Assessing the vulnerability of Thailand’s forest birds to global change

A thesis submitted by

Nantida Sutummawong

(M.S. (Forestry))

For the degree of Doctor of Philosophy

Centre for Tropical Biodiversity and Climate Change
College of Science and Engineering
James Cook University

July 2017

In Remembrance of His Majesty

King Bhumibol Adulyadej

1927 - 2016

Acknowledgements

I would like to thank a number of people from James Cook University, without whom, the completion of this work would not have been possible. Firstly, I would like to thank my supervisors: Professor Steve Williams and Dr Alex Anderson for their ideas, enthusiasm, patience, edit, support and advice. Especially, I would like to thank Steve for great advices on the fieldwork, giving me advices about my research sites in Thailand, providing me good foods during my study, extreme patience, and everything. I would like to give an enormous thank to Alex for helping me on fieldwork which we had a great time with six Leopards in one day after a day of treacherous flooding and thank for thoughtful comments, helpful ideas, and meditation class in the beautiful village in France that I have never know before. Without all of you this thesis would not have been possible.

I would like to acknowledge my unofficial supervisor, Lorena Falconi for sharing vast knowledge of species distribution modeling and editing my thesis; Watchara Sanguansombat for introducing me to love birds and learn how to identify birds, helping me for bird surveys during two year of my field works even he was sick, helpful ideas, and extreme patience; Dr Justin Welbergen for his ideas, comments and the incredible technic on how to write a research funding proposal when I just started my PhD; Professor Yongyuth Trisuraut for teaching me on CLUE-S model, sharing some spatial data, and his enthusiasm; Dr Brett Scheffers for his hiking to the top of mountain to have a look my field site, also his comments on my thesis Chapter 3.

Special thanks to Phill Round, Gorge Gale, Suporn Phonpan, Sunet Karaphan, Rangsrit Kanjanavanit, and Woraphot Bunkwamdi for kindly sharing data to me.

I am deeply grateful to Wutthipong Dongkumfoo, Sunet Karaphun, Supote Maneerat, Supote Daungjanthamanee, Suporn Phonpan, Weeraphong Koprachan, and Kullabon Pollawan for their supports on an accommodation, staffs, food, transport, and an incredible knowledge of field site during two year of my fieldwork with vast patience.

An enormous thank to all friends and colleagues who took their time to help me in the field with the most beautiful forest, but almost uncomfortable conditions and remote locations, thank you for sharing the memorable adventures with me: Watchara Sanguansombat, Prasit Wongprom, Dome Pratumthong, Therawat Kenmee, Wassana Surawut, Tassania Chinthong, Sunchai Megchai, Nareerat Sangkachai, Anuchat Wiriyathamsakul, Uppadit Chatkum, Supahwat Keawphakdee, Wisoot Supong, Waraphon Phothisan, Sirimat Kumsaiin, Ingkayut Saart, staff from Doi Inthanon National Park, staffs from Khao Yai National Park, staffs from Huai Kha Khaeng, staffs from Kaeng Krachan National Park, and staffs from Hala Bala Wildlife Research Station.

Many thanks also to staff from Doi Inthanon National Park, Huai Kha Khaeng Wildlife Sanctuary, Huai Kha Kaeng Wildlife Research Station, Kaeng Krachan Nantional Park, Khao Yai National Park, and Hala Bala Wildlife Research Station, Doi Chaing Dao Wildlife Research Station, particularly Hala Bala's family and Huai Kha Khaeng Wildlife Research Station for helping me in the field, cooking for me, and also for the transportation to very uncomfortable field sites. I also thanks to the National Science Museum's family to help me on fieldwork, photography, data, and amazing food at the top of mountain.

A special thanks to Nadiah Rosland for enthusiasm, encouraging, editing, helpful comments, bird watching, and supporting everything.. Also heartfelt thanks to Tiptiwa Samphuntamit who is colleague, sister, and friend, for sharing PhD time, spiritual guidance and supports. Also, thanks to Peeranarth Kiddee and Sunisa Kongprasit for listening and supporting when I had a hard time during my study.

I really enjoyed the chats, advice, support and friendship from fellow students and staff from Centre for Tropical Biodiversity and Climate Change; in particular Louise Banett, Stewart Mcdonal, Stephen Zozaya, Collin Storlie, Christina Buelow, April Reside , James Moloney, and Yvette Williams who is generously granted advice.

I would also like to thank Thai' students from James Cook University particularly; Orachun Hayakijkosol, Noppadon Prasertsincharoen, Kittikarn Sakuna, Wansadej Jaroenram, Pasuwat Yatip, Nareerat Sangkchai, Jarujet Thanksooks, Woramon Saehia, Nonthawit Saehia, Dave Siu, Nam Shenista, Melisa Sidara, Krerkkrai Songin, Benza Gluaymai, Paiboon Sriboonmak, Tip Kerdsap, Pote, Mo Chotnipat, and Anita Bousa for their enthusiasms, friendship, food, and supports.

I am deeply grateful to friends in Townsville who is my families that usually feed me, cook special foods for me when I requested to make my life smooth: Nikki Ladthong, Jo and Boonta Pinket, Laddawan Yubon and Aussie Thai restaurant, Tommy and Anong Inthaboualy, Aroi Bangkok Thai restaurant, Thai Inter restaurant, Ladda and Peter Henry, Sucha Muray, Runjuan Waitem, Patsuda Inthaboualy, Tom Numsri, Michael Hutchinson, and my landlord (Nick and Gay Fielder).

Also, thank you to friends and colleagues from Thaksin University who were working very hard, understanding, and supporting me during my PhD, particularly Anut Kirirathanikom, Sunisa Kongprasit, Wichuda Klawet, Vikanda Thongneaukaeng, Payomwan Yoksri, Chamada Chiajareun, and Benjawan Baukhawn. In particular Jumrouen Srichaichana for the advice on GIS, the remote sensing technic and the CLUE-S model.

Deeply thanks to the Royal Thai Government Scholarship (Scholar NSTDA) and Thaksin University for scholarships to pay for tuition fees and living costs in Australia. I would like to thank to the Centre for Tropical Biodiversity and Climate Change, the Asia Institute at Melbourne University andthe Rufford Small Grants Foundation for research fundings. Also thanks to OEA's family from Canberra, Kamonwan Satthayayuth, Somchitr Wattanatassi, Ploypaphat Ruanwong, and Kewalee Somboon for helping me on scholarship documents and supports.

I also wish to acknowledge to the Department of National Parks, Wildlife and Plants Conservation, The Lanna Bird Club, National Science Museum, King Mongkut's University of Technology Thonburi, Wildlife Research Division, Bird Conservation Society of Thailand, Doi Inthanon National Park, Hala-Bala wildlife reseach station, Kaeng Krachan National Park, Khao Yai National Park, Yongyut Trisurat, Anak Pattanavibool, Gorge Gale, Phillip Round, Wanlaya Chaiphakdee, and Kairat Iamaumphai for the use of their standardize data in my species distribution modeling.

My heartfelt thanks also go to my family for their love, and support in my interest in ecology, ornithology and my dreams to study abroad from the outset. Also special thanks to my mom, dad, my sister, my nephew, and father-in-law for their love and support. And finally, a truckload of gratitude goes towards my husband, Uppadit Chatkum, for listening to endless hours of listening, for cooking for me, for extreme patience waiting me to follow my dream, bandaging my soles (and soul), being my field colleague, the hugs and the love.

This thesis would not have been possible without any helps from many people. I am deeply grateful to have all of them.

Statement of contribution of others

Scholarship for tuition fee and stipend

- Royal Thai Government Scholarship
- Thaksin University

Research funding for data collection

- Centre for Tropical Biodiversity and Climate Change
- Asia Institute, Melbourne University
- Rufford Small Grant Foundation

Supervision

- Professor Stephen Williams, Centre for Tropical Biodiversity and Climate Change, JCU
- Dr Alex Anderson, Centre for Tropical Biodiversity and Climate Change, JCU
- Professor Simon Robson (Advisor mentor), Centre for Tropical Biodiversity and Climate Change, JCU

Statistical, analytical and modeling support

- Lorena Falconi
- Yongyuth Trisurat
- Jumrouen Srichaichana

Editorial assistance

- Stephen Williams
- Brett Scheffer
- Lorena Falconi
- Nadiah Roslan
- Orachun Hayakijkosol
- Wachara Sanguansombat

Important note about the structure of this thesis:

The thesis has been written in “paper” format with each chapter potentially being a separate publication. The aim was to have each chapter as a “stand alone” publication. Unfortunately, this approach inevitably leads to some unavoidable, but necessary, duplication in explaining methods, the significance of concepts and some discussion points.

Thesis Abstract

Anthropogenic climate change and the loss or degradation of vegetation cover are key threats to global biodiversity and ecosystem health. However, little is known of how these two important drivers of change on ecosystems will combine in the future to further threaten global biodiversity. This is of particular importance in the tropics, where global biodiversity is concentrated and there is ongoing habitat modification. Thailand is within the Indomalayan biodiversity hotspot and although there is an extensive and reasonably well managed protected area network there has been a high level of historical and ongoing land-cover change. There is limited information on how climate and land-cover changes will impact on the future vulnerability of biodiversity in Thailand. To help address this knowledge gap, this study uses a powerful combination of a collation of existing bird occurrence data, systematic standardised field surveys and spatial modelling to examine the potential future impacts of changes in both land-cover and climate on the spatial patterns of species distributions, species richness and population size for Thailand's forest birds. The study evaluates the vulnerability to global change of individual species and geographic regions under a range of future climate and land cover scenarios.

This thesis investigates the vulnerability of Thailand's forest bird species to climate change and land-cover change in three stages. Firstly, current patterns of species distribution, abundance and assemblage structure were examined using a combination of a collation of existing bird occurrence data and standardized field surveys. A total of 827 standardized transect surveys of bird assemblages were carried out at 96 transects of 32 sites across Thailand and recorded a total of 431 species of birds. Sampling was conducted in five different mountain ranges spanning the available latitudinal (5° 47' - 18° 32'N) and elevational (100-2500 m asl) gradients of closed forest to maximize the coverage of environmental space.

The field survey data was used in Chapter 2 to examine the relationships between assemblage structure and elevational/temperature gradients. Individual species distributions and assemblage structure of forest birds were strongly and consistently associated with the elevational/temperature gradient with a predictable change in species composition and abundance with increasing elevation. However, despite the strong pattern of assemblage

change, there was surprisingly little evidence of any consistent elevational species richness pattern. There was a tendency for species richness within forest to be lower at the low-elevation with some indication of slightly increasing species richness up to 500m, plateauing across mid-elevations (500-1500m) and slightly declining above 1500m. Another clear pattern was the biogeographically difference in assemblage structure with a clear separation between the southern assemblages present in Hala Bala (Sundaic species) and the rest of Thailand dominated by Indochinese species. The demonstration of such clear elevational/temperature gradients in assemblages of birds right across Thailand suggests that it is highly likely that as global temperatures increase there will be significant shifts in the distribution of these assemblages and the potential for significant impacts on biodiversity.

Chapter 3 used the combined datasets from both field surveys and the collation of existing data from other sources to produce high-resolution species distribution maps for all species. Species distribution models were used to explore the relationships between bird distributions and assemblage structure and environmental variables of climate and land cover. Maximum temperature, annual mean temperature, and rainfall seasonality were the most consistently important climatic factors related to species distributions. Models based purely on land cover performed poorly in comparison to climatic models, however, when both climatic and land-cover variables were included into the species distribution models, land cover was the most consistently important variable, followed by maximum temperature, annual mean temperature, and rainfall seasonality.

Chapter 4 used the species distribution models produced in Chapter 3 to examine the potential impacts of projected climatic change on Thailand's forest bird species. Overall, the projections predict a massive loss in the population size of most species and a lesser decline in distribution area. Using an index of total population size based on summed environmental suitability for each species distribution model (an index to measure effects on species conservation status under IUCN criteria A3), the results predict that over 85% of bird species assessed will become threatened in Thailand, while only 5% become threatened using purely range size criteria (IUCN criteria B1). This has significant implications for the widespread use of range size in projecting future vulnerability of biodiversity to climate change and emphasizes that indices of total population size are more biologically meaningful and provide a more sensitive and realistic assessment of vulnerability based on the both the spatial extent and spatial pattern of habitat quality. Not surprisingly, impacts are greatest in high elevation assemblages across Thailand.

Chapter 5 explores the combined impacts of projected future change in both climate and land cover by evaluating the vulnerability of individual species under a range of future climate and land cover scenarios. Species distribution models for each species from previous chapters were projected into a range of future environmental scenarios in three combinations: climate change only (from Chapter 4), land-cover change only, and climate change combined with land-cover change. Four scenarios of future climate change were used (representative concentration pathways - RCP 2.6, 4.5, 6.0, and 8.5) from the Fifth IPCC Assessment Report (AR5). Four future scenarios of land cover change were used that vary based on a combination of predicted on population and economic policy (mild, moderate, severe, and most severe) were used for land-cover based on the Thailand strategic planning for the next 20 years with assummed each separate development scenario that policy would continue.

Chapter 5 demonstrates that there will potentially be a large decrease in species richness in lowland areas of Thailand and increased species richness in the uplands, particularly in the protected highland areas of western Thailand. This was associated with the maintenance of forest cover in protected areas, concomitant with a shift in species distributions into higher elevation areas. Climate change models predicted much larger negative impacts on species richness, species distributions and population size than did land-cover change models. The combination of business-as-usual global emissions combined with ongoing land cover change could be devastating with up to 95% of all forest birds species becoming threatened and of these approximately 85% becoming critically endangered and potentially extinct in Thailand due to complete loss of suitable environment. The analyses identify species and geographic areas that are most vulnerable and areas where protection of upland refugial forest cover will provide some resilience to some species.

It is imperative that environmental management and policy makers utilise this information to strategically plan the most effective adaptation actions aimed at maintaining functional ecosystems in the face of serious climatic and land cover changes. By understanding the combined and individual effects of climate and land-cover change, effective conservation approaches could be designed and implemented, but only if there is a concerted global and local effort that combines global emission reduction, adaptive forest management and the design of strategically selected protected area networks to help increase the resilience for the high number of species at risk in a rapidly changing world.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1:
Introduction

1.1 Background

In a rapidly changing world, understanding and assessing species vulnerability to global changes is necessary to make informed policy and management decisions aimed at minimizing negative impacts on natural ecosystems. A greater understanding of the mechanisms that drive impacts on ecosystems and the ability to forecast the impacts of future environmental changes on biodiversity are a global priority (Pacifici et al., 2015). A critical element of this knowledge is the understanding of how increasing temperature will impact on species, biodiversity and ecosystem processes. It is often intractable to examine direct temperature effects across many species and processes and we must rely on knowledge gained by the examination of existing environmental gradients that provide a "space-for-time" substitution as a natural experiment to increase our knowledge on the impacts of higher temperature. Elevational gradients are a commonly used and powerful opportunity to do this and offer a parallel to both latitude and temperature gradients over short geographic distances that can help minimize confounding effects. Elevational gradients have been broadly used in this manner as a tool to examine the mechanisms that relate to patterns of biodiversity, particularly the influence of temperature (Rahbek, 1995, McCain, 2009a, McCain and John-Arvid, 2010, Sanders and Rahbek, 2012, Guo et al., 2013).

