measures would likely to be needed to
maintain the status quo, which is to be climatically suitable for 25% to 75% or more than 75% of the species studied, as the colour gradient changes from green (7) to cream (0). Information such as the location of Malaysia’s national park and oil palm plantations (Hamzah et al., 2013) were also compiled and imposed on potential refugia maps to be analysed in tandem with the results from the models.

4. RESULTS

A complete collection of all the maps which was modelled for this study is incorporated as Appendix A. In this chapter, a summary of the all the figures will be given. Significant and noteworthy outcomes are highlighted and elaborated in this chapter.

4.1 Identifying Potential Refugia

The Wallace Initiative defines refugia as any areas continuing to be climatically appropriate for more than 75% of the species currently present in that area. This was a level that was considered to represent a compromise given the scale of the analyses. While there is the potential for micro-refugia to transpire within that 50 x 50 km area, the potential loss of the 25% of the species in an ecosystem could still lead to significant decreases in ecosystem services and functioning (Price et al., 2013).

In the refugia maps for this study, refugia are classified as areas where at least five general circulation models (GCMs) are in agreement that the area is climatically suitable for more than 75% of the species currently present in the area, to give the results a higher level of certainty and also stronger clarity. In these maps, areas in yellow are areas where less than 5 GCM models are in agreement while areas in the darkest green are refugia in cells where 7 out of 7 GCM patterns are in agreement that the specific area remains climatically suitable for more than 75% of the species in that area.

In general, it is expected that as time extend, refugias for all the taxa under the SRES A1B scenario will decrease. The results for this study confirm this prediction although the degree of decline in refugia for each taxa is different (Appendix A). Under the SRES A1B scenario in the 2020s, the whole of Malaysia is a refugia for birds. Most of Malaysia is also climatically suitable for amphibians in the 2020s although there are some areas, particularly in the coastal areas of Peninsular Malaysia, which are not potential refugia. For mammals, a small area at the southwest of Sarawak is not a refugium in the 2020s (Figure 2). This is a striking revelation
as there are some national parks, such as the Semonggok Orang Utan Sanctuary, close to that region. There are fewer refugia for reptiles, especially in Sarawak, in the 2020s. Refugia for plants are generally found inland in Peninsular Malaysia although the whole of Sabah remains a refugia in the 2020s.

In 2050s, refugia for birds decreases to about half of Peninsular Malaysia. Most of Sarawak and Sabah are still identified as potential refugia for birds in the 2050s. For amphibians, by the 2050s, coastal areas at Peninsular Malaysia and East Malaysia were no longer defined as refugia. Peninsular Malaysia is still regarded as refugia for mammals. More than half of Sarawak were not classified as refugia but parts of Sabah is classified as a refugia. Only the coastal areas of Malaysia are classified as refugia for reptiles in the 2050s. The largest loss of refugia between the 2020s and 2050s is for plants. Only small fragmented areas remains potential refugia for plants in the 2050s.
Figure 3a: Refugia for Birds in year 2080s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 3b: Refugia for Amphibians in year 2080s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 3c: Refugia for Mammals in year 2080s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)
Figures 3a-e display the potential refugias in Malaysia under the SRES A1B scenario in the 2080s. With the exception of a tiny area, the whole of Peninsular Malaysia is no longer defined as refugia for birds by the 2080s. Although, there is only a few parts of Sabah which remains refugia, there is substantial refugia for birds in Sarawak particularly in the highlands at the southern border. It should be noted that these refugia for birds in East Malaysia are mainly in the mountains. On the other hand, amphibians do not fare so well in Sarawak in the 2080s. Much of the potential refugia for amphibians in the 2050s no longer remains as refugia particularly in Sarawak in the 2080s. Only a small area of the northern Sarawak remains as refugia. It is the same situation with Peninsular Malaysia although Sabah retains much of the potential refugia for amphibians. Refugia for amphibians were also generally found in the higher lands of Malaysia. Reptiles fare much better in that they retained much of the refugia
from 2050s. The coastal areas for Malaysia generally remain as refugia with the exception of some areas in Sarawak. By the 2080s, there are no more areas defined as refugia for plants in Malaysia.

Out of all the five taxa, birds have the greatest amount of refugia in Malaysia collectively. This could be a noteworthy conservation knowledge for conserving birds in the region of Southeast Asia. The timeline for the changes in refugia for birds is illustrated in Figure 4.

On the other hand, the results showed that unlike animals, there is no potential refugia identified for plants by the 2080s (Figure 5). These potential changes in plants will likely have additional interactive impacts on animals through loss of habitats. Nearly the whole of Malaysia is already no longer classified as refugia by the year 2050s with the exception of a few fragmented areas.
4.2 Identifying Areas of Concern

The Wallace Initiative defines areas of concern as areas where the climate is predicted to be inappropriate for more than 75% of the species in that area. In these area of concern (AOC) maps, lack of adequate data is indicated in white, areas which are cream in colour are not an AOC under any GCM while the other colours correspond to the amount of GCMs in concordance that the area is an AOC. The areas coloured in the darkest red denote that all the seven models concurred that the area becomes climatically inappropriate for more than 75% of the species analysed in that cell.

Under the SRES A1B scenario in the 2020s, no GCMs showed any AOC for the taxa in Malaysia (Appendix A). With rising temperatures, more areas would be expected to become areas of concern. However, for Malaysia, the situation is relatively positive. Out of all the taxa, only amphibians have shown some sensitivity under the SRES A1B scenario in the 2050s (Figure 6). There are no AOC identified for the other taxa. Some small parts of the western
coast of the Peninsular Malaysia are potential AOC. There are two areas in Sabah identified as potential AOC for amphibians while there are no areas of concern classified in Sarawak for amphibians in 2050s.