Elevational gradients represent a unique opportunity to examine many hypotheses about the determinants of biodiversity pattern and process (Guo et al., 2013). Climate, especially temperature, and habitat are both strongly related to elevation, with higher temperatures in the lowlands and cooler in the uplands. Given the obvious importance of understanding the relationships between temperature and global climate change, elevational patterns of biodiversity along elevational gradients have been widely utilized to assess the impacts of climate change (Körner, 2000, Wilson et al., 2005, Colwell et al., 2008, Sekercioglu et al., 2008, Raxworthy et al., 2008, Tingley et al., 2009, Laurance et al., 2011, Forero-Medina et al., 2011b, Forero-Medina et al., 2011a, Tingley et al., 2012, Anderson et al., 2013, Freeman and Class Freeman, 2014, Ferrarini et al., 2017).

Elevational patterns in biodiversity have received attention on various taxa such as insects (Pyrcz and Wojtusiak, 2002, Merrill et al., 2008, Chen et al., 2009, Yu X-D et al., 2013), amphibians, reptiles (Fu et al., 2006, Chettri et al., 2010), mammals (McCain, 2005, Wu et al., 2013b), and birds (Blake and Loiselle, 2000, Lee et al., 2004, Kattan and Franco, 2004, McCain, 2009a, Williams et al., 2010, Acharya et al., 2011, Wu et al., 2013a, Pan et al., 2016). However, little attention has been given to this topic in Thailand or South-east Asia in general: only one study has been done on birds along elevational gradients (PratumThong and Pattanavibool, 2006) where they showed a strong relationship between species richness and elevational gradients with a peak in species richness at mid-elevation and lower richness at both lower and higher elevations (PratumThong and Pattanavibool, 2006). They emphasized that further research using elevational patterns in biodiversity on understanding changes in distribution and abundance associated with climate change impacts was vital for future conservation management in Thailand.

Generally, changes in distribution and population size of species are used to evaluate species vulnerability to any impact (IUCN, 2001, AkÇAkaya et al., 2006, Keith et al., 2014, Rodriguez et al., 2015, IUCN, 2017). Changes are usually calculated by empirical field observations (Taylor and Pollard, 2008, Gale et al., 2009), or calculated by projections of species distribution models (SDMs) (Beaumont et al., 2005, Beaumont et al., 2007, Pearson and Dawson, 2003, Phillips et al., 2004, VanDerWal et al., 2009a, VanDerWal et al., 2009b). SDMs are a commonly used tool to predict the spatial distribution of species based on the relationship between presences/absences and environmental variables (Pearson et al., 2004, Phillips et al., 2004, Phillips et al., 2006, Phillips and Dudík, 2008, Elith and Leathwick, 2009, VanDerWal et al., 2009b, VanDerWal et al., 2009a, Jiguet et al., 2010, Hof et al., 2012, Fourcade et al., 2014). SDMs use environmental variables to predict changes associated with environmental changes such as climate and land cover change (Elith et al., 2010, Gillingham et al., 2012, Pimm et al., 2014).

Climate and land cover changes are considered to be the major threats to global biodiversity and ecosystem function (Jetz et al., 2007, Barbet-Massin et al., 2012, Frishkoff et al., 2016, Sirami et al., 2017). There is a rapidly growing body of literature building on early works such as Parmesan and Yohe, 2003, Root et al., 2003, on the global impacts of climate change indicating that species are being subjected to increasing impacts on distribution, movement dynamics, population size, biotic interactions and assemblage structure (. Temperature changes have already been associated with shifts in species distribution towards the poles (increasing latitude) and increasing elevation, population declines, and changes in assemblage structure (Parmesan and Yohe, 2003, Parmesan, 2006, Colwell et al., 2008, Rosenzweig et al., 2008, Sekercioglu et al., 2008, Bellard et al., 2012, Anderson et al., 2013, Jenouvrier, 2013, VanDerWal et al., 2013, IPCC, 2014, Freeman and Class Freeman, 2014, Gibson-Reinemer et al., 2015, Pecl et al., 2017).

In the future, accelerating climatic change is predicted to drive rapid changes in species' abundance and distributions, potentially resulting in significant levels of extinction among the world's biota (Parmesan and Yohe, 2003, Root et al., 2003, Williams et al., 2003, Thomas et al., 2004, Laurance et al., 2011, Dullinger et al., 2012, Gardali et al., 2012, Parmesan et al., 2013, Urban, 2015). Birds are excellent indicators of global change (Şekercioğlu et al., 2012), and tropical bird species may also be particularly vulnerable to climate change (Harris et al., 2011, Sodhi et al., 2011). Shifts in bird distributions attributable to climate change have already been detected in the tropics (Williams et al., 2017). However, the majority of studies to date have been in the temperate zone (Harris et al., 2011, Laurance et al., 2011). Tropical biotas are expected to be more vulnerable to climate change (Deutsch et al., 2008), because they have evolved and experience minimal fluctuations in annual temperature and many species are potentially already close to their maximum thermal tolerance (Tewksbury et al., 2008). Southeast-Asia, and particularly Thailand, is of great conservation as a globally significant biodiversity hotspot (Myers et al., 2000, Sodhi et al., 2010a, Koh et al., 2013), but few studies have attempted to examine the future vulnerability of this biodiversity (Hughes et al., 2012). There is a lack of data and knowledge about the potential future impacts on biodiversity in the region, especially the synergistic impacts of land cover and climate change. There is some evidence based on elevational shifts in the range boundaries of 94 species of common resident Southeast Asians birds toward a higher elevation in response to climate warming (Peh, 2007), and in bats (Hughes et al., 2012). Given the importance of the avifauna in Thailand, their recognized vulnerability, the lack of information of species distribution responses to climate change and the existing high levels of other human impacts (Trisurat, 2011) it is critical to collate and collect baseline data and provide comprehensive assessments of the vulnerability of this important biodiversity.

Deforestation and land cover change have been the biggest threats to biodiversity globally and particularly in the Tropics (Myers et al., 2000, Sala et al., 2000, Trisurat et al., 2010, Newbold et al., 2015, Hughes, 2017). Species responses to change in land cover and habitat fragmentation such as loss in suitable habitat, reduced population size and connectivity is leading to increased extinction risks (Trisurat et al., 2010, Lee and Jetz, 2011, Trisurat et al., 2013). Although climate variables are often the key drivers of range extent, land cover variables are important to define habitat extent locally, therefore the combination of both climate and land cover will provide the most useful and robust evaluation of species distribution (Thuiller et al., 2004a, Luoto et al., 2007, Howard et al., 2015). Many conservation studies on species distributions have focused on either climate or land cover and little is known about their combined impacts or the potential for truly synergistic impacts (Clavero et al., 2011, Barbet-Massin et al., 2012, Eglington and Pearce-Higgins, 2012, Schneider and Root, 2013, Martin et al., 2013, Maggini et al., 2014, Oliver and Morecroft, 2014, Trisurat et al., 2014, Zhang et al., 2016, Frishkoff et al., 2016).

The impacts of climate change combined with land cover change can be simply additive, synergistic (amplify) or antagonistic (buffer) to biodiversity (Radinger et al., 2016). Many studies have emphasized the potential for synergistic effects of climate and land cover change on biodiversity and called for greater research effort on these multi-faceted impacts rather than the more common approach examining single stressors (Brook et al., 2008, Brodie et al., 2012, Selwood et al., 2014, Williams et al. 2017) across a variety of taxa, including: plants (Asner et al., 2010, Bennett et al., 2013, García-Valdés et al., 2015, Zhang et al., 2016, Barros et al., 2017), insects (Fox et al., 2014, Vermaat et al., 2017), aquatic species (Maina et al., 2012, Radinger et al., 2016), amphibians-reptiles (Hof et al., 2011, Frishkoff et al., 2015), mammals (Trisurat et al., 2014, Sultaire et al., 2016), and birds (Jetz et al., 2007, Barbet-Massin et al., 2012, Eglington and Pearce-Higgins, 2012, Maggini et al., 2014, Sohl, 2014, Fraixedas et al., 2015, Virkkala, 2016, Vermaat et al., 2017). This research was identified as one of the top five highest priority research topics in natural ecosystems in Australia in a large, multi-sector analysis involving scientists, governments and diverse stakeholder groups under the Australian National Adaptation Research Plan for Natural Ecosystems (Williams et al. 2017). However, most existing studies are located in the temperate zone (Fraixedas et al., 2015, Zhang et al., 2016, Sultaire et al., 2016, Barros et al., 2017, Vermaat et al., 2017), with few studies explicitly examining the combined impact of climate change and land-cover change in the tropics (Trisurat et al., 2014, Osipova and Sangermano, 2016). Given the concentration of global biodiversity in the Tropics and the predictions of high physiological and evolutionary sensitivity in tropical species this is a vitally important topic for current research.

Many studies assess species vulnerability to global changes using the IUCN Red List Criteria based on measured changes in range size (Thomas et al., 2004, Bomhard et al., 2005, Franco et al., 2006, Schwartz et al., 2006, Raxworthy et al., 2008, Maclean and Wilson, 2011, Dullinger et al., 2012, Boucher-Lalonde et al., 2014, Pimm et al., 2014, White and Bennett, 2015, Urban, 2015, Zhang et al., 2016). However, there is general recognition that estimates that consider the spatial patterns of abundance within the distribution or total population size, and not just the overall range of the species, are more useful to assess the impacts of climate change on the conservation status of a species (Shoo et al., 2005b). Despite this, few studies employ population data in conservation risk assessments (Shoo et al., 2005a, Keith et al., 2008, Brook et al., 2009, Gasner et al., 2010, Jenouvrier, 2013, Vedder et al., 2013, Selwood et al., 2014).

As discussed above, comprehensive assessments of vulnerability to global change can be informed by combinations of projections of range size, local population density, total population size and a consideration of both climate and habitat change. However, conservation assessments in Thailand have thus far largely depended on expert opinions (Sanguansombat, 2005, ONEP, 2007), with only one study assessing the distribution and conservation status of hornbills using projected distribution change to evaluate conservation status (Trisurat et al., 2013).

Thailand is one of the mega-diverse countires of the world with many species from both 'Indo-Burma' and 'Sundaland' biodiversity hotspots (Myers et al., 2000); unfortunately, this biodiversity is highly threatened by the impacts of extensive deforestation, hunting, poaching and fire (Trisurat, 2011). Habitat degradation has been widespread and extensive with subsequent impacts on biodiversity and now there is a very real threat of climate change exacerbating and accelerating current problems (Jetz et al., 2007, Trisurat et al., 2014). Coupled with this lack of information in Thailand, there has already been an increase in average air temperature of ~0.95°C between 1955 and 2009 in the region, exceeding the average increase of world temperature (Limsakul, 2011). To date the only documented impact of climate change on Thailand's birds showed that the lowland Siamese Fireback (*Lophura diardi*) has significantly increased in abundance at a high-altitude site formerly only inhabited by the highland Silver Pheasant (*L. nycthemera*), and attribute a temperature increase and changes in rainfall as the most likely cause (Round and Gale, 2008). Thus far, the only assessment of the vulnerability to global change of Thailand biodiversity has been based on expert opinion (Sanguansombat, 2005a), despite the availability of modelling techniques for evaluating species vulnerability to global changes (Thomas et al., 2004, Keith et al., 2015, Rodriguez et al., 2015).

Therefore, the overall aim of this thesis is to assess the vulnerability of the forest avifauna of Thailand using a combination of systematically collected field data across both latitudinal and elevational temperature gradients, collated existing data on species occurrences and projections of the potential impacts on species distributions and population size using future scenarios of both climatic change and land cover change. This knowledge will enable more informed decisions on environmental management and policy in Thailand that will help minimize the future losses of Thailand's biodiversity

1.2 Thesis outline

The goal of this study is to assess the vulnerability of Thailand's forest birds to climate and land cover change. Here I focus on three main aspects: identifying the relative influences of current patterns of assemblage structure and diversity in birds across existing climatic gradients; secondly, predicting the potential response to the impacts of climate change, land cover change, and the interaction between these two drivers, and lastly assessing the vulnerability of Thailand's avian biodiversity to future global changes. Specifically, my research seeks to achieve the following aims:

1. To use standardised field surveys to examine patterns, and potential environmental determinants, of species distribution, species richness, local abundance and assemblage structure in Thailand's forest birds across elevational and latitudinal gradients. I sought to determine how the current patterns of species distributions, assemblage structure and diversity are related to the environmental gradients present across elevation and latitude. (Chapter 2).
2. To investigate the relative influence of climate and land cover on species distributions and spatial patterns of diversity. I aimed to examine the relative influence of climate, land cover and the combination of climate and land cover on species distributions across the forest bird species (Chapter 3).

3. To examine the potential impacts of future climate change on spatial patterns of species distributions, species richness, and abundance, and evaluate species vulnerability due to climate change. I explored the different impacts predicted under different future emission scenarios to assess the vulnerability of bird species to projected climate change and identified risks and conservation status of individual species based on IUCN Red List Criteria (Chapter 4).
4. To examine the potential impacts in spatial patterns of species distributions, species richness, and abundance, and evaluate species vulnerability due to future climate change, land cover change, and combined climate and land cover change. I sought to evaluate if changes were amplified by climate and land cover or by individual factors. I also evaluate how much these change affects to birds, and I project he future changes in the conservation status, trends and threats for Thailand's birds on global changes and the relative impacts of climate and land cover change (Chapter 5).

1.3 Data used in this thesis

Two main datasets were used in this study:

1.3.1 Bird data used on distributions and abundance and another on spatial environmental data of climate and land cover. The bird data focuses on evergreen forest birds and is based on both my own field data and collation of existing data from a wide variety of sources and literature in Thailand: (1) observed data with 827 standardized field surveys across five mountain ranges resulting in coverage of 13 elevational bands (100 – 2500 m) at 32 local sites each with three transects at least 200m apart giving a total of 96 transect locations that encompass the altitudinal and latitudinal breadth of Thailand (full details in Chapter 2), and (2) collation of existing data from various organizations and individuals (full details in Chapter 3 and Appendix Table 1.1). Chapter 2 focuses on elevational patterns of abundance, richness and assemblage structure based on my empirical field data. All subsequent chapters utilize the combination of my field data and the collated data. There are a number of appropriate bird guides that could be used in Thailand (Lekagul and Round, 1991, Craig, 2005, Craig, 2009, Napheethapat et al., 2012). In my study I followed the bird guide of Thailand (Lekagul and Round, 1991, Napheethapat et al., 2012) and a guide of the birds of Southeast Asia (Craig, 2009) to identify bird species.

I examined a variety of ecological subsets of species to determine if different ecological groups showed major differences in their environmental relationships and future vulnerability (detail in Chapter 3).

All of the data used in this thesis comes from within Thailand. Although it is not ideal to be limited to a politically defined region rather than the natural distributions of the species, it was unavoidable in this case. My field data was limited to within Thailand due to the logistic limitations of a PhD project and my access to other data was primarily primarily imposed by availability of data and collaborators to provide additional data that was limited due to only having contacts with individual ornithologists, bird clubs, the Department of National Park, Wildlife and Plant Conservation (DNP), and universities within Thailand. Although this reduces the applicability of the models to species that are broadly distributed outside of Thailand, most of the species used in the analyses are primarily forest (often montane) species in an isolated, patchy environment within Thailand and as such the spatial models should still be robust and suitable for the questions addressed here.