![Figure 6: AOC for Amphibian in year 2050s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)](image)

There are no AOC for mammals and plants in Malaysia under the SRES A1B scenario in the 2080s. For reptiles, only two small areas, one in the north of Peninsular Malaysia and one on the southern part of Sarawak appeared to be potentially climate sensitive (Figure 7). On the other hand, more AOC have been identified for amphibians in Malaysia in 2080s (Figure 8). By 2080s, there are some potential AOC for amphibians at the coastal areas of Sarawak. More areas in the south of Peninsular Malaysia have been classified as potentially climate sensitive for amphibians. The AOC for amphibians for the 2050s and 2080s are consistent with the results from the modelled potential refugia. Areas identified as refugia are not in conflict with those identified as AOC. The situation is similar with reptiles. None of the areas identified as AOC are classified as refugia. This could indicate that no inaccuracies occurred in the results.
4.3 Adaptation Effort Levels

The following maps (Figures 9a–e) are maps of overall adaptation efforts potentially required under the no mitigation scenario (SRES A1B) for each taxa. These maps exhibit the refugia, labelled 1 to 7 with the colours and numbers corresponding to the number of GCM in agreement. The areas coloured as creams which is labelled as 0 are areas climatically proper for 25% to 75% of the species studied. Rising amounts of adaptation measures would likely to be needed to maintain the status quo, which is to be climatically suitable for 25% to 75% or more than 75% of the species studied, as the colour gradient changes from green (7) to cream (0). Areas which are climatically suitable for 25% or less of the species studied, namely AOC,
are shaded in pink to red (labelled from -1 to -7). In these areas, possible gradual changes to new species accumulations over time will increase the possibility of thresholds to adaptation to be exceeded. In order to preserve current biodiversity, these areas may necessitate novel adaptation strategies.

Under the baseline scenario, Malaysia remains largely suitable for its birds (Figure 9a). East Malaysia particularly have high concordance among models as refugia for birds. Conserving avian biodiversity in a changing climate for Malaysia could shift its focus on East Malaysia. Inland areas of Malaysia are suitable for amphibians with relatively high concordance among models (Figure 9b). However, parts of the coastal areas mainly along the border of Peninsular Malaysia and some parts on the northern boundary of East Malaysia could potentially necessitate high levels of adaptation efforts.

Malaysia remains relatively suitable for mammals in Malaysia in the 2080s (Figure 9c). This would indicate that while adaptation measures would definitely be required, conservation should require low adaptation measures. Malaysia is largely suitable for reptiles under the baseline scenario in 2080s (Figure 9d). Models are in high concordance that coastal areas of Malaysia and even inland areas of Peninsular Malaysia are refugia for reptiles. There is a small area in Peninsular Malaysia and in Sarawak which may entail increasing levels of adaptation measures.

Figure 9a: Adaptation Effort Map for Birds in year 2080s under the SRES A1B scenario (Green means refugia, labelled 1 to 7 corresponding to the number of GCM in agreement, areas of concern are shaded red with -7 meaning 7 out 7 of GCM in agreement and 0 are areas climatically proper for 25% to 75% of the species present.)
Figure 9b: Adaptation Effort Map for Amphibians in year 2080s under the SRES A1B scenario (Green means refugia, labelled 1 to 7 corresponding to the number of GCM in agreement, areas of concern are shaded red with -7 meaning 7 out 7 of GCM in agreement and 0 are areas climatically proper for 25% to 75% of the species present.)

Figure 9c: Adaptation Effort Map for Mammals in year 2080s under the SRES A1B scenario (Green means refugia, labelled 1 to 7 corresponding to the number of GCM in agreement, areas of concern are shaded red with -7 meaning 7 out 7 of GCM in agreement and 0 are areas climatically proper for 25% to 75% of the species present.)
Figure 9e indicated that Malaysia is to be climatically suitable for 25% to 75% of the existing plant species. Although higher levels of adaptation efforts could be required, the possibility of thresholds to adaptation to be exceeded is unlikely as no AOC are identified.
Malaysia has a substantial amount of national park or sanctuary reserve (Figure 10a-c) as an effort to conserve its unique biodiversity. These areas are plotted on the refugia maps which has all seven GCMs in agreement that the area is climatically suitable for the species present. It is crucial to assess the location of these national parks and reserves in relation to refugia areas to ensure effective nature conservation. Additionally, oil palm has replaced large areas of forest in Malaysia (Fitzherbert et al., 2008). Oil palm area has expanded to 5.23 million ha in 2013 (Malaysian Palm Oil Board (MPOB), 2014). Besides contributing to deforestation, oil palm plantations may act as a barrier to species dispersal ability. The data for oil palm plantations in Malaysia obtained (Hamzah et al., 2011) are plotted on the refugia maps to evaluate the potential impacts of oil palm plantations on refugia.

Figures 10a-c illustrate the refugia for all the taxa under the SRES A1B scenario, in relation to Malaysia’s national park and sanctuary reserve as well as oil palm plantations. These maps combined all taxa’s refugia which has concordance of all seven GCM models. The areas that are shaded green are refugia with the colours corresponding to the number of taxa in concurrence. The darkest green means that the area is refugia for 5 out of 5 taxa while white colour indicates that the area is not a refugia which has the agreement of all seven GCM models for any of the taxa. The high level of concordance of the GCM models will provide a higher degree of certainty that the area is a potential refugia.

The results showed that the refugia for the different taxa are generally not collocated. By 2050s, only two small areas are potential refugia for three taxa, the highest number of combined taxa found in Peninsular Malaysia. The situation is slightly healthier in East Malaysia where there are more areas identified as refugia for three to five taxa. Nevertheless, not all of these areas are being preserved. For example, in Sarawak there is a small area in at the southern border which is a refugia for five taxa in the 2050s but it has not been alienated for conservation. It should be thoroughly stressed that this small area should be totally protected and conserved. It is the only area in Malaysia which is a refugia for all five taxa in the 2050s. Most of the existing reserve are on refugia for at least on taxa in the 2050s. Half of the reserve are on refugia for two taxa in the 2050s and only quarter of the national reserve are on refugia for at least three taxa by the 2050s. Oil palms have encroached mainly into refugia for two taxa

The Usun Apau National Park is situated on potential refugia for three taxa in Sarawak in the 2050s although this national park only covers a small portion of the refugia. The Mount Kinabalu National Park is partially situated on refugia for four taxa in Sabah in the 2050s. As
By the 2080s, the highest amount of taxa identified as refugia is three taxa. This is found in a small area at the eastern coastal part of Sabah and this area is already being conserved under the Kulamba National Reserve. Less than one tenth of the area reserved for conservation in Malaysia is within areas identified as refugia for at least two taxa by the 2080s. It is also a concern that approximately one tenth of the Malaysian national reserve are on areas which are not classified as refugia in the 2080s. Moreover, expansion of oil palm plantations have invaded into refugia for two taxa. As refugia for two taxa have dwindled by the 2080s, it is crucial to prevent future oil palm plantations from developing on these refugia.