1.3.2 Spatial environmental data utilized in this study are current and future climate and land cover data. Climate data included the current and future climate datasets of 8 variables based on temperature and precipitation from the WorldClim at 1x1 km^2 resolution, which was the highest resolution available for the entire study area (Hijmans et al., 2005) (detail in Chapter 3 and Chapter 4). Land cover data used was classified into four classes: (1) agriculture, (2) forest, (3) urban, and (4) others. Current land cover data was derived from image interpretation from Landsat 8TM downloaded from USGS data free download (https://landsat.usgs.gov/landsat-data-access), past land cover data came from the Royal Forest Department land use database in 2000, which is the most detail and appropriate coverage available at the time of analysis (detail in Chapter 3). Future land cover employed the CLUE-S models (Verburg and Overmars, 2009b) to predict future land cover change based on the Thailand National Strategic Plan over the next 20 years (2017 – 2036) (NESDB, 2017) (further detail in Chapter 5).

Chapter 2:
Species richness and assemblage structure along elevational gradients of Thailand's forest birds

---

2.1 Abstract

Understanding the relationships between biodiversity pattern and climate is a critical aspect of conservation management in the Anthropocene. Elevational gradients encompass strong climatic gradients and associated patterns in species richness and assemblage structure and have been widely used to examine environmental drivers of species distributions and diversity. This study examined patterns of species richness, local abundance and assemblage structure in Thailand's forest birds across elevational and latitudinal gradients to increase our broad understanding of the future impacts of a changing global climate in this globally significant biodiversity hotspot. I used standardized transect surveys sampling birds at 96 transects of 32 sites across latitudinal and elevational gradients at five mountain ranges spanning elevations from 100-2500 m asl and latitudes from 5˚-20˚N.

A total of 431 species of birds were recorded by field survey. Overall, species richness was lower at low elevation with some indication of slightly increasing species richness up to 500m, plateauing across mid-elevation (500-1500m) and slightly declining above 1500m. Surprisingly, there was little evidence of any consistent elevational richness pattern, despite the strong pattern of assemblage change. Assemblage structure of forest birds was strongly and consistently associated with the elevational gradient with a predictable change in species composition and abundance with increasing elevation. Another clear pattern was the biogeographic difference in assemblage structure with a clear separation between the southern assemblages present in Hala Bala (Sundaic species) and the rest of dominated by Indochinese species. The demonstration of such clear elevational/temperature gradients in assemblages of birds right across Thailand suggests that it is highly likely that as global temperatures increase that there will be significant shifts in the distribution of these assemblages and the potential for significant impacts on biodiversity.

2.2 Introduction

One of the fundamental questions in ecology is understanding the mechanisms that drive patterns of species distribution, abundance and species richness along environmental gradients (Rahbek et al., 2007, McCain, 2009a, Acharya et al., 2011). In recent decades, elevational gradients have been widely used as a tool to examine the mechanisms that shape patterns of biodiversity as they offer a parallel to global latitudinal and temperature gradients at a small scale, thereby reducing other confounding influences (Rahbek, 1995, McCain, 2009a, Sanders and Rahbek, 2012). Generally richness patterns across elevational gradients have four forms: (1) decreasing richness with increasing elevation, (2) high richness across a plateau at lower elevations then decreasing monotonically, (3) lower-elevation plateaus with mid-elevation peaks, and (4) unimodal mid-elevational peaks (Rahbek, 1995, Rahbek, 2005, McCain, 2009a). These patterns vary across taxonomic groups with birds showing all four patterns with almost equal frequency (McCain, 2009a).

Elevational patterns in tropical bird assemblages, particularly Thailand's birds, have been less studied than temperate birds in Europe (Herzog et al., 2005) and North America (Terborgh, 1977, Kattan and Franco, 2004). Significant research has been conducted in subtropical assemblages in the Himalayas and China (Acharya et al., 2011, Wu et al., 2013a, Pan et al., 2016), and tropical birds in South America, Central America, Australia, and some islands in Southeast Asia (Blake and Loiselle, 2000, Williams et al., 2010, Forero-Medina et al., 2011b); However, despite the fact that Thailand, as part of the Indomalayan biodiversity hotspot (Myers et al., 2000), has high levels of threatened avian biodiversity it has received very little attention. The only previous study on bird diversity along elevational patterns in Thailand showed a low-elevation plateau with mid-elevational peak in richness patterns of montane evergreen forest birds (PratumThong and Pattanavibool, 2006). Their study highlighted the significance of elevational/temperature gradients in determining species distribution patterns. Thus they concluded that understanding the elevational gradient in Thailand was vital for future conservation management and that a systematic study across elevations was needed.

Elevational gradients, and the associated strong gradients in climate and habitat, also represent a unique opportunity to examine many hypotheses about the determinants of biodiversity including the relative influence of climatic variables, productivity, sampling biases, habitat area, geographic constraints such as the mid-domain effect (MDE), evolutionary history, and to help tease out the interactions between these factors (Rahbek, 1995, Kattan and Franco, 2004, McCain, 2004, McCain, 2009a, Sanders and Rahbek, 2012). A global review of elevational patterns in bird assemblages (McCain, 2009a) suggested that current climate and productivity are the primary drivers of bird diversity, whereas area, the mid-domain effect and niche conservatism all had some, although inconsistent, support. Given the demonstrated relationships between climate, productivity and bird diversity, combined with ongoing and accelerating global climate change, , the importance of understanding elevational gradients, and their concomitant temperature gradient, has been emphasized due to the critical need to understand and manage the impacts of increasing temperature under a changing global climate.

This chapter aims to describe, document and explain the assemblage structure and species richness pattern of forest birds along elevational gradients in Thailand, using empirical field data based on standardized transect surveys across five mountain ranges spanning the latitudinal gradient in the region. These analyses and data provide the baseline information and understanding of assemblage patterns that can be used in subsequent chapters to examine the future impacts of climate change and land cover change.

2.3 Methods

2.3.1 Study area

In order to describe the pattern of abundance, assemblage structure and species richness in Thailand forest birds, I established replicated, standardized sites across elevational gradients in five protected areas: Doi Inthanon National Park; Huai Kha Khaeng Wildlife Sanctuary; Khao Yai National Park; Kaeng Krachan National Park; and Hala Bala Wildlife Sanctuary that span the latitudinal (5° 47’ to 18° 32’N and 98° 35’ to 101° 49’E), temperature and rainfall gradients present in Thailand’s evergreen forests (Figure 2.1). The mountain ranges that I surveyed varied in their elevational range: Doi Inthanon 300 – ~2500 m; Huai Kha Khaeng 100 – 1500 m; Khao Yai 100 – 1300m; Kaeng Krachan 300 – 1500 m; and Hala Bala 80 – 1500 m. The sampling sites were set up at 200-m elevational intervals across available gradients within each subregion (mountain range), I established three permanent transects for bird sampling at each site, with a minimum of 200 m between adjacent transects (see Figure

2.1 and Table 2.1). All sites were selected, as much as possible, to be within relatively intact forest and as far away from human disturbance as feasible. For more detailed description of the locality/elevation of every site within each mountain range see Appendix Table E1.

2.3.2 Bird sampling

Bird abundance at these sites was estimated based on standardized surveys, adopting the methodology developed by Williams over 20 years of biodiversity research in the rainforests of the Australian Wet Tropics (Shoo et al., 2005b, Williams et al., 2010). Briefly, these consist of 30 minute, 150m long audio-visual surveys through evergreen forest, conducted between 06:00 – 09:00 am and 03:00 – 06:00 pm.. All birds seen or heard were identified and recorded. In addition, I recorded all calls by portable Sony PCMD50 recorder for later validation of species not identified during the field surveys. All transects were repeated 2 – 4 times each during both the wet season (Jun – Dec) and dry seasons (Jan – May) of 2013 and 2014. Thus, a total of 829 surveys were carried out across five mountain ranges resulting in coverage of 13 elevational bands (100 – 2500 m) at 32 local sites each with three transects at least 200m apart giving a total of 96 transect locations that were surveyed during this study (Table 2.1). I obtained the permission to do field survey from the Thailand Department of National Parks, Wildlife and Plant Conservations permit number TS 0907.4/23665, and James Cook University Animal Ethics approval ID A2066.

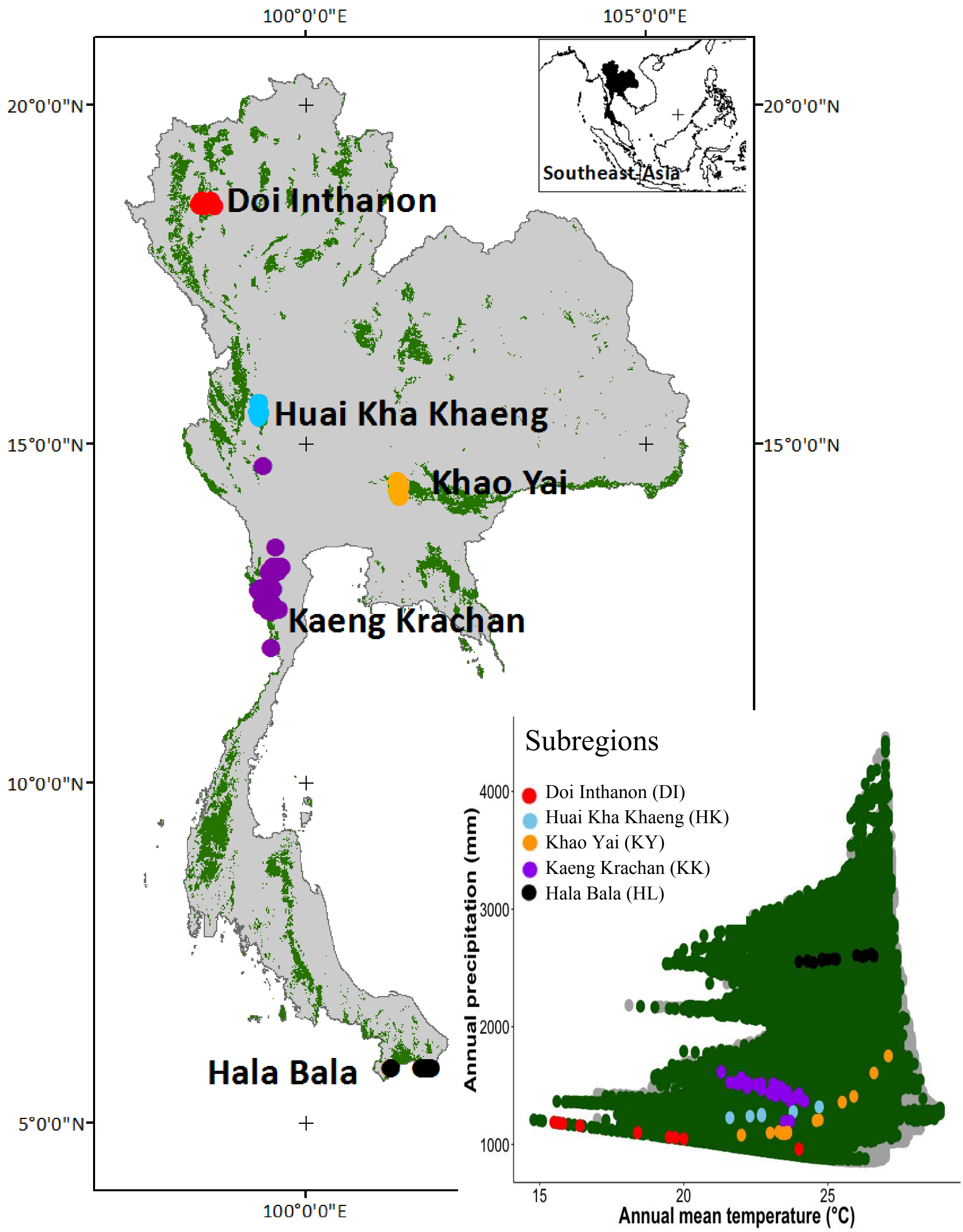


Figure 2.1 Map of geographic locations and climatic space of the standardized bird transect surveys used in this thesis. Green areas represent evergreen forest and dots represent subregions; Doi Inthanon (red); Huai Kha Khaeng (blue); Khao Yai (yellow); Kaeng Krachan (purple); and Hala Bala (black). X-axis is annual mean temperature and y-axis is annual precipitation from WorldClim climatic varibles at 1x1 km^2 resolution.

Table 2.1 Details of the number of bird surveys conducted at each sampling site showing the available elevational range present in each mountain range: DI=Doi Inthanon; HK=Huai Kha Khaeng; KY=Khao Yai; KK=Kaeng Krachan; and HL=Hala Bala (see dates and location of each transect in Appendix Table E1).

Region	Site	Number of surveys along Elevation (transect)													Total
		100	300	500	700	900	1100	1300	1500	1700	1900	2100	2300	2500	
DI	DI07A				24										24
DI	DI09A					24									24
DI	DI11A						24								24
DI	DI13A							24							24
DI	DI15A								24						24
DI	DI17A									24					24
DI	DI19A										24				24
DI	DI21B											24			24
DI	DI23A												24		24
DI	DI23B												21		21
DI	DI25A													24	24
HK	HK03A		27												27
HK	HK05A			24											24
HK	HK07A				25										25
HK	HK09A					24									24
HK	HK11A						24								24
HK	HK13A							24							24
KY	KY01A	24													24
KY	KY03A		24												24
KY	KY05A			24											24
KY	KY07A				24										24
KY	KY07B				15										15
KY	KY09A					24									24
KY	KY11A						24								24
KK	KK03A		27												27
KK	KK03B		18												18
KK	KK05A			24											24
KK	KK07A				24										24
KK	KK09A					36									36
HL	HL01A	48													48
HL	HL03A		39												39
HL	HL05A			46											46
Total	32	72	135	118	112	108	72	48	24	24	24	24	42	21	827

2.3.3 Data analysis

Species accumulation curves were used over surveys to evaluate sampling adequacy at each elevation in each region . Observed species richness (S_{obs}) was examined by counting total number of species detected across all seasons at each transect within each elevational band as suggested by Gotelli and Colwell (2011) for all species and separately for resident species. Since species accumulation curves had not completely plateaued in all sites, it was necessary to use rarefaction techniques to estimate total species richness at any site and to help reduce sampling bias due to unequal sampling intensity (Williams et al., 2010, Gotelli and Colwell, 2011). I used a non-parametric estimator for abundance data (Chao1) to estimate total species richness (S_{chao1}) (Chao et al., 2005, Chao and Chiu, 2016). Some studies recommend using interpolated richness, a technique designed to smooth occurrence data where the species was observed both above and below any elevation (Hu et al., 2016). I calculated interpolated estimates for each site, however given my sampling design, interpolating richness would produce a consistent bias by exagerating the richness at mid-elevations compared to upper and lower elevation sites. On this basis, I did not use interpolated estimates. I employed the 'vegan' package in R (Oksanen et al., 2015) to compute the species accumulation curves, S_{obs} and S_{chao1}.

Polynomial regressions analyses were performed to clarify the elevational distribution pattern (linear or hump-shaped) for dependent variables S_{obs} and S_{chao1} and independent variable elevation. I selected the best polynomial regression by compared the corrected Akaike information criterion (AIC_c) of first-order, second-order and third-order polynomial regressions, where the lowest AICc values indicated a better fit of the model (Akaike, 1987). This analysis was performed using the R statistical package version 3.2.2. To describe elevational biodiversity gradients, I categorised type of patterns of species richness along elevational gradients following (McCain, 2009a) as (1) decreasing diversity, (2) low-elevation plateaus, (3) low-elevation plateaus with mid-peaks, and (4) unimodal mid-elevational peaks (hump-shaped).

I also examined the relationship between patterns of species richness along climatic gradients. I stacked the annual mean temperature and annual rainfall values of each sampling site derived from the current climate of the WorldClim (Hijmans et al., 2005) using ArcGIS version 10.2 (ESRI, 2014). I then computed the relationship by polynomial regression analyses selecting the best model by the lowest AICc for S_{obs} and S_{chao1}.