It is noteworthy that Mount Kinabalu National Park, Crocker Range National Park and Tabin wildlife reserve are positioned on refugia for two taxa by 2080s. There are some refugia for two taxa at the southern border of Sarawak. These areas form the ranges of high hills and mountains that are part of the central mountain range of Borneo. The development of oil palm plantations has entered some of the refugia identified for two taxa in the 2080s. With the exception of a part the Royal Belum State Park, none of the reserve in Peninsular Malaysia are situated on any refugia of two taxa. These small refugia, found on the eastern part of Peninsular Malaysia, are not only not being conserved but are being invaded by the development of oil palm plantations. Oil palm plantations are also intruding into refugia for two taxa in East Malaysia.
5.0 DISCUSSION

5.1 Main Findings

The results of this study suggest that some of the existing national parks and wildlife sanctuary in Malaysia are situated on potential refugia by the 2080s. With the exception of birds and amphibians as well as a minor segment of reptiles, there are no major AOC identified for the biodiversity of Malaysia. This study also illustrated that the potential adaptation efforts required for each taxa are generally moderate although increasing adaptation measures are necessary for amphibians. Less than one tenth of the area reserved for conservation in Malaysia is within areas identified as refugia for at least two taxa by the 2080s. It is also a concern that by the
2080s, approximately one tenth of the Malaysian wildlife reserves are on areas which are not classified as refugia by any GCMs. Moreover, expansion of oil palm plantations are encroaching into refugia.

### 5.2 Significance of Findings on Each Taxonomy

#### 5.2.1 Birds

There is a substantial amount of potential refugia for birds in 2080s under the SRES A1B particularly in East Malaysia. However, the refugia for birds in Malaysia is moving towards the highlands. Lowland birds in Southeast Asia have high habitat specificity (Peh *et al.*, 2012). These species are likely to be constrained to low elevations only and even those species which could endure habitat adaptability are inclined to transpire across the altitudinal gradient (Peh *et al.*, 2012). This would indicate that more emphasis should be focused on refugia on lowlands for a more effective conservation of birds in Malaysia. It has been implied that variations of habitats from climate change will cause the strictly lowland birds to be highly susceptible (Peh *et al.*, 2012). Their inability to move uphill due to the increasing warming temperature or to other appropriate territory and their inflexible habitat requirement will restrict these birds to their shrinking territories (Williams *et al.*, 2007).

Although birds could be extremely mobile, it is positive that there are no vast AOC identified for birds in Malaysia as research have shown they have higher and inflexible habitat specificity (for example, Williams *et al.*, 2007; Peh *et al.*, 2012). Nonetheless, even though ecological specialists species (Sekercioglu *et al.*, 2004) and habitat specialist (Jiguet *et al.*, 2007) are more vulnerable and facing a higher decline in population than the generalists, conservation should not be totally focused on lowland birds. Habitat specificity could not be totally indicative of sensitivity to habitat loss (Peh *et al.*, 2012). For example, Soh *et al.* (2006) showed in their study that lowland bird species were projected to be less vulnerable to habitat loss than the montane birds in Peninsular Malaysia while both lowland and montane birds, which are also deemed as thermal specialist, may not be able to endure extreme climatic events (Loarie *et al.*, 2009). As such, all types of birds in Malaysia should be judged possibly susceptible to extinction and evaluated regularly without any bias. This approach would be critical to protect birds such as the iconic Hornbills. Not only is the Hornbill iconic and has cultural importance, the Hornbill plays an important role in seed dispersal (Kitamura, 2011).

Identified birds’ refugia on the mountains are of great importance as Brooks *et al.* (1999) perceived that due to their constrained geographic ranges, montane specialists could be more
vulnerable to the effects of habitat loss. Soh *et al.* (2006) emphasized that highlands forests could be the last refuge for regional biodiversity considering the level of which lowland forests in Southeast Asia have been lost or degraded. This highlight how crucial it is to preserve the refugia identified for birds in Malaysia. It is positive to note that as these high areas are potential refugia, adaptation measures in relation to climate change will be relatively less complex.

Most of the existing national reserve in East Malaysia, particularly in Sabah, is well situated on refugia for birds. Although, by 2080s, there are no refugia classified in Peninsular Malaysia with the exception of a small at the south eastern border, it should be highlighted that it is still suitable for approximately 25% to 75% of the existing species. More conservation and adaptation measures would be required to protect the birds in Peninsular Malaysia, home to critically endangered birds such as Spoonbill Sandpiper and Chinese Crested Tern (International Union for Conservation of Nature (IUCN), 2014), as compared to the birds in East Malaysia. The results obtained from this study, showing lack of AOC but significant refugia in Borneo, signified that conservation and rehabilitation efforts for birds could be relatively less complex but essential.

5.2.2 Reptiles

Although Malaysia has an abundance of herpetofauna species and habitats, there is a major lack of information on these species and its habitats (Jaafar *et al.*, 2012). The same study noted that the poor situation of these herpetofauna data in Malaysia is highlighted by the fact that 16 out of the 30 species is documented as “Data Deficient” in their conservation status (Jaafar *et al.*, 2012). Amphibians and reptiles are generally unnoticed or unheeded but these taxa are important components of any ecosystems (Bickford *et al.*, 2010). Nevertheless, amphibians and reptiles could be among the first taxa to be influenced by climate changes in sudden and harsh ways (Bickford *et al.*, 2010). Bickford *et al.* (2010) estimated that amphibians and reptiles in Southeast Asia, in less than 50 years, will be reached or surpassed thresholds in their capabilities to acclimatize to increasing temperature. The perseverance of reptiles may also pivot on maintaining sufficient unmodified habitat (Bickford *et al.*, 2010).

Although the deteriorations of many reptile populaces are comparable to those faced by amphibians in terms of taxonomic range, geographic extent and severity, reptiles seem to be in a more danger of extinction than amphibians (Gibbons, 2000). Reptiles fared better in Peninsular Malaysia than East Malaysia. There are refugia identified for reptiles at the inland areas and also the coastal areas of Peninsular Malaysia. There is also potential refugia for reptiles around the whole coastal area of Sabah. However, only parts of Sarawak coastal areas
have been classified as refugia and only a small patch of area at the mountainous southern region of Sarawak. On the other hand, as refugia are generally on the coastal, dispersal capability of the reptiles will not be hampered by any mountainous terrain. Lack of knowledge on reptiles in Malaysia will be a huge hindrance in the efforts for its preservation. Although the location of the potential refugia for reptiles are identified, there is much more to be done, such as increasing the records of reptiles, upgrading their status of conservation and analysing their reactions to changes, to construct a more effective and successful conservation strategies.

5.2.3 Amphibians

Conservation of amphibians in Malaysia may be a tougher undertaking compared to the other taxa as not only should the AOC classified for amphibians be a concern but Sodhi et al. (2010) noted that not many studies have been carried out to assess impacts on amphibian communities. Moreover, studies are concerned that the moderately low dispersal abilities of amphibians may restrict their survival chances (Ficetola et al., 2007) and persistence of amphibians may hinge on retaining adequate unmodified habitat (Wanger et al., 2009; Bickford et al., 2010). Refugia for amphibians in Malaysia generally moved inland as temperature increases. However, the poor dispersal ability of amphibians will hinder their movement to these refugia. On the other hand, the findings from Gillespie et al. (2012) suggested that areas of remnant and semi degraded forest in Southeast Asia could be vital reservoirs of amphibian diversity. Malaysia should make efforts to conserve the refugia area identified and existing forests for amphibians rather than expect amphibians to disperse accordingly. This would ensure that the 63 amphibian species endemic to Malaysia, which is the sixth highest number of endemic species in Asia are given a higher chance of survival in the face of climate change (IUCN, 2014).

Having underwent unprecedented degrees of decline in recent decades, amphibians are thought to be one of the most endangered animal group worldwide (Stuart et al., 2004). In his study, Stuart et al. (2004) disclosed that overexploited amphibian species are concentrated particularly in Southeast Asia. As such, more research on climate change impacts on Malaysia’s amphibians are required. Adding to these challenges are the AOC identified for amphibians. Amphibians is the taxonomy with the most AOC in Malaysia. These AOC are generally situated on the coastal areas of Malaysia in the 2080s. As refugia for amphibians in Malaysia in the 2080s are largely inland, in the nonexistence of mitigation, intensive amount of adaptation efforts will be required. Taking into consideration the poor dispersal abilities of amphibian as well as the variation of species at the inland areas and the coastal region,
conservation efforts should not only be focused on refugia but also the coastal areas which are not AOC to ensure all amphibians’ species are protected.

5.2.4 Mammals

Alarmingly, refugia for mammals in Malaysia is reduced significantly by the year 2080s. Mammals in Malaysia are fascinating and also flagship species, such as the Asia’s only great ape, known as the orang-utan, the Borneo Pygmy elephant and the Malayan tiger (World Wide Fund for Nature (WWF), Malaysia, 2014), for conservation of biodiversity (Azlan, 2006). Much of Malaysia’s ecotourism are based on mammals such as the Semonggok Wildlife Centre and the Sepilok Orang Utan Sanctuary. In Sarawak, there is no refugia identified for mammals by the 2080s. There are refugia for mammals on the north eastern and south western part of Sabah. Refugia for mammals in the Peninsular are mostly scattered around its entire border. The largest refugia area is found at the south of Peninsular Malaysia. Interestingly, most of the refugia for mammals in Malaysia is situated on lowland areas although the range of Mount Kinabalu in Sabah is identified as refugia for mammals. This is noteworthy as lowland forest are in higher risk of being threatened by development such as agriculture and oil palm plantation expansion as well as timber harvesting. This will increase the challenge of mammals’ conservation in Malaysia.

The Sepilok Orang Utan Sanctuary in Sabah is located just on the border of the refugia at the north eastern part of Sabah. Another famous orang utan ecotourism attraction is in Semonggok, Sarawak which is not defined as a refugia for mammals. Moreover, Meijaard and Shell (2008) noted in their study that many Borneo mammals, which are endemic, are confined to mountainous habitats and are generally safer from anthropogenic threats such as logging. However, the results from this study showed that although mammals in mountainous habitats may be safer from logging or expansion or oil palm plantations, these habitats are likely to be climatically unsuitable for more than 75% of the existing species. Conservation plans for mammals in Sarawak will be more challenging than Sabah or Peninsular Malaysia as no area in Sarawak, whether highland or lowland, are classified as potential refugia.

For Peninsular Malaysia, there is a different type of challenge for conservation of mammals. Existing national reserves in Peninsular Malaysia are not favourably located to be a refugia for mammals. The most sizeable refugia for mammals, found at the southern part of Peninsular Malaysia, have mostly been developed in oil palm plantations. Policymakers need to decide if some of the oil palm plantations should be allowed to regrow to secondary forests to aid in providing habitats for mammals. The other identified refugia for mammals in Peninsular
Malaysia is scattered around. Connectivity of these refugia will move southerly as movement from east to west are obstructed by the mountainous Titiwangsa range. Research has shown that species richness of mammals are fewer in forest fragments compared to the mammals’ communities in continuous forest (Laidlaw, 2000). Formation for corridors will need to accommodate the terrain hurdle or the corridors will not be efficient. Even though there are no AOCs classified for mammals, the potential loss of species from climate unsuitability would possibly increase the complication of mammals’ conservation in Malaysia. It is critical that Malaysia needs to take these factors into consideration when formulating conservation strategies for mammals to ensure its effectiveness.

5.2.5 Plants

The results from this study indicated that the utmost concern for Malaysia is the absence of refugia for plants by the 2080s. There are many flowering plants which are endemic to the forests in Malaysia, which accounted for approximately 12,500 species (Noor et al., 2011). In Peninsular Malaysia itself, 13.5% of the vascular plants species are critically endangered (Saw et al., 2010). Saw et al. (2010) stated that Malaysian flora is not effusively recorded and this is highlighted by the fact that relatively little species have been judiciously evaluated on their conservation status. As such, the conservation of plant species have been comparatively neglected, compared to the animals in Malaysia. Conservation of plants have to take priority now as the lack of refugia identified are a huge concern.

However, the main crux of the absence of potential refugia for plants is the deficiency of habitat for animals. Not only are plants used as gauges for biodiversity (Myers, 1988), these plants form habitats for all the other animal taxa. The animal communities are reliant on plant resources. Research have proved that habitat quality, including characteristics such as canopy cover of the forest, have a powerful effect on animal species richness (for example, Soh et al., 2006; Laidlaw, 2008; Gillespie, 2012). These probable changes in plants communities will likely have further interactive effects on animals. Undisturbed forests are crucial for many species as species abundance normally declined with rising disturbance (Lawton et al., 1998). For example, animals rely on specific vegetation types which offer resources for scavenging, breeding and as cover (Preston et al., 2008). It has to be noted that even though no areas in Malaysia have at least five GCMs in agreement that an area is a refugia for plants, Malaysia would still be climatically suitable for 25% to 75% of the existing plant species. This means that it is not a lost cause for Malaysian flora but it does imply additional complexity in conserving and preserving plants species in Malaysia. Conservation efforts must view this seriously as this is a potential precarious situation for the biodiversity in Malaysia. Lack of
refugia for plants could possibly be a major impediment on any conservation efforts in Malaysia.