To explore pattern in the assemblage structure based on composition and relative abundance of bird species over the elevational gradients for all birds species and only resident species, I used semi-strong hybrid multidimensional scaling (MDS) in the vegan package in R (Oksanen et al., 2015). I used the mean abundance of each species across all samples within each transect of each protected area to assess systematic trends in assemblage structure with elevation (Williams et al., 2010). To explain elevational patterns of assemblage structure, I performed simple ordinary least squares (OLS) regressions of assemblage structure (MDS axis scores) against individual environmental factors such as temperature, precipitation, and latitude.

2.4 Results

2.4.1 Species richness across elevation

A total of 827 surveys at 96 transects sites along 13 elevational bands were carried out during this study, representing closed forests in five of Thailand's protected areas (Doi Inthanon, Hala Bala, Huai Kha Khaenge, Kaeng Krachan, and Khao Yai) (Appendix Table E1). A total of 22,548 individuals of 431 bird species in 17 orders and 63 families were observed, with the number of species recorded at a single elevational band varying from 54 to 229 species. Species accumulation curves showed that my sampling effort was insufficient to completely capture all species at every site due to the very high species richness of these systems, therefore observed richness could be unequally biased across sites (Figure 2.2 and Appendix Figure E2.1). To address this limitation and to reduce biases across sites with variable numbers of samples and numbers of individual birds, I used rarefaction to calculate statistical estimates of total species richness at each elevational site. The estimates of total species richness using the Chao1 technique also suggested that there was still species at each site that were not recorded in the field sampling as illustrated by the differences between observed and total species richness in Figure 2.2.

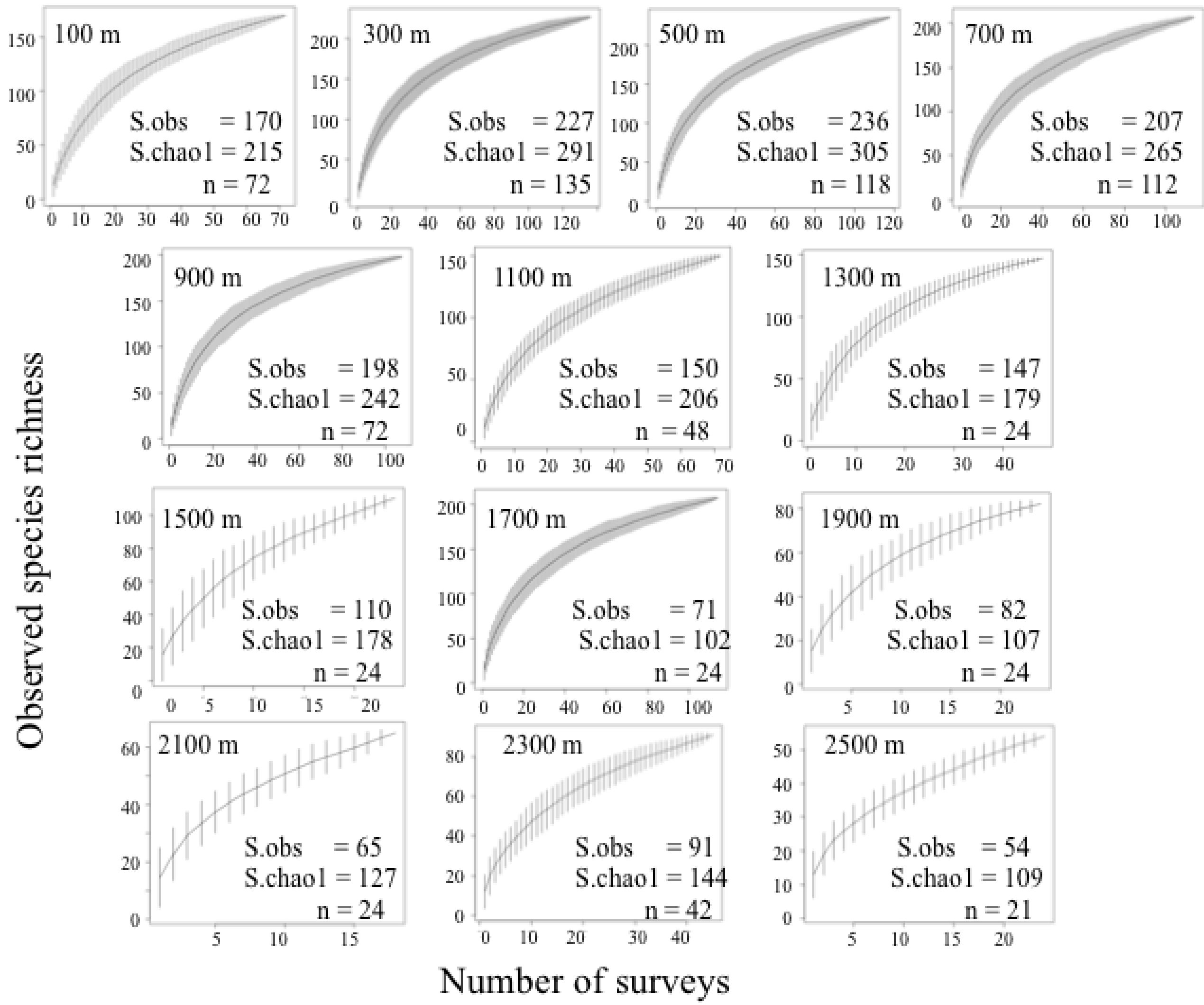


Figure 2.2 Relationship between observed species richness (S_{obs}) and the number of standardised surveys within each elevational band. Each point is the mean of 50 randomizations of the samples with 95% confidence intervals. Estimates of total species richness (S_{chao1}) within each elevational band are also provided. Numbers in the figures indicate elevation (m) of each sampling site.

The patterns of both observed richness (S_{obs}) and estimated richness (S_{chao}) along elevational gradients were most consistently described using second-order polynomial regression based on AICc values although first order regressions were only marginally less so (Table 2.2).

Table 2.2 Polynomial regressions of the overall species richness pattern along elevational gradients.

Regressions	Observed	Chao1
First-order R^2	0.2031	0.1686
AICc	757.7706	924.7667
Second-order R^2	0.2149**	0.2417*
AICc	757.4836	917.0814
Third-order R^2	0.2159	0.2335
AICc	758.5574	919.3044

* Significant at $p<0.05$, ** significant at $p <0.01$; bold numbers indicated the best regression model selected based on AICc.

The elevational pattern in observed species richness across all forest bird species (n=431) exhibited a relatively flat curve, with a slight decline with increasing elevation (Figure 2.3a), with the non-parametric estimator (chao1) yielding slightly higher values compared to observed species in all elevations (Figure 2.3b). However, the pattern of chao1 richness was slightly hump-shaped, it is lower at the low-elevations with some indication of slightly increasing species richness up to 500m, highest across mid-elevations (500-1200m) and slightly declines in elevations above 1500m (Figure 2.3b).

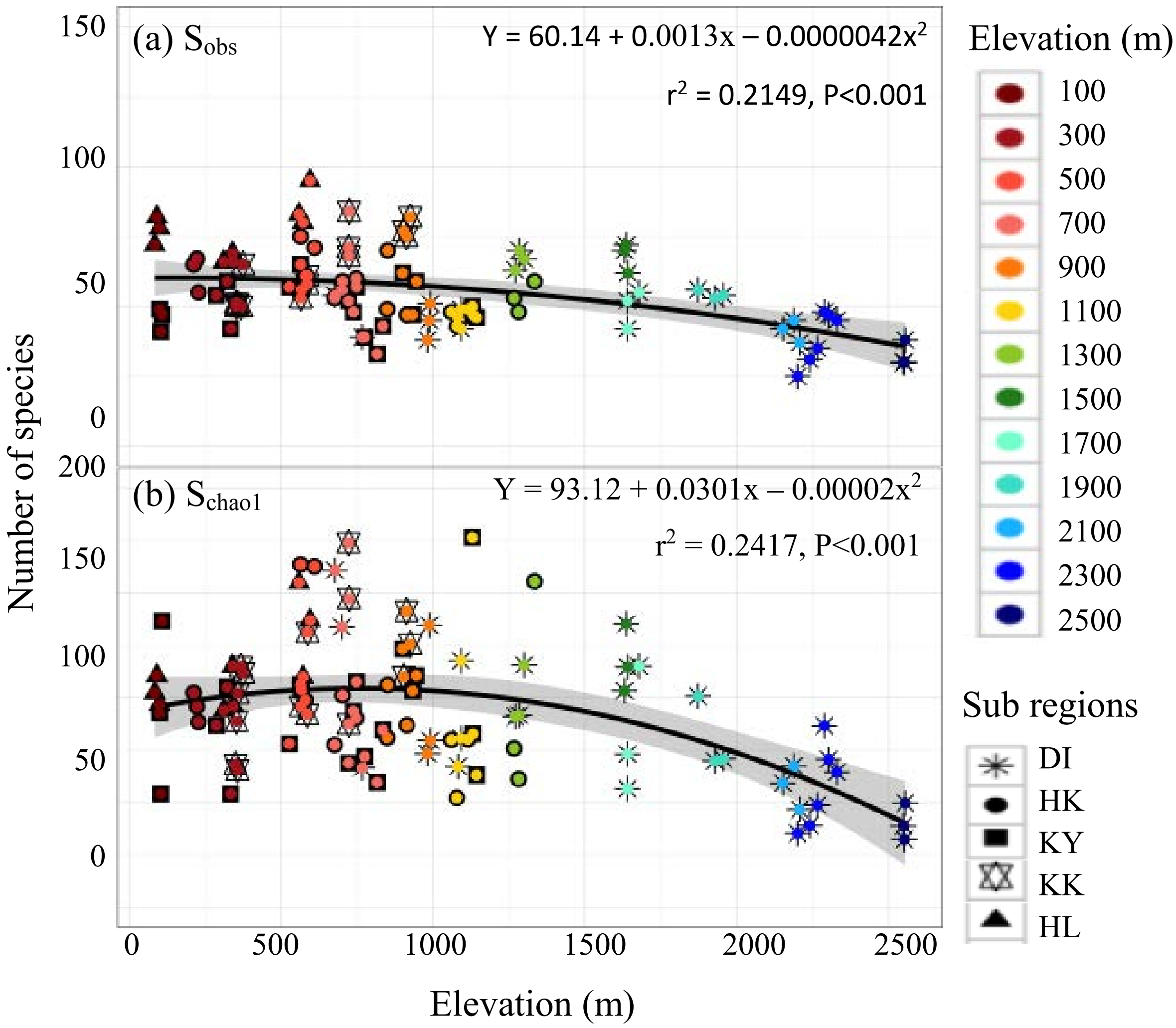


Figure 2.3 The patterns of species richness along elevational gradients: (a) observed richness (S_{obs}) and (b) estimated richness (S_{chao1}) of overall Thailand's forest birds across Thailand: DI = Doi Inthanon; HK = Huai Kha Khaeng; KY = Khao Yai; KK = Kaeng Krachan; and HL = Hala Bala.

Different subregions showed different species richness patterns along elevational gradients although none of the mountain ranges showed particularly strong or consistent elevational diversity patterns (Figure 2.4). The pattern of observed and estimated (chao1) species richness along elevational gradients at Doi Inthanon and Huai Kha Khaeng showed a hump-shaped curve that slightly peaks at the mid-elevation (Figure 2.4a, 2.4b, 2.4f, and 24g), whereas Kaeng Krachan displayed increased species richness along elevational gradients (Figure 2.4d and 2.4j). The pattern of observed and estimated species richness at Hala Bala demonstrated low richness at mid-elevation (Figure 2.4e and 2.4k). Interestingly, observed species richness along elevational gradients at Khao Yai showed a slight peak at mid-elevation, while estimated species richness was low at mid-elevation (Figure 2.4c and 2.4i).

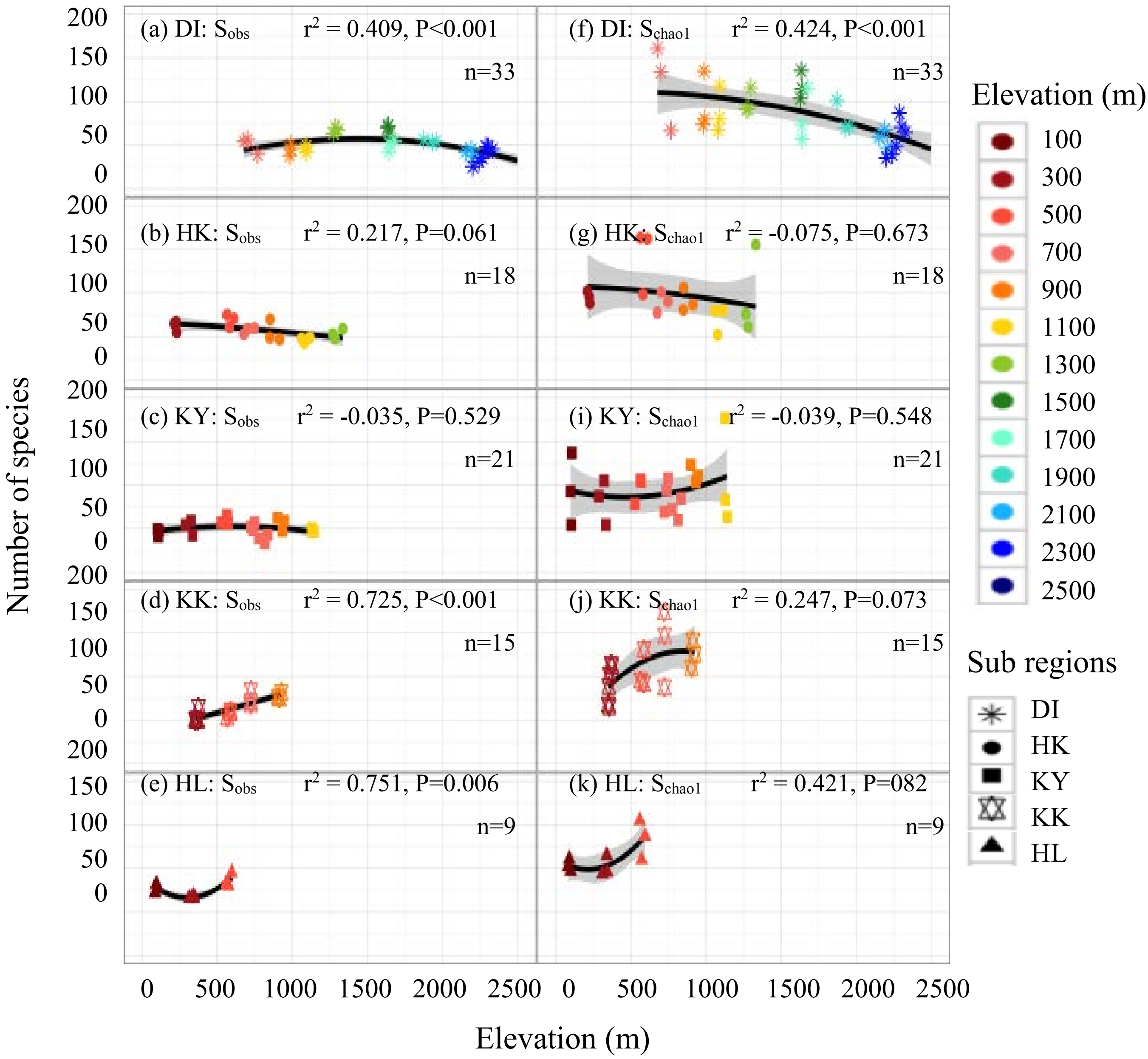


Figure 2.4 The patterns of species richness along elevational gradients at each subregion: (a-e) observed richness (S_{obs}) and (f-k) estimated richness (S_{chao1}) of overall Thailand's forest birds: DI = Doi Inthanon; HK = Huai Kha Khaeng; KY = Khao Yai; KK = Kaeng Krachan; and HL = Hala Bala.