5.3 Implications of Conservation Strategies

Alienation of wildlife reserve in Malaysia did not integrate potential climate change impacts into its decisions and this is commonplace in other countries (Araújo et al., 2004). Even when competent management is carried out, reserves risk losing a fraction of their species as species ranges are dynamic (Araújo et al., 2002). To enable wildlife reserve or sanctuary to adapt species range shifts, identification of potential variations in species distributions is critical to protect biodiversity and to improve perseverance of rare species (Araújo et al., 2004; Williams et al., 2007). Recognition of the impending climate change impacts been acknowledged through the formulation of Malaysia’s National Policy on Climate Change which includes conservation of the natural resources and environment.

It is encouraging to note that it is achievable to considerably lessen the extent of environmental change without escalating the overall cost of the protected area network by incorporating climate change refugia as a component of the national conservation valuation (Game et al., 2011). It has been recognized that there is a real danger that the existing reserves will not be capable to protect the species and ecosystems from the shifting climatic regimes as numerous protected areas are found in extremely human modified landscape (Game et al., 2011). The increasing magnitude climate change adaptation measures being integrated into national policies for protected areas has been clearly conceded in the 10th Convention on Biological Diversity Conference of Parties in 2010. The results from this study should benefit the endeavours Malaysia is starting to undertake in response to climate change. Formulation of policies related to biodiversity could be aided by the results from this study to ensure more effectual plans.

In their review, Heller and Zavaleta (2009) amassed an inventory of recommendations for biodiversity management to adapt to climate change. Instead of listing all possible of suggestion from an increasing literature, the approaches deemed most practical for Malaysia is recommended. First and foremost, conservation policymakers in Malaysia should appraise the possible results for biodiversity from continuing existing management and conservation paths in the context of climate change (Heller and Zavaleta, 2009). Climate change must be incorporated current and future planning (Araújo et al., 2004) and protect the potential refugia identified (Game et al., 2011). The most popular recommendation for climate change adaptation approaches is increasing connectivity either by eliminating obstacles for dispersal,
creating corridors, reforestation or locating reserves near to each other (Heller and Zavaleta, 2009). Studies have shown that fragmentation of forests not only decreases the capability of species to react through range shifts (for example, Hof et al., 2011; Araujo et al., 2004) but also hampers the capacity of species to acclimatize to changing environmental conditions (Davis & Shaw, 2001).

Although most refugia for Malaysia are not fragmented except for mammals, there is lack of connectivity for some taxa refugia with existing national parks. For example, some corridors leading to potential refugia should be created for conserved areas in Sarawak which are not located on any potential refugia (Figure 10c). Malaysian policy makers should design buffer zones around reserves and to refugia areas. Studies such as Peh et al. (2006) and Meijaard and Sheil (2008) demonstrated that degraded habitats and even plantations still have high conservation value to play an important role on preservation of biodiversity. Linkie et al. (2006) also agreed that logged forests which are allowed to regenerate into old-growth forests could be a sustainable conservation strategy. As most of the existing areas in Malaysia are secondary forests or plantations, these results are encouraging and should be integrated into the conservation strategies and policies.

More studies should also be undertaken for behavioural, physiological and demographic reactions of species to climate change (Hulme, 2005). Basic monitoring plan is ideally implemented although Lawton et al. (1998) acknowledged that monitoring variations in biodiversity requires resources which significantly exceed what is presently available. Nonetheless, Malaysia being a tropical country will experience climate change in terms of increased temperature which is similar to a long term condition of El Niño Southern Oscillation (ENSO). Species’ responses to an El Nino event is likely to be parallel to reactions to climate change in Malaysia and these responses can be observed and monitored in a relatively shorter term, thus averting higher resources requirement. Allocation for more research, particularly on El Nino impacts on biodiversity, and monitoring plan should be stipulated as part of the Malaysian conservation strategies.

An increase in the quantity of reserves is an obvious strategy although political, economic and social implications may make this approach tricky. Conservation managers would also have to decide whether to shift or expand the sanctuary to connect to a refugia. However, this is necessary as it has been shown that some important potential refugia for combined taxa are currently beyond the protected areas of Malaysia (Figures 10a-c). With the results from this study, policymakers can decide the location of new reserves based on the taxa which they wish to protect and conserve. In Sarawak there is a small area in at the southern border which
is a refugia for five taxa in the 2050s but it has not been alienated for conservation. It should be thoroughly stressed that this small area should be totally protect and conserved. It is the only area in Malaysia which is a refugia for all five taxa. They could also identify areas which require less complex adaptation efforts to maintain (Figures 10a-e). For example, the Semonggok Wildlife Centre which is a sanctuary and rehabilitation for orang utan is not a refugia for mammals.

Policymakers should also conserved area which are refugia for multiple taxa (Figures 10a-c) as conservation efforts are more effective when biotic relationships are taken into consideration. This can be achieved by expanding existing conservation reserve such as the Usun Apau National Park, Mount Kinabalu national park, the Sukau reserve, Kulamba wildlife reserve and Kinabatangan wildlife sanctuary which are all situated on refugia for three taxa in the 2050s. Policymakers and conservation managers in Malaysia could focus on the results from the 2050s when there are some areas which are refugia for four taxa. These refugia, which has three and four taxa in concordance, should be conserved and applied adaptation measures as soon as possible to attempt to maintain these areas climatically suitable even by the 2080s. Another option available to the managers would be to maintain the existing location but rigorous adaptation measures will be required to try and maintain the existing area to be suitable for mammals especially the orang utan.

The lack of competence to observe and govern all aspects of biodiversity has brought on the concepts of focusing on the conservation of either the whole ecosystems or focusing on a single species (Payton et al., 2002). Simberloff (1998) advocates that the concept of keystone species may let policymakers or conservation leaders to merge the best elements of sole species and ecosystem based managing methods. He contends that the necessity to analyse every species is averted as the utilization of keystones maintains a focus on species and accentuates the processes that precisely rather than indirectly control biodiversity. Management of that keystone species could be an effective measure of conserving a much broader range of biodiversity although there have been very little research on keystones studies (Payton et al., 2002). Conservation efforts in Malaysia could focus on keystone species such as the Beringin (Ficus benjamina) and Rain Tree (Samanea saman) (Mohamad, 2012) and could turn out to be critical in conservation efforts.
5.4 Limitations of Results

The analyses in this study come from the most inclusive global analysis tool thus far of estimated climatic range losses of animals and plants. However, there are still limitations in such models of which are potentially important and could result in overestimation or underestimation of likely climatic range changes (Dormann, 2007; Warren et al., 2013). There are elemental thresholds to the accuracy of future species distributions forecast due to the huge complexity of natural systems (Pearson and Dawson, 2003). Factors such as environmental and biotic interactions, dispersal and migration or evolutionary alteration are usually not accounted for in such models (Pearson and Dawson, 2003; Guisan, 2006). Pearson and Dawson (2003) went further to concede that precise forecasts of biogeographically reactions to potential climate change are presently impossible due to the combined intricacies of all these factors.

Warren et al. (2013) examined the various factors that could cause over- or underestimation of probable shifts of climatic range. These factors include survivability limits of some species might have surpassed before even the average climate becomes inappropriate and the vagueness of the extent species might operate in novel climates. Although GBIF is the most robust global data for species observations (Warren et al., 2013), there are some limitations in its data such as the lack of georeferencing of the species' locations (Guralnick et al., 2007) and insufficiency of raw data (Hortal et al., 2007). This study was also unable to include the total species in the GBIF database for Malaysia. This would require a script to go through the database, collate all of the cells that were in Malaysia and then generate a list of unique species. This is planned for the second version of Wallace Initiative.

An interesting find by Krawchuk et al. (2009) is that modifications in fire regimes can possibly bring about major changes in biodiversity as fire frequency is also greatly connected to bioclimatic variables. The findings should be taken into consideration as increased dry spells, droughts and forest fires are predicted for Malaysia (for example, Deni et al., 2010; Meng et al., 2013). While variations in fire regimes are not taken into account directly but are incorporated indirectly, fire can possibly trigger huge changes in biodiversity (Warren et al., 2013).

Malaysia’s climate is significantly influenced by monsoon and droughts. Climate models have some difficulties in forecasting and replicating monsoon rainfall in East Asia (Wang et al., 2008; Kitoh et al., 2012). Prediction skills are still moderate as CMIP3 models were noted to underestimate the monsoon domain and CMIP5 models have not improved (Kim et al., 2008).
Kitoh et al. (2012) also indicated that compared to other monsoons, the sensitivity of Asian monsoon to global warming is greater. El Niño and the Southern Oscillation (ENSO), which are the variations in the warming of the tropical atmosphere, influence the climate in Malaysia. However, the ENSO cycle is not a forte for climate models (Cane, 2005). History have shown that ENSO is fairly sensitive to climatological settings and the future of ENSO remains in depths of massive uncertainty (Cane, 2005). A small increase of temperature is likely to cause a greater effect in Malaysia as compared to seasonal countries such as the United Kingdom where higher change of mean temperature occurs. The risk from increase of temperature is higher in Malaysia than perceived because the change of mean is higher than the variability. The inability of climate models to predict monsoon and ENSO might cause inaccuracy or underestimation in the projections for this study.

Buisson (2006) found that species with constrained environmental conditions such as smaller elevation ranges or species with a large geographical coverage such as latitudinal gradients have more consistency in the modification of range for future projections. The accuracy of the results will be undermined by the variation of reactions from species. It should be stressed that careful consideration should be applied when using forecasting ensembles from the use of various climate models and statistical processes as there are disparities in projections (Buisson, 2006). Decision on management and conservation in Malaysia should only be applied with the consideration of their ambiguity and comprehensive information of their reliability (Buisson, 2006).

Nonetheless, these bioclimatic models are presently the best approach to forecast climate-induced range shifts for biodiversity despite these limitations (Lawler, 2006) and have been widely used (for example, Pearson et al., 2006; Dormann, 2007; Price et al., 2013). In spite of the limitations deliberated here, the Wallace Initiative is one of the best tool presently available for predicting impacts of climate change on species’ distributions. With plans of looking at more climate models and species, the second iteration of the Wallace Initiative will be more robust and increasingly useful in forecasting climate-induced biodiversity range shifts (Wallace Initiative, 2014).

### 5.5 Potential Future Research

Nonetheless, despite the limitations, presently the best existing guide for conservation policy making is possibly bioclimate envelope models (Hannah et al., 2002). This approach have been useful in ascertaining the potential extent of future modifications to species distributions and possible threats from climate change (for example, Hannah et al., 2002; Price et al., 2013).
An enhanced comprehension of the multifaceted interactions between the various factors influencing species distributions in Malaysia will provide more realistic simulations on species distributions affected by climate change (Pearson and Dawson, 2003). A general consensus from literature on the models predicting species range shifts from climate change is that better understanding and more information on both climatic and ecological variability are required (for example, Guisan, 2006; Howard et al., 2014, Harris et al., 2014).

Further research on Malaysian species as well as its biotic relationship and processes should be carried out as studies have shown the lack of such data (for example, Soh et al., 2006; Peh et al., 2011; Gillespie et al., 2012; Laidlaw, 2000). Various studies have asserted that improved understanding and integration of biotic relationships, especially habitat specialists species (Preston et al., 2008), and biotic processes such as dispersal capability and interactions (Brooker et al., 2007) will provide more realistic and accurate simulations of the effects of climate change on the distributions of species. Research on these processes is urgently needed to foresee tropical reactions to climate change.

A better understanding of the ambiguity related to future projections or the differences between accessible downscaling means and discourse between modellers and community are vital to bridge the gap of comprehending climate projections (Harris et al., 2014). More rigorous species’ distributions models and reduced uncertainties related to these models will give enhanced forecasts of the consequences of impacts on ecosystems and biodiversity. If more progress is to be achieved, it is essential to have a better grasp of causes of species’ distributions, particularly their range thresholds, ecosystem functions and ecological assembly rules (Guisan, 2006). However, to achieve these targets, an improved collective effort between both functional and theoretical ecologists, ecological statisticians as well as ecological modellers is needed (Guisan, 2006).