To examine patterns in more detail and to remove the potential effects of migratory/nomadic species, I also examined the patterns for species that are present at all times (resident). Resident species (n = 334) showed similar patterns to the overall species with observed species richness displaying a flat curve with a slight decline with elevation while total estimated species richness (chao1) exhibited some indication of a slight mid-elevation hump with slight declines above 1500m (Figure 2.5). At each subregion, observed species richness of resident birds showed similar patterns to the overall species richness (Appendix Figure 2.2a - 2.2e). The pattern of estimated total species richness (chao1) declined with elevation at Doi Inthanon and Huai Kha Kaeng, and increased with elevation at Khao Yai, Kaeng Krachan and Hala Bala (Appendix Figure 2.2f - 2.2j).

Exploring the pattern of species richness across temperature gradients (annual mean temperature of each site) found that both observed and estimated (chao1) species richness unsurprisingly showed patterns concordant with the elevational pattern (Figure 2.6). Pattern of observed richness exhibited relatively flat curve at high temperature, with a slight decline with decreasing temperature (Figure 2.6a). Whereas estimated species richness showed a slight hump-shaped pattern with lower species richness at high-temperature, slightly increase when temperature decreases with flat curve across mid-temperature (20-24˚C) then below 20˚C declined (Figure 2.6b).

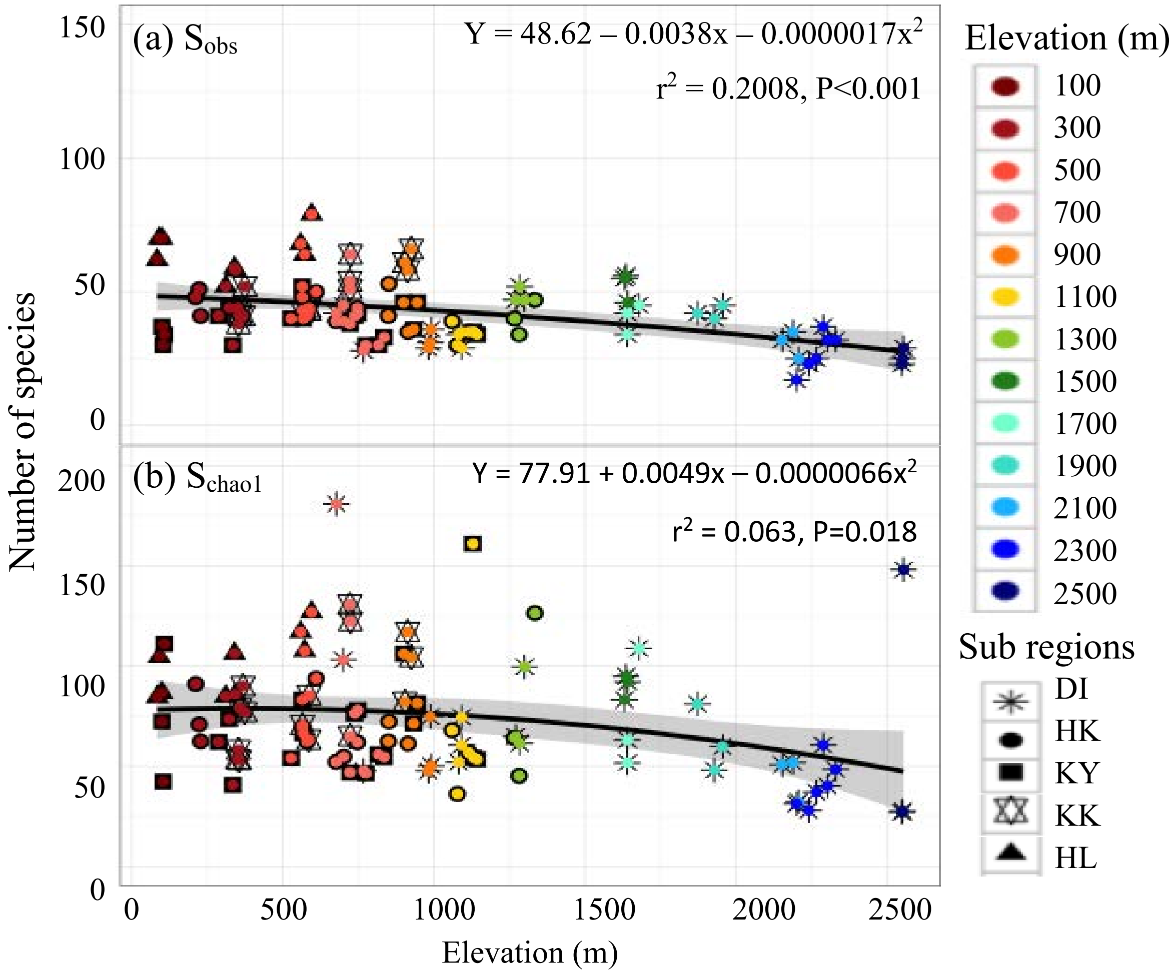


Figure 2.5 The patterns of species richness along elevational gradients: (a-e) observed richness (S_{obs}) and (f-j) estimated richness (S_{chao1}) of resident birds across Thailand: DI = Doi Inthanon; HK = Huai Kha Khaeng; KY = Khao Yai; KK = Kaeng Krachan; and HL = Hala Bala.

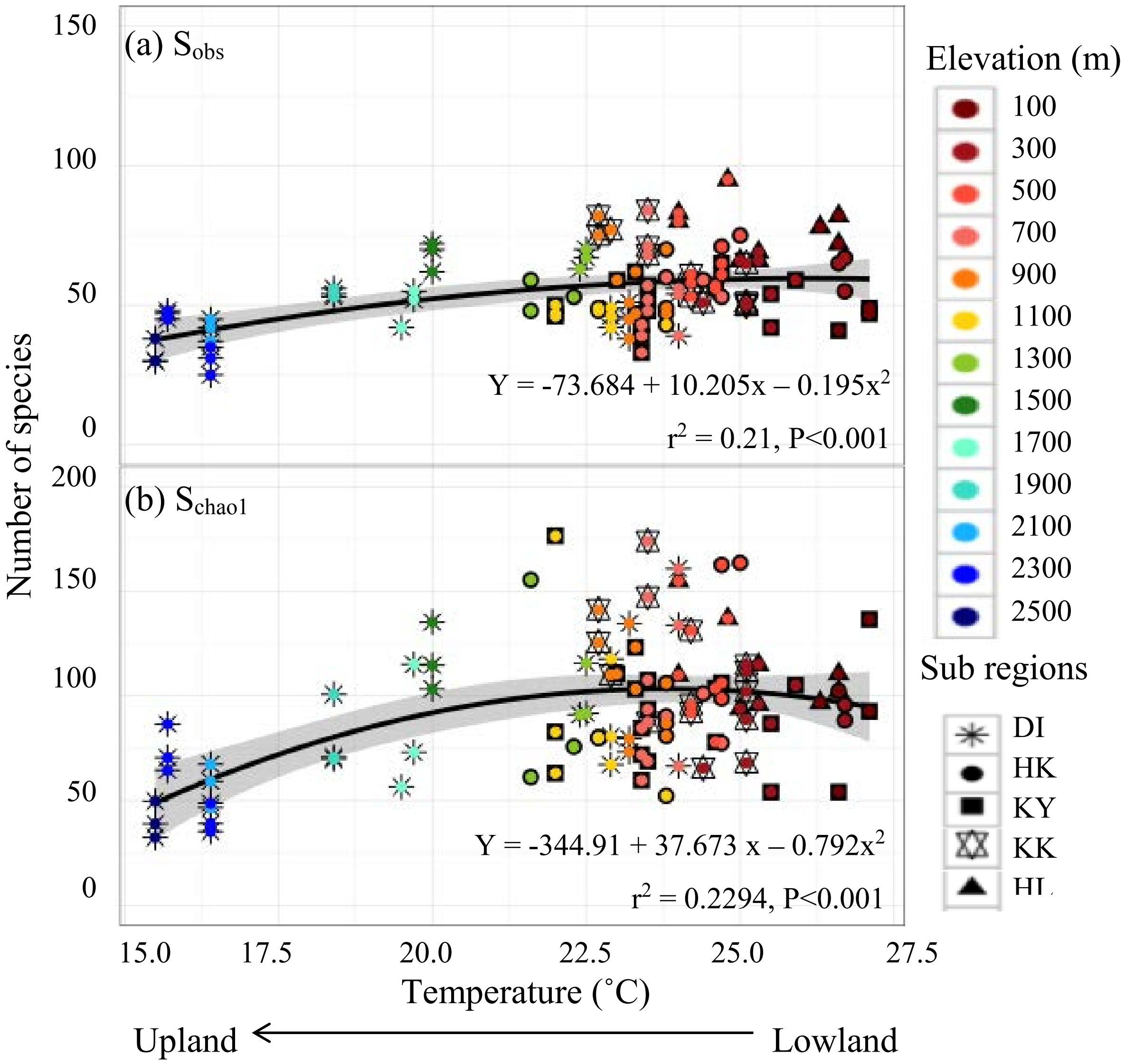


Figure 2.6 The patterns of species richness along temperature gradients: (a) observed richness (S_{obs}) and (b) estimated species richness (S_{chao}) of all Thailand's forest birds (n=431) across elevational and latitudinal gradients: DI = Doi Inthanon; HK = Huai Kha Khaeng; KY = Khao Yai; KK = Kaeng Krachan; and HL = Hala Bala.

There was no clear pattern of species richness associated with annual rainfall (Figure 2.7). It is clear that rainfall was highest in the southern Sundaic region of Hala bala and that richness (and rainfall) was higher therehowever, this was inconsistent and highly variable within the other subregions. (Figure 2.7). The significance of this relationship is only maintained by extreme leverage on the relationship produced by the Hala Bala sites.

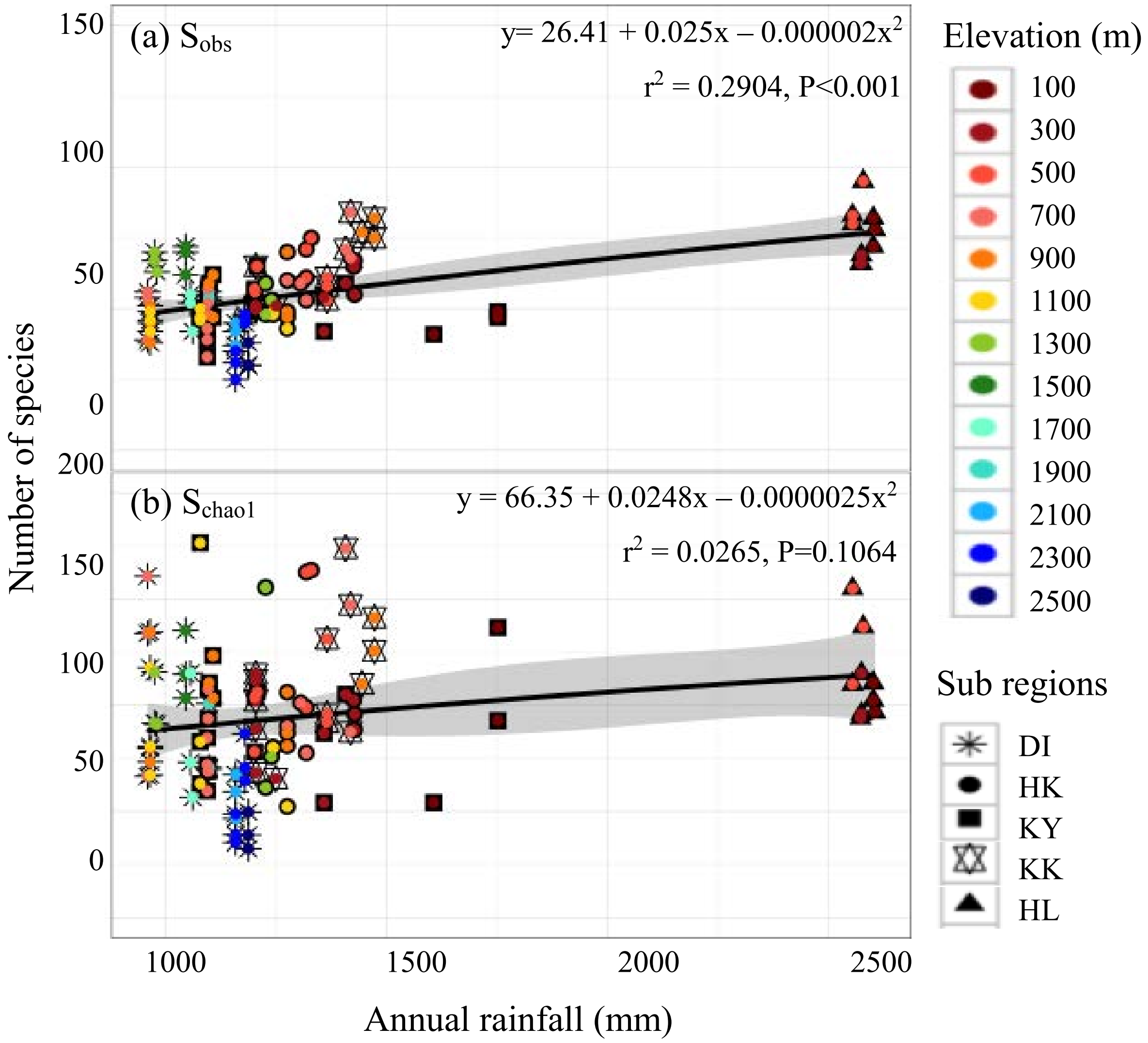


Figure 2.7 The patterns of species richness along rainfall gradients: (a) observed richness (S_{obs}) and (b) estimated species richness (S_{chao}) of all Thailand's forest birds (n=431) across Thailand's elevational gradients: DI = Doi Inthanon; HK = Huai Kha Khaeng; KY = Khao Yai; KK = Kaeng Krachan; and HL = Hala Bala.

2.4.2 Assemblage structure along elevational gradients

Assemblage structure patterns based on species composition and mean abundance displayed a strong and consistent change with elevation across all sites (Figure 2.8). This was clearly the strongest pattern in assemblage similarity with a large degree of overlap between assemblages at similar elevations in different mountain ranges (subregions) except for the assemblages in the most southern subregion, Hala Bala. The second dimension of the MDS ordination showed a clear separation of the assemblage of forest birds present at Hala Bala from the rest of Thailand.