Howard et al. (2014) discovered that instead of presence and absence information, abundance data should be utilized to better accurately forecast the impacts of environmental change from ecological effects. Moreover, their discoveries stressed the significance of informative baseline information sets and encouraged more gathering of abundance information (Howard et al., 2014). Biodiversity data for this study are obtained from GBIF. In GBIF, Malaysia has 340,269 records from 476 occurrence datasets. It is not a high quantity of records and this could affect the accuracy of this study. Although the significance of bioclimatic model forecasts should not be undervalued, indication of the potential scale and general pattern of future effects should be scrutinized as approximations and interpreted with caution (Pearson and Dawson, 2003).
Preservation of keystone species have been recommended but while the identification and preservation of a keystone species could be critical for the continual survival of other numerous species in its community, the challenge is to ascertain the relationships and functional importance of keystone species within the natural ecosystems (Payton et al., 2002). Efficient conservation of keystone species requires thorough management strategies which are built on precise and dependable information on the status and ecology of the species population (Wilting et al., 2006). However, the lack of such data is a substantial challenge for conservation efforts in Malaysia. As such, future research could be directed on keystone species in Malaysia and its relationships in the ecosystem to assist in safeguarding its biodiversity.

The current Malaysian landscape which consist of housing developments, agriculture clearing and vast oil palm plantations offers little flexibility for species to move in response to climate change. The modern landscape, in contrast to historical landscape, are a new and different challenge which requires further research to try and establish how to assist these species, particularly for species with low adaptability or dispersal capability, to disperse to their refugia (Walther et al., 2002). Further research on how the mountainous terrain in Malaysia will affect the dispersal of the species to their respective refugia can be carried out to aid in establishing the effective corridors or networks for species.

Temperature in Malaysia is expected to increase (for example, Cane, 2005; IPCC, 2013). El Nino condition will become the norm rather than extreme weather situations. The 1997–1998 El Nino brought on an acute drought and impacted on the tropical forest dynamics through an abnormally high mortality (Nakagawa et al., 2000; Cane, 2005). More research on the impacts of El Nino on the biodiversity in Malaysia because the future climate change means a constant El Nino state for Malaysia. Not only will more studies established biodiversity’s reaction to El Nino, the analysis will assist in predicting the potential impacts from climate change and act as a gauge to grasp if conservation and adaptation measures works.

In spite of the urgency for instant action, there is paucity of specificity in most of the recommendations offered by literature to guide this act (Heller and Zavaleta, 2009). The accessibility and applicability of conservation options for climate change adaptation need to be greatly increased and this can be achieved through more illustrated case studies and concrete strategies (Heller and Zavaleta, 2009). There is a need for research to incorporate ecology with other fields such as social science and approaches that clearly deal with the responsibilities of institutions, politics, policy and people in effective conservation plans.
5.6 Broader Implications

The results from this study also have wider implications not only for Malaysia but for Southeast Asia. Refugia for birds, amphibians and reptiles spilled over to the neighbouring countries namely Indonesia, Thailand and Brunei. Particularly in Borneo, refugia in Sabah and Sarawak spread out to Kalimantan, the Indonesian part of Borneo. Sarawak and Sabah is separated from Kalimantan by the central mountain range of Borneo which are formed by ranges of high hills and mountains. The vast potential refuge spread over other countries would necessitate international cooperation if the refuge were to be successfully preserved.

The central of Borneo is a large contiguous area of potential refugia for birds, encompassing southern part of Sarawak and the north western part of Kalimantan. Lowland altitudinal specialization birds in Southeast Asia revealed high habitat specificity while birds which can endure habitat variability inclined to transpire cross the altitudinal gradient (Peh et al., 2012). These birds would be restricted to their dwindling habitat area due to the inflexible occupancy requirement (Manne et al., 1999) and be incapable to move uphill (Williams et al., 2007). Since the birds could not move uphill but moved across the gradient, it is crucial that the whole mountainous range of Borneo are preserved to ensure the effectiveness of conservation of the birds.

The unremitting refugia for amphibians found at the north eastern part of Borneo encompassed three countries, namely Brunei, Sabah and Sarawak of Malaysia as well as Kalimantan of Indonesia. As was mentioned previously, amphibians are believed to be one of the most endangered animal group worldwide (Stuart et al., 2004) and not many research have been performed to assess climate change impacts on amphibian communities (Sodhi et al., 2010). Amphibians’ survival chances are constrained by their moderately low dispersal abilities (Ficetola et al., 2007) and may centre on retaining adequate unmodified habitat (Wanger et al., 2009; Bickford et al., 2010). Preserving and maintaining this vast area of refugia is essential to provide the 63 amphibian species endemic to Malaysia (IUCN, 2014) and other species endemic to the Borneo Island, a higher chance of survival in the face of climate change.

Refugia for reptiles in East Malaysia are found in the coastal areas and it joins to the other coastal areas around the whole of Borneo, encompassing Brunei and Kalimantan, Indonesia. Refugia for reptiles at the northern part of the Peninsular Malaysia links to the refugia area to southern Thailand. Reptiles have limited dispersal abilities and are susceptible to fast habitat degradations and variations (Gibbons, 2000). Fragmented forests are known to harbour less species richness as compared to joined forests (Laidlaw, 2000). Management and
preservation of biodiversity in significant areas which span international boundaries, known as transboundary conservation, are important foundations of successful conservation programmes (Secretariat of the Convention on Biological Diversity, 2005). Transboundary conservation encompasses a broad array of conservation strategies such as an assortment of land-uses in at least two countries playing a role in biodiversity conservation or a synchronized management of two protected areas among different countries which shared borders (Secretariat of the Convention on Biological Diversity, 2005).

Southeast Asian countries is gradually realising the significance of transboundary biodiversity conservation. Several projects have been started such as the Lanjak-Entimau Wildlife Sanctuary in Sarawak, Malaysia and Betung Kerihun National Park in West Kalimantan, Indonesia. This International Tropical Timber Organization (ITTO) funded project was the region's first transboundary biodiversity conservation area (TBCA) of tropical forest and forms the most focal sanctuary in Borneo for orang utan as well as other threatened and valuable animal and plant species (Susilo, 2003). Effective implementation of TBCA projects faces issues such as changes in political situation, diverse management classifications and sizes of the conservation zones, authority and security aspects of the border as well as continuousness funding for the TBCA (Susilo, 2003).

Chang and Rajan (2001) stated that in view of the common transboundary pollution troubles in the Southeast Asia region such as the haze, it should have been expected that the countries in the region are more pre-emptive in enabling cooperation on environmental and climatic issues. However, this is not the case and this could be attributed to the issue of disproportionate benefits and costs, enticement for any country to free ride on the endeavours of others bearing in mind the public goods nature of environmental protection as well as the contrasting priorities and preferences between countries (Chang and Rajan, 2001). The Southeast Asian situation demonstrates that regional efforts for transboundary conservation are not sufficiently sustained by economic and political resources (Chang and Rajan, 2001). An effective transboundary conservation would require an integrated approach and strong political will. As such, it could be beneficial for developing countries to back the formation of a new global environmental organisation as global support for regional efforts would be vital.