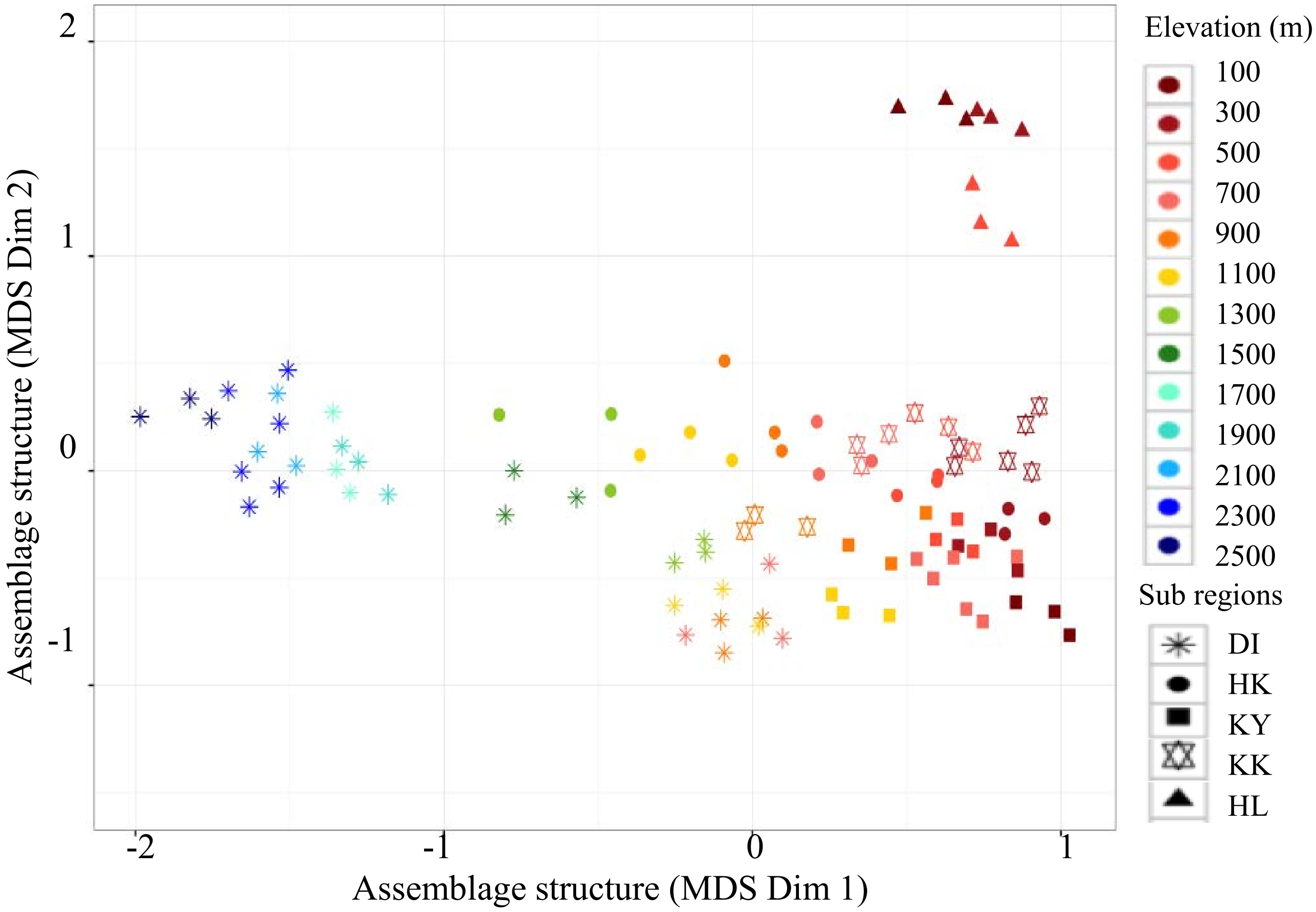


Figure 2.8. Ordination of bird assemblage structure using a two-dimensional MDS ordination (stress = 0.15) within each elevational band in each subregion sampled, based on mean local abundance of each species recorded (Total number of transect sites = 96: DI = Doi Inthanon; HK = Huai Kha Khaeng; KY = Khao Yai; KK = Kaeng Krachan; and HL = Hala Bala.

Exploring the relationship between assemblage structure (as described by the first MDS axis from Figure 2.8) and spatial location (elevation and latitude) shows clearly that the assemblage structure of Thailand's forest birds is closely related to elevation and mean temperature (Figure 2.9a and Figure 2.9b). This pattern is evident both across Thailand and within each mountain range at the different latitudes (Figure 2.9c – see the elevations colour gradient within each location). Species composition also showed steady change across temperature gradients with assemblages above 22.5˚C having little in common with assemblages below 22.5˚C (Figure 2.9b). Latitude strongly separates bird species composition as northern (above 15˚N) and southern (below 10˚N) with species composition of the mid-latitude (10-15˚N) bird assemblages were similar to both northern and southern bird assemblage (Figure 2.9c). Interestingly, within each mountain range at the different latitudes bird species composition also strongly related to elevational gradients (Figure 2.9c). Hala Bala in the far south of Thailand is dominated by Sundaic species, rather than Indochinese species, and is in a hotter and wetter part of the country and assemblage structure clearly separates out from the other sites in Figure 2.9d based on annual mean rainfall (Figure 2.9). The second MDS axis further demonstrates the biogeographic differences between Hala Bala and the other sites (Figure 2.10).

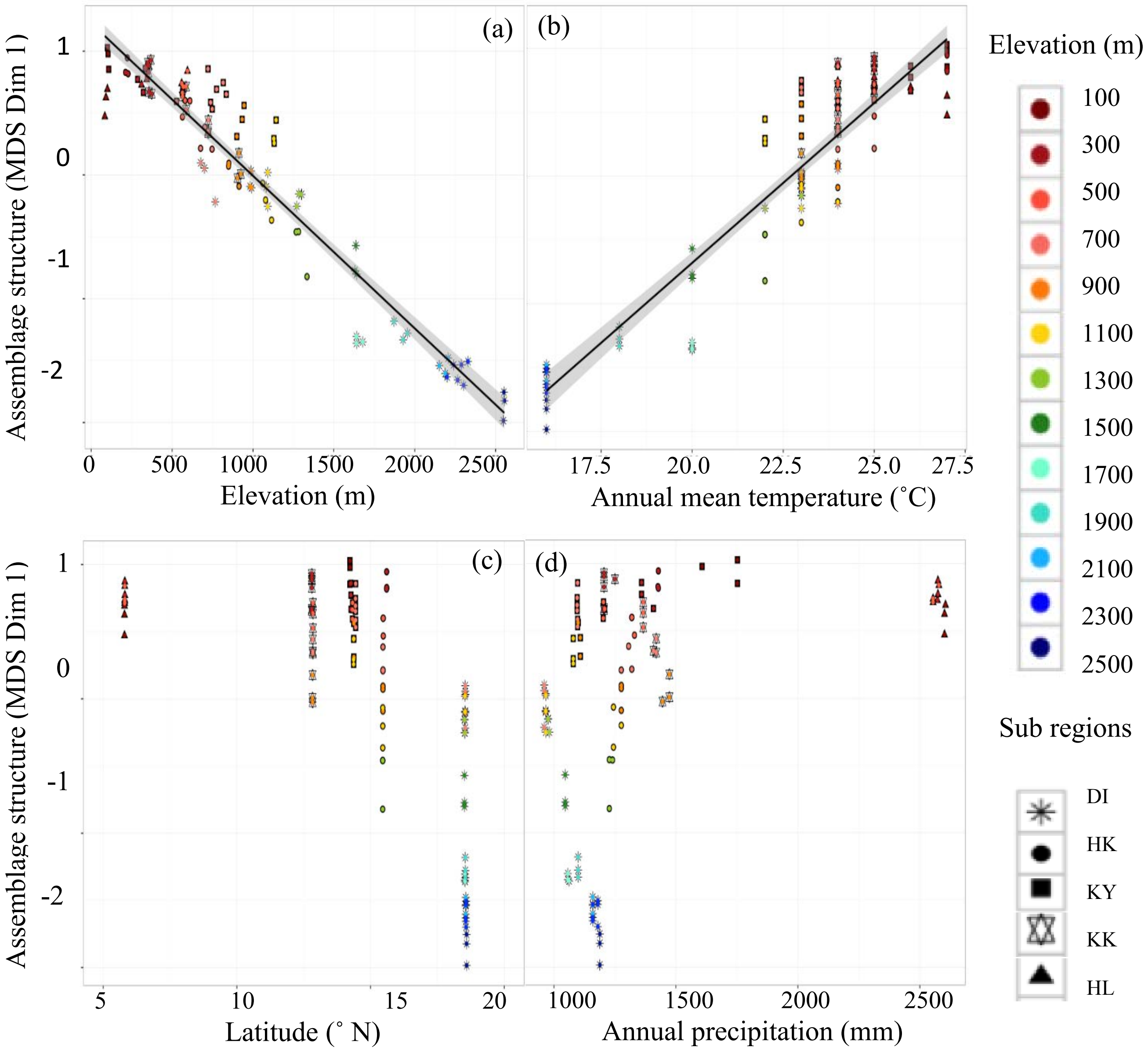


Figure 2.9. Change in assemblage structure across environmental gradients based on species composition and relative mean abundance of all species –MDS Dimension 1 from Figure 2.8: (a) elevational gradients, (b) annual mean temperature gradients, (c) latitudinal gradients, and (d) annual precipitation: DI = Doi Inthanon; HK = Huai Kha Khaeng; KY = Khao Yai; KK = Kaeng Krachan; and HL = Hala Bala.

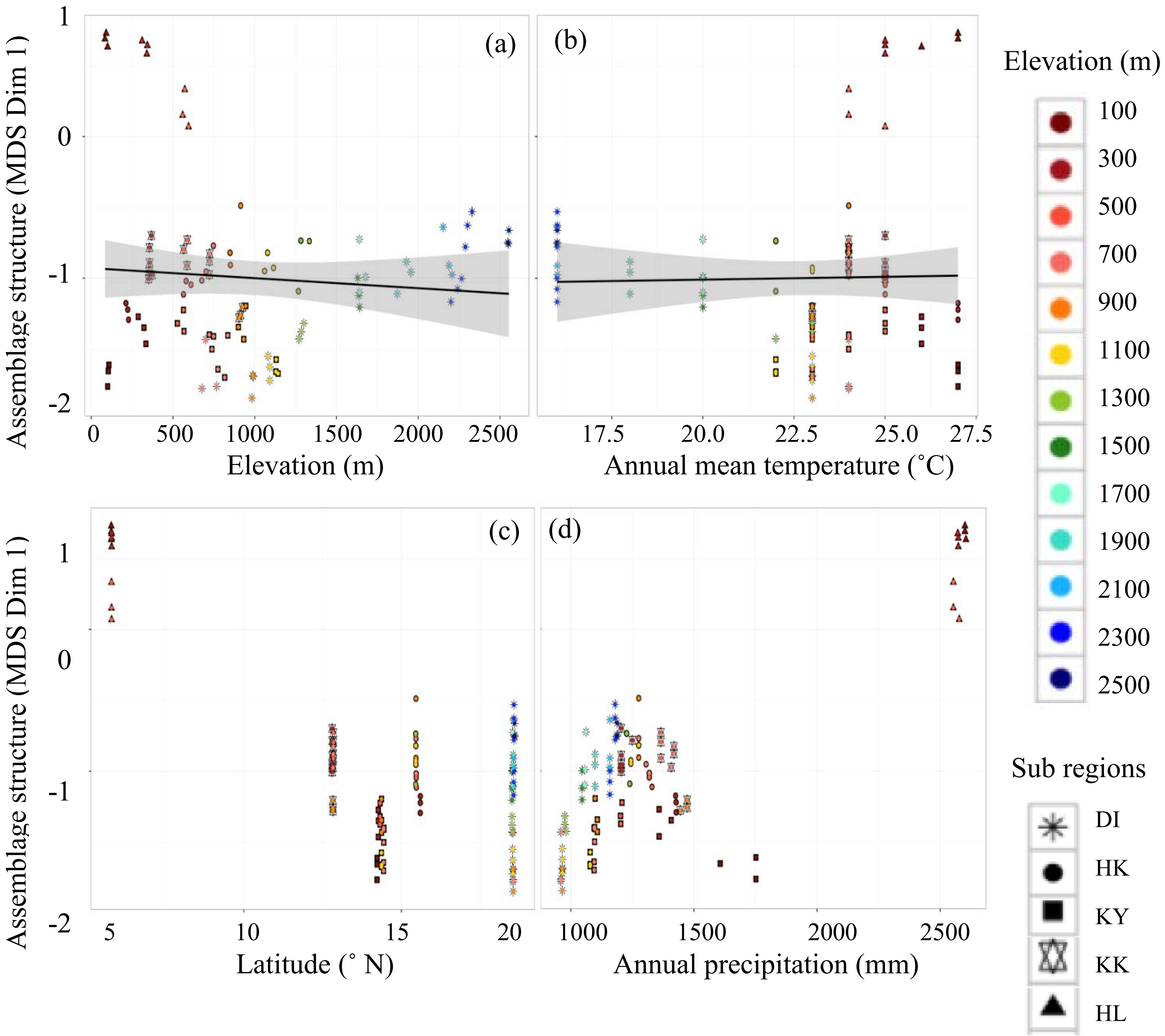


Figure 2.10. Change in assemblage structure across environmental gradients based on species composition and relative mean abundance of all species –MDS Dimension 2 from Figure 2.8: (a) elevational gradients, (b) annual mean temperature gradients, (c) latitudinal gradients, and (d) annual precipitation: DI = Doi Inthanon; HK = Huai Kha Khaeng; KY = Khao Yai; KK = Kaeng Krachan; and HL = Hala Bala.

2.5 Discussion

Here I present the first study to use standardized surveys that systematically measure the abundance and distributions of closed forest birds across elevational and latitudinal gradients in Thailand. Sampling such a large and diverse geographic area across five different mountain ranges makes it impossible to standardize sampling effort equally across all elevations because the elevational range is completely different in each place. This unavoidably causes unequal sampling. Within this limitation, I sampled the complete elevational range as much as logistically possible and used standardized techniques and equal sampling at any given local site. Given these natural limitations, I used best practice techniques to make the most of the available elevational ranges by using rarefaction to help minimize the effects of unequal sampling. Rarefaction is a well recognized and accepted method for exactly this situation (Chao and Chiu, 2016). Since this dataset provides a baseline measurement of the bird assemblage across most of the available environmental space in Thailand it is a powerful resource to examine the current status and future trends in each individual species, patterns of richness and assemblage structure.

The assemblage structure of forest birds was tightly and consistently associated with elevation/temperature gradients (Figure 2.9). This was evident at the scale of the entire country (Figure 2.9a) and also within each mountain range at different latitudes (see consistent colour=elevation gradient within each subregion Figure 2.9c). This is an important result within the context of this thesis as it suggests a clear importance of temperature in driving bird assemblage structure in both Indochinese and Sundaic regions. Many previous studies have documented and discussed the importance of climate (temperature and rainfall) as an important factor influencing bird species richness, abundance, and species composition (Acharya et al., 2011, Wu et al., 2013a, Freeman and Class Freeman, 2014, Pan et al., 2016). Generally, temperature declines with elevation, although patterns of precipitation are much more variable and dependent on latitude, mountain height, and aspect (McCain, 2006, Guo et al., 2013). The implication is that as global temperature increases there will be associated shifts in assemblage structure into higher elevations across Thailand.

Although assemblage structure changed consistently over elevation, there is a suggestion of limited overlap between the assemblages below 500 m and between 500-1500 m elevation and an even more noticeable separation with the assemblages above 1500 m. This is weakly linked to the patterns of species richness discussed in more detail below with slightly lower richness below 500 m and above 1500 m.

The second notable pattern in assemblage structure is the large difference between the southern assemblages dominated by Sundaic species and the more northern Indochinese assemblages. This broadly agrees with previous studies suggesting two important biogeographic clades of birds in Thailand, with Indochinese species predominantly occurring above 13˚N in latitude and Sundaic species to the south (Hughes et al., 2003, Hughes J. B. and Woodruff, 2003, Woodruff and Turner, 2009, Round et al., 2003). Understanding the drivers of this biogeographic pattern require further work as there is also a significant difference in the rainfall patterns, with the southern regions being much wetter in addition to being hotter (Figure 2.9c and Figure 2.9d). Additionally, the broad surveys conducted within this study clearly demonstrate that this boundary is perhaps more diffuse and more to the north than previously thought (Hughes et al., 2003, Hughes and Woodruff, 2003, Round et al., 2003) with many Sundaic species such as *Hemixos cinerea* and *Ixos malaccensis* (Appendix Table 1) recorded as far as 15˚ further north than previously thought. Alternatively, many species may have already moved northwards due to a warming climate in the intervening time between this study and these earlier assessments of the avian biogeography (Hughes et al., 2003, Hughes and Woodruff, 2003, Round et al., 2003). . The data presented here will enable future studies to monitor ongoing changes in more detail and with a more robust baseline for comparison.

In contrast to overall assemblage structure, there was no consistent strong relationship between elevation/temperature/rainfall/latitude gradients and species richness of forest birds. Across the different regions within Thailand, the elevational patterns of species richness exhibited weakly hump-shaped curve with some indication of slightly increasing richness up to 500m, a plateau in richness across mid-elevations, then declines above 1500m. A hump-shaped pattern of richness across elevational gradients has been commonly observed, and much discussed, in the literature (Colwell et al., 2004) (Rahbek, 1995, Williams et al., 2010, Acharya et al., 2011, Wu et al., 2013a, Pan et al., 2016). However, in this system, there appears to be no strong and consistent richness pattern with high species richness across many sites in all elevations. There is a more consistent trend of declining richness above 1500 m however this is based on a single mountain range (Doi Inthanon). Variation in elevational range in each subregion is also likely to influence observed elevational patterns across Thailand due to the fact that smaller ranges are more likely to show monotonic patterns even with more intensive sampling (Guo et al., 2013). The elevational extent varied widely among subregions (Table 2.1), further limiting capacity to draw out finer-scale patterns across elevation. These results would suggest that local species richness would not unduly change as assemblages are pushed upslope by increasing temperature, however, the unique high elevation assemblages will be highly vulnerable. This conclusion is similar to studies elsewhere in the world (Williams et al., 2003, Shoo et al., 2005a, Williams et al., 2010, Beniston, 2003, Colwell et al., 2008, Sekercioglu et al., 2008, Raxworthy et al., 2008, Li et al., 2009, La Sorte and Jetz, 2010b, Laurance et al., 2011, Forero-Medina et al., 2011a, Anderson et al., 2013, Freeman and Class Freeman, 2014, Ferrarini et al., 2017)

Chapter 3:
The relative influence of climate and land-cover on spatial patterns of current species distributions and diversity for the forest birds of Thailand

---

3.1 Abstract

A vital element of informed environmental management and policy is a basic understanding of the spatial distribution of species and biodiversity. For Thailand, this basic understanding is lacking for most taxa even relatively well-known taxa such as birds. This study produced the first quantitative, high-resolution maps of species distributions and biodiversity pattern for forest birds across the whole of Thailand based on explicitely relationships with climate and vegetation cover. Species distributions were based on a collation of existing occurrence data and standardized bird surveys across most of the available latitudinal and elevational gradients in Thailands forests. Three sets of predictors were used in species distribution modeling (Maxent): (i) combined climate and land-cover, (ii) climate only, and (iii) land-cover only. Distribution models based on land-cover only produced reasonable species distribution maps, however using climate variables vastly improved overall model performance statistics while the inclusion of both climate and land-cover produced models of similar accuracy to the climate-only models.

The pattern of species richness and diversity estimated by all these three sets of predictors are similar, mainly peaking at higher latitudes and higher elevation areas especially in the western and central part of Thailand, with strong latitudinal patterns in assemblage structure. The variables that most consistently made the greatest contribution to species distributions were land-cover, maximum temperature of warmest period, mean temperature, precipitation of driest quarter, and precipitation of wettest quarter. Examination of the patterns within different ecological subgroups showed that land-cover was consistently influential especially for resident species, temperature variables were particularly important to the upland species, and rainfall was especially important for Sundaic, forest specialist, and granivore species.

This study suggests that although climate-only variables will produce robust broad distribution maps they will perform poorly for predicting higher resolution local distributions. Conservation management at more localized scales requires distribution maps that include

land-cover. This is likely even more important for projections of future changes as there will be ongoing changes in both climate and land-cover and a strong likelihood for synergistic, additive impacts that will be more severe than the individual drivers of change.

3.2 Introduction

Determining how species are distributed in space is a fundamental aspect of ecology, conservation biology and applied environmental management and policy development (Araújo et al., 2004, Araújo and Rahbek, 2006, VanDerWal et al., 2009b). The need for accurate species distribution maps at a spatial resolution relevant to the study has driven the development of a diverse range of methods for modeling the distributions of species. Species distribution models (SDMs), also known as ecological niche models (ENMs) (Peterson et al., 2011)), climate envelope models and habitat models (Hijmans and Elith, 2014), are a commonly used tool to estimate the spatial distribution of a species. SDMs are usually correlative models that use occurrence data (and non-occurrence data) and environmental variables to explain patterns of species occurrences (Araújo and Guisan, 2006, Phillips and Dudík, 2008, Elith and Leathwick, 2009, Elith and Graham, 2009, Dormann et al., 2012). The SDMs are not only used for estimating species' ranges and environmental preferences, they can also be used for estimating patterns in diversity and also for predicting changes associated with environmental changes such as projected climate change impacts (Araújo et al., 2005).

A key challenge in SDMs is the selection of environmental variables to use as predictors (Araújo and Guisan, 2006, Watling et al., 2012). The most robust and useful models are constructed from variables that most directly influence the species distributions (Araújo and Guisan, 2006). Climate is often assumed to be the dominant driver of species distributions (Pearson and Dawson, 2003, Thuiller et al., 2004a, Jiménez-Valverde et al., 2011); land-cover is another widely considered driver of species distributions and has been often been included in SDMs (Bethke and Nudds, 1995, Dale, 1997, Bomhard et al., 2005, Berry et al., 2006, Jetz et al., 2007, Lemoine et al., 2007, Pompe et al., 2008, de Chazal and Rounsevell, 2009, Darling et al., 2010, Newbold et al., 2013, Virkkala, 2016). Based on these two main drivers of biodiversity, there are three approaches to building robust SDMs, that is to use climate only variables, land-cover variables, or a combination of both (Howard et al., 2015). Biodiversity syntheses utilizing robust SDMs for many species can provide an incredibly important conservation and management resource in megadiverse regions such as Thailand and Southeast Asia in general.

Southeast Asia represents a globally significant biodiversity hotspot (Myers et al., 2000, Sodhi and Liow, 2000, Sodhi et al., 2004, Sodhi and Smith, 2007, Sodhi et al., 2010a, Sodhi et al., 2010b, Sodhi et al., 2011, Hughes et al., 2012). It has incredibly high levels of diversity but it also has the highest rate of forest loss and other human impacts on natural ecosystems (Sodhi et al., 2010a, Hughes et al., 2012). Thailand is considered a biodiversity hotspot and contains highly threatened biodiversity (Myers et al., 2000, Trisurat, 2011, Trisurat et al., 2013). In particular, Thailand holds significant global avian biodiversity with 10% of the world's bird species (Robson and Allen, 2008, Napheethapat et al., 2012, Jenkins et al., 2013), located in the two main zoogeographic clades: (i) Indochinese, and (ii) Sundaic regions (Hughes et al., 2003, Round et al., 2003). However, in Thailand, the effects of extensive deforestation threaten biodiversity (Trisurat, 2011), which may exacerbate the impacts of climate change (Jetz et al., 2007, Brook et al., 2008, Brodie et al., 2012). Despite this, few studies have concentrated on understanding patterns of threat to the region's biodiversity from these key factors (Trisurat, 2011). An understanding of the spatial patterns of species distributions, abundance, assemblage structure, and the environmental drivers of these patterns, is therefore a fundamental knowledge gap currently limiting effective conservation planning and management of Thailand's biodiversity (Round and Gale, 2008, Trisurat, 2011).

One of the best ways to gain a broad understanding of the potential drivers of species distributions and biodiversity pattern is to use spatially explicit SDMs combined with standardized surveys across the primary environmental gradients in the area in order to improve knowledge of species distributions, species richness and the potential environmental drivers of these patterns. In this study, I compiled all available records of species occurrences and conducted standardized bird surveys across the available elevational and latitudinal gradients of evergreen forest in Thailand. Thus, the aims of this study are targeted at helping to fill the important knowledge gap in the spatial patterns of biodiversity in Thailand evergreen forest birds.

Here, I evaluate the relative roles of climate and land-cover in describing and predicting species distributions of Thailand's forest birds, based on the hypothesis that an inclusion of land-cover into pure climatic models improves the delineation of species distributions locally. In addition, I examined the role of different environmental correlates of the spatial patterns of species distributions and species richness then examined the implications of these patterns for predicting the future impacts of climate and land-cover change. I identified which areas and which groups of species are likely to be more susceptible to climate and land-cover change. I examined these relationships separately for all species together and within ecological subgroups so that I could compare, for example, patterns of resident versus migratory species.

Specific questions addressed in this chapter include:

1. What is the spatial distribution and environmental correlates of each species of forest bird in Thailand at a resolution fine enough to be useful to national, regional and local conservation planning and management?
2. What are the spatial patterns of species richness of Thailand's forest birds?
3. What are the relationships between the distribution of species and environmental factors?
4. What are the most consistently important environmental variables across all species in predicting the limits of species distributions and the patterns of richness?
5. Is there concordance in the variables that consistently explain the variance in species distributions and are there contrasting patterns in different functional groups based on 1) habitat preference, 2) dietary guilds, 3) elevational range limits, 4) biogeographic or zoogeographic clades, and 5) seasonal status?
6. If there are consistently useful climatic variables across groups of species, what are the implications of these patterns for predicting the future impacts of global climate change?

3.3 Methods

3.3.1 Species data and study areas

I collated 94,112 occurrence records of 612 species over 461 locations across five subregions that span the available latitudinal and elevational range of evergreen forest in Thailand (Appendix Table 1). Standardized surveys were conducted in five main protected areas including Doi Inthanon National Park, Huai Kha Khaeng Wildlife Sanctuary, Khao Yai

National Park, Kaeng Krachan National Park, and Hala Bala Wildlife Sanctuary (Figure 3.1). These sites cover a large proportion of the geographic, environmental and zoogeographic clades of Thailand (Lekagul and Round, 1991, Craig, 2005, Craig, 2009, Napheethapat et al., 2012). The primary source of data in my research project is the standardized surveys I conducted between 2013 and 2015, however between 2000 and 2015, I also collated and georeferenced species location data from a variety of other sources including individual ornithologists, bird clubs, the Department of National Park, Wildlife and Plant Conservation (DNP), and universities (see Appendix Table 1.1 for list of species collated from these sources). Only data where the identification and geographic locality was considered to be accurate were incorporated into the analysis dataset.

Species were identified using the latest classification followed by the Thailand Bird Guide (Lekagul and Round, 1991, Craig, 2005, Craig, 2009, Napheethapat et al., 2012) and the new Thailand revised national bird listing by Bird Conservation Society of Thailand (BCST) records committee (BCST, 2016). I examined species records in geographic space using ArcGIS version 10.2 as a first-pass filter to identify records that had incorrect geo-references and I checked coordinates of the location of birds' occurrences. All records were recorded in the Thailand geographic coordinate system, GCS_WGS_1984.

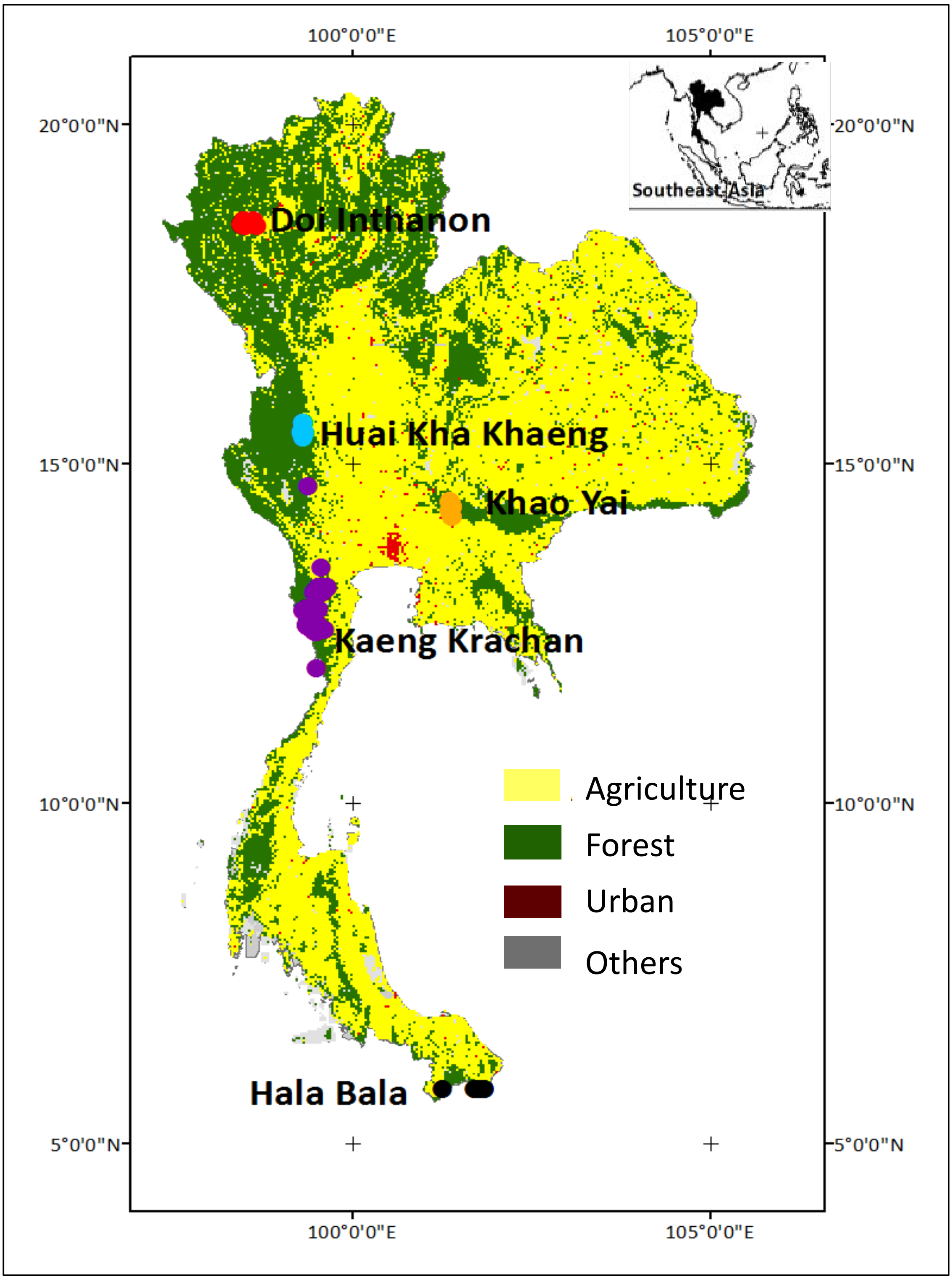


Figure 3.1 Map of Thailand's land-cover showing the geographic locations of the standardized bird transects surveys used in this thesis: Doi Inthanon (red); Huai Kha Khaeng (blue); Khao Yai (pink); Kaeng Krachan (purple); and Hala Bala (black). Land-cover classification is based on satellite imagery from the Landsat 8TM for the year 2012.