5.7 Recommendations

While GBIF is presently the most robust global data for species observations, more data on species in Malaysia could be added to the database. With the additional species presence data, this analysis can be redone with higher accuracy and credibility. There is planning for a
second version of the Wallace Initiative. Among its improvement is the facility to obtain species data for each country. A remodelling of this study with the second version of the Wallace Initiative will procure enhanced results. Further analysis can be carried out for Figures 10a-c. These figures can be rigorously analysed using GIS to calculate the exact areas of national park and oil palm plantations in the refugia for the various taxa. This will enable specific recommendations for conservation planning in Malaysia.

6.0 CONCLUSIONS

The study was set out to investigate the impacts of climate change on the distribution of biodiversity of Malaysia by distinguishing refugia and areas of concern. Similar study have been carried out (for example, Williams et al., 2007; Price et al., 2013) but none has been carried out specifically for Malaysia. Literature is inadequate on various fundamental questions on safeguarding biodiversity in Malaysia from the effects of climate change. This study intend to fill the gap as well as assist in shaping effective conservation policies and adaptation measures. This study mainly strived to show the changes in the distributions of for all the taxa and imply the implications of these patterns on the existing and future conservation strategies in Malaysia. However, the findings also indicated that international cooperation with neighbouring countries are essential for fruitful conservation of biodiversity in Malaysia and in Southeast Asia.

The Wallace Initiative used in this is currently one of the best tool to forecast climate-induced range shifts for biodiversity. The maps modelled by the Wallace Initiative and presented in this paper illustrate the refugia and AOC for every taxa thus demonstrating the shift in the distributions of the species in Malaysia due to climate change. Adaptation effort for each taxa are also illustrated reflecting the amount of endeavours required in its conservation. Positively, existing national reserves are generally on potential refugia indicating Malaysia is on the right path to successfully conserving its biodiversity.

The findings of this paper agrees with the latest IPCC fifth assessment report (2014) that climate change have impacted on the shifts of the species distributions. In developing this paper, it can be affirmed that there are major research gaps in the Southeast Asia and lack of knowledge on the biodiversity in Malaysia which had been highlighted in various studies (for example, Sodhi et al., 2004; Jaafar et al., 2012; IPCC, 2014). It is hoped that this research serve as a catalyst for further research on biodiversity. Decisions such as whether to continue conservation efforts at current reserve or to shift to the reserve to a potential refugia are some
questions to which this study has raised. The findings of this study will also allowed policymakers to choose which taxonomy to prioritize on if they wished. Resolutions on restoration of secondary forests or conversion of plantations into forests to create green corridors to provide connectivity for refugia can also be determined. These findings can assist policymakers and conservation managers in Malaysia to determine appropriate locations for additional new wildlife reserve and also on the essential adaptation measures for the existing national parks.

Limitations in this study were acknowledged although the most inclusive global analysis tool presently available of estimated climatic range losses of animals and plants are used in this study. Climatic influences such as monsoon and ENSO can undermine the results from this study too. More information and better understanding on both climatic and ecological variability will increase the accuracy of predictions from models on species range shifts (Guisan, 2006; Howard et al., 2014). More crucially, an increase of the quantity of data on species of Malaysia and also on its keystone species will benefit the conservation efforts in Malaysia tremendously.

This study clearly illustrates the climate-induced shifts in the distribution range of species in Malaysia. The adaptation efforts needed and the suitability of existing national wildlife reserve have been demonstrated. The findings of this study will greatly help policymakers and conservation managers in Malaysia to formulate effective policy and strategies for conservation of biodiversity. This paper could be the most thorough predictions of climate change effects on Malaysia’s biodiversity yet conducted.
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APPENDIX A

Potential Refugia

Figures 1a - e illustrates the potential refugias in Malaysia under the SRES A1B scenario in the 2020s.

Figure 1a: Refugia for Birds in year 2020s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 1b: Refugia for Amphibians in year 2020s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)
Figure 1c: Refugia for Mammals in year 2020s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 1d: Refugia for Reptiles in year 2020s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 1e: Refugia for Plants in year 2020s under the SRES A1B scenario
Figures 2a-e display the potential refugias in Malaysia under the SRES A1B scenario in the 2050s.

Figure 2a: Refugia for Birds in year 2050s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 2b: Refugia for Amphibians in year 2050s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 2c: Refugia for Mammals in year 2050s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)
Figures 3a-e exhibit, under the SRES A1B scenario in the 2080s, the potential refugia in Malaysia.

Figure 2d: Refugia for Reptiles in year 2050s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 2e: Refugia for Plants in year 2050s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 3a: Refugia for Birds in year 2080s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)
Figure 3b: Refugia for Amphibians in year 2080s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 3c: Refugia for Mammals in year 2080s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 3d: Refugia for Reptiles in year 2080s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)
Potential Areas of Concern

Figures 4a-e illustrates the areas of concern for Malaysia under the SRES A1B scenario in the 2020s.

Figure 3e: Refugia for Plants in year 2080s under the SRES A1B scenario (Darkest green means that 7 out of 7 GCM agree that a particular cell is a refugia)

Figure 4a: AOC for Birds in year 2020s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)
Figure 4b: AOC for Amphibians in year 2020s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)

Figure 4c: AOC for Mammals in year 2020s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)

Figure 4d: AOC for Reptiles in year 2020s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)
Figures 5a-e display the potential areas of concern in Malaysia under the SRES A1B scenario in the 2050s.
Figure 5c: AOC for Mammals in year 2050s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)

Figure 5d: AOC for Reptiles in year 2050s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)

Figure 5e: AOC for Plants in year 2050s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)
Figures 6a-e show the potential areas of concern in Malaysia under the SRES A1B scenario in the 2080s.

Figure 6a: AOC for Birds in year 2080s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)

Figure 6b: AOC for Amphibians in year 2080s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)

Figure 6c: AOC for Mammals in year 2080s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)
Figure 6d: AOC for Reptiles in year 2080s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)

Figure 6e: AOC for Plants in year 2080s under the SRES A1B scenario (Darkest red means that 7 out of 7 GCM agree that a particular cell is an area of concern)