This study focused on bird species within the evergreen forests of Thailand, including vegetation types described as tropical forest, dry evergreen forest, hill evergreen forest, and coniferous forest, however some of these species also occur within mixed-deciduous and dry dipterocarp forest so these forest types are also included. SDMs were constructed for all species, where there were 10 or more geographically unique localities in Thailand following recommendations by Elith et al. (2006). All specialist water birds, sea birds, human associated, and open grassland birds were excluded.

In order to better understand the patterns of bird biodiversity and ecological relationships between species and the environment, I classified bird species in five ways for additional pattern exploration (see Table 3.1 for number of species of each subgroup and see Appendix Table 1 for details of each species):

1. **Habitat preferences**: evergreen forest specialist (EFS), evergreen forest specialist but occur in deciduous forest (EDS), evergreen forest specialist but occur in bamboo forest (EBS), evergreen forest specialist but occur in edge forest, open area, and other (not include forest) (EOS), occur in evergreen forest but common in other forest, occur in evergreen forest but common in edge forest, open area and other (not include forest area) (GEN), and never occur in evergreen forest (NOF). These classification followed the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012);
2. **Feeding guilds**: note that these ecological groupings are exploratory and not mutually exclusive, thus some groups contain only one species (scavenger) some groups contain more than 50 species (insectivorous, omnivorous) - frugivorous (F), granivorous (G), insectivorous (I), nectarivorous (N), omnivorous (O), raptor (R), and scavenger (S). Feeding guilds defined by Lekagul and Round (1991), Round et al. (2003), and Napheethapat et al. (2012);
3. **Elevational groups** defined on published elevational range limits: lowland (L), montane (M) and widespread across all elevations (W) species based on the definitions provided by Lekagul and Round (1991), Round et al. (2003), and Napheethapat et al. (2012);
4. **Biogeographic**: Thailand’s birds occur in an overlap zone between two major zoogeographic clades of birds - the Indochinese and Sundaic subregions of the Oriental zoogeographic region. Species were defined as Indochinese (IN), Indochinese-southern cross (INS), which is the Indochinese specialist distribute cross

south to 13˚ , Sundaic (S), Sundaic-northern cross (SN)), which is the Sundaic specialist distribute cross north to 13˚, and Widespread (W) based on the definitions provided by Hughes et al. (2003), Round et al. (2003) and the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012); and

5. **Migratory status**: Seasonal status as resident or presumed resident (R), non-breeding visitor (N), breeding visitor (B), mainly spring and autumn passage migrant (P), mainly resident but maybe non-breeding visitor (RN), mainly non-breeding visitor but maybe resident (NR), and uncertainty according based on the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012, BCST, 2016).

Table 3.1 Number of species of each ecological subgroup.

Category	Subgroup	Code	Number of species
Habitat preference (Lekagul and Round, 1991, Napheethapat et al., 2012)	• Evergreen forest specialist but occur in bamboo forest	EBS	56
	• Evergreen forest specialist but occur in bamboo forest	EDS	107
	• Evergreen forest specialist	EFS	75
	• Evergreen forest specialist but occur in edge forest, open area, and other (not include forest)	EOS	6
	• Occur in evergreen forest but common in other forest, occur in evergreen forest but common in edge forest, open area and other (not include forest area)	GEN	18
	• Never occur in evergreen forest	NOF	42
Feeding guild (Lekagul and Round, 1991, Round et al., 2003, Napheethapat et al., 2012)	• Frugivorous	F	20
	• Granivorous	G	3
	• Insectivorous	I	149
	• Nectarivorous	N	13
	• Omnivorous	O	112
	• Raptor	R	6
	• Scavenger	S	1
Elevational range (Lekagul and Round, 1991, Round et al., 2003, Napheethapat et al., 2012)	• Lowland	L	72
	• Montane	M	40
	• Widespread across all elevations	W	192
Biogeography (Lekagul and Round, 1991, Hughes et al., 2003, Round et al., 2003, Napheethapat et al., 2012)	• Indochinese	IN	46
	• Indochinese-southern cross	INS	39
	• Sundaic	S	27
	• Sundaic-northern cross	SN	22
	• Widespread	W	170
Migratory status (Lekagul and Round, 1991, Napheethapat et al., 2012, BCST, 2016)	• Non-breeding visitor	N	30
	• Mainly non-breeding visitor but maybe resident	NR	5
	• Mainly spring and autumn passage migrant	P	2
	• Resident	R	238
	• Mainly resident but maybe non-breeding visitor	RN	27
	• Uncertainty according	U	2
	• Breeding visitor	B	0

3.3.2 Environmental predictors

i) Current climatic variables

The current climate data of 19 bioclimatic variables were downloaded from the WorldClim database which is climate averages based on ~1960 - 1990 at 1x1 km^2 resolution, which was the highest resolution available for the entire study area (Hijmans et al., 2005). Eight standard bioclimatic predictors were selected that have previously been shown to have wide generality across large sets of species, are biologically meaningful and have been successfully used in a number of studies based on SDMs (Williams et al., 2003, Graham et al., 2006, VanDerWal et al., 2009b, VanDerWal et al., 2009a, Williams et al., 2010, Anderson et al., 2013). These eight variables represent the annual average, quarterly maximum, quarterly minimum and annual variability (seasonality) for both temperature and precipitation (summary in Table 3.1). All variables were converted into Raster ASCII grids (.asc) format. The projection of all variables was set to GCS_WGS_1984 using ArcGIS version 10.2 with a resolution of 1x1 km^2.

ii) Land-cover

To get the land-cover data, I classified current land-cover data classified based on satellite imagery downloaded from the Landsat 8^{TM} (https://landsat.usgs.gov/landsat-data-access), then interpolated images into four classes as (1) agriculture area, (2) forest area, (3) urban area, and (4) others areas (Table 3.2 and Figure 3.1) (Campbell and Wynne, 2011). This classification was validated against other published data analyses: for the correction of agriculture and urban features I validated using the of report of land use 2012 classification by the Land and Development Department (LDD, 2014), and forest extent was validated with final report for 2012 forest classification by the Royal Forest Department (RFD, 2014). Using ERDAS imagine version 2014 to interpolate satellite image. I converted these variables into Raster ASCII grids (.asc) format at a resolution 1x1km^2. The projection of all variables was set to GCS_WGS_1984 using ArcGIS version 10.2.

Table 3.2 Environmental variables used in the current species distribution modeling across Thailand.

Environmental variables	Code	Unit	Range (min-max)
Bioclimatic data (~1960 - 1990)			
Annual mean temperature	BIO1	°C	14.8 – 28.9
Temperature seasonality (standard deviation of monthly means x 100)	BIO4	°C	42.8 – 293.8
Maximum temperature of warmest month	BIO5	°C	24.3 – 39.2
Minimum temperature of coldest month	BIO6	°C	2.6 – 23.5
Annual Precipitation	BIO12	mm	856 – 4458
Precipitation Seasonality (Coefficient of Variation)	BIO15	n.a.	36 – 105
Precipitation of Wettest Quarter	BIO16	mm	416 – 2580
Precipitation of Driest Quarter	BIO17	mm	6 - 388
Land-cover (2000)			
Agriculture area	A	Presence/absence	0/1
Forest	F	Presence/absence	0/1
Human settlement	U	Presence/absence	0/1
Others	O	Presence/absence	0/1

3.3.3 Species distribution modeling

Species distribution models were created for all species (313) where there was adequate data (10 or more unique geographic records from all data sources). I employed the maximum entropy algorithm (MaxEnt) version 3.1.3 as a tool for creating species distribution models (SDMs) (Phillips et al., 2006), MaxEnt is a common species distribution modelling tool widely used by ecologists or conservation practitioners for predicting the distribution of species from presence-only species records and environmental predictors (Yackulic et al. 2013, Fourcade et al. 2014).

For each species, three different SDMs were computed; each with a different set of variables based on i) climate only, ii) land-cover only, and iii) combined climate and land-cover. In order to identify optimal setting for all models, I set up a default of each model in the MaxEnt for each predictor and ran 10 cross-validations, with 75% of the data sample points to generate a species distribution model. The remaining 25% was kept as independent data to test the accuracy of each model (random test percentage = 25); regularization multiplier = 1; maximum number of background points = 10000 (Kramer-Schadt et al., 2013).

There are several common biases associated with SDMs such as a bias in the distribution of species occurrence across geographic and/or environmental space (Fourcade et al., 2014). To minimize this bias, I followed recommendations from previous studies and used a target group background based on all species occurrences in the dataset, that is, background points of all bird records in our dataset (target group) (Phillips, 2008, Kramer-Schadt et al., 2013, Fourcade et al., 2014). The default in MaxEnt for the maximum number of background points is 10000 pseudo-absences randomly selected from the whole rectangular study area (Fourcade et al., 2014). It has been argued that any sampling bias in occurrence records for a single species can also be observed in the background points (Phillips, 2008, Reside et al., 2010), so it may strongly affect the resulting model and a target group background is therefore recommended, that is, background points in the model are based on the occurrence points of all bird records in the dataset (target group) (Phillips, 2008, Fourcade et al., 2014).

3.3.4 Model evaluation

The first step in evaluating the quality of a species distribution model is a test of its accuracy in representing the species occurrence data (Fielding and Bell, 1997). I used area under the receiver-operating characteristic curve (AUC) and the True Skill Statistic (TSS) resulted from the MaxEnt, to test the predictive performance of the SDMs for the three sets of variables (climate only, vegetation cover-only, climate-vegetation cover) and each of the 313 species across the 10 replications in the cross-validation step. The use of AUC to estimate the predictive accuracy of models on birds has been widely used (Barbet-Massin et al., 2012, Reside et al., 2012a, Bucklin et al., 2015). AUC uses the area under the receiver-operating characteristic (ROC) curve as a measure of the probability that a model is performing better than a random selection of background points (Phillips et al., 2006). The AUC values for each model were calculated within MaxEnt and interpreted as any model that has an AUC value less than 0.5 = ‘poor’; 0.5-0.6 = ‘no discrimination’; 0.6-0.7 = ‘discrimination’; 0.7-0.8 = ‘good’; 0.8 – 0.9 = ‘very good’; and 0.9 – 1.0 = ‘excellent’ (Phillips et al., 2006).

The use of an AUC value alone is insufficient to measure the accuracy of the predictive model and it is recommended to also use the True Skill Statistic (TSS) as an additional measure of model's accuracy (Allouche et al., 2006, Barbet-Massin et al., 2012, Bucklin et al., 2015). The TSS values are computed from the proportion of correctly classified presences (sensitivity) plus the proportion of correctly classified absences/pseudo absences (specificity) minus 1 (sensitivity + specificity -1) (Allouche et al., 2006). TSS values less than 0.2 can be assigned as 'poor'; between 0-2 and 0.6 as 'fair'; and greater than 0.6 as 'good' (Jones, 2012).

I used post-hoc multiple comparisons tests using Tukey's contrasts on the linear mixed-effects (LME) models to compare AUC and TSS values of all three sets of variables. The R packages lme4 (Douglas et al., 2015) and the multcomp (Torsten et al., 2008) were used to execute LME analyses. To compare the AUC and TSS values of all three sets of variables for ecological subgroups; Habitat preferences, Feeding guilds, Elevational range limits, Biogeographic, and Seasonal status the LME analyses also was used.

3.3.5 Predicted current spatial patterns of species richness and diversity index

To produce spatially explicit estimates of the bird diversity patterns across Thailand's forest complexes I used the compilation of the individual species SDMs. I focused on estimating the species richness of local community and a diversity index, Shannon-Wiener Index, which is a mathematical expression that combines species richness and the evenness of relative abundance across sites as a measure of diversity (Shannon and Weaver, 1949, Spellerberg and Fedor, 2003).

Firstly, I converted the MaxEnt default probability distribution to a binary presence/absence with the threshold values of the balancing training omission rate, predicted area and logistic threshold (VanDerWal et al., 2009b, Reside et al., 2010). The threshold was read in from the MaxEnt results output file, so that every pixel in the raster (ascii) output above the threshold value was marked as presence, and every pixel below the threshold value was counted as absence (VanDerWal et al., 2009a, Reside et al., 2010). The SDMTools package (VanDerWal et al., 2011) and the MASS package (Venables and Ripley, 2002) in R were used to compute the binary presence/absence of each species and each set of variables.

Secondly, I computed the spatial distribution of species richness for Thailand's forest birds and produced a species richness map for each ecological subgroup described above for each set of variables of the SDMs. I summed all values of species considered as present for each grid cell that I already converted with the MaxEnt output based on the threshold values using ArcGIS 10.2 to stack species richness values of each pixel. The SDMTools package (VanDerWal et al., 2011) and the MASS package (Venables and Ripley, 2002) in R were used to compute the spatial distribution of species richness.

Lastly, I calculated a spatial map of assemblage diversity for Thailand's forest birds and for each ecological subgroup described above and each set of variables included in the SDMs, applying a simple diversity index, the Shannon-Wiener Index, to the assemblage composition in each cell. Environmental suitability was used as an index of relative abundance following the methods from Vanderwal et al. (2009a) and the above described binary presence/absence maps produced by MaxEnt. I also used the R package SDMTools to calculate the Shannon-Wiener Index for each cell, using the environmental suitability of each species present in the cell as the species abundance based on the Shannon Function H' concept (Shannon and Weaver, 1949), and then mapped the index of diversity. I then explored the relationships between spatial patterns of diversity that I estimated from the SDMs of each set of predictor and the environmental variable.

3.3.6 The relative influence of climate and land-cover variable in determining species distributions and spatial pattern of species richness

In order to identify which environmental variables that were the most consistently important across species, I used the percentage of contribution of each species obtained from the MaxEnt model (Phillips et al., 2006). To enable comparison and gauge the relative influence among variables, I calculated an average of the percentage contribution of all species of each variable for each of the three approaches: combined climate and land-cover, climate only, and land-cover only. I then used post-hoc multiple comparisons tests using Tukey's contrasts on the linear mixed-effects models (LME), employed R packages lme4 (Douglas et al., 2015) and the multcomp (Torsten et al., 2008) were used to execute LME analyses. I also applied this approach to investigate the relative influence within each ecological subgroup.

To examine the relationship between climatic variables and projected spatial pattern of species richness of each approach, I used an ordinary least squares regression (OLS) to assess the relationship of each climatic variable to projected species richness present within pixels of each modeling approach. Then I used the gplot package in R (Gregory et al., 2016) to display these relationships.

3.4 Results

3.4.1 Species distributions of Thailand's forest birds: climate and land-cover

Species distribution maps (potential) were produced for 304 species of 313 evergreen forest bird species, nine species were removed due to poor AUC and TSS values. These species distribution models explore the relative influence of climate and land-cover on species distributions; however, they are also the first nation-wide, high-resolution distribution maps of most of the forest birds of Thailand that can be explicitely linked to specific climatic and/or land cover variables. Each species potential distribution map is a significant advance on previous range maps for Thailand's avifauna and as such they are a significant resource for conservation management in the region. The estimated distributions are based on a combination of collated available data and a systematic, standardized field survey across the entire latitudinal and elevational range within Thailand. Additionally, these distribution models explore the relative influence of including only climate variables and/or land-cover in species distribution models in the region. All of the distribution maps are included in Appendix Figure E 3.1 for use as a baseline biodiversity assessment database and as a tool for conservation planning and management. Examples of representative biogeographic distribution types are presented in Figure 3.2 illustrating the five primary types of distribution patterns exhibited including Indochinese, Sundaic, high elevation restricted, low elevation forest species, and widespread species for each set of variables.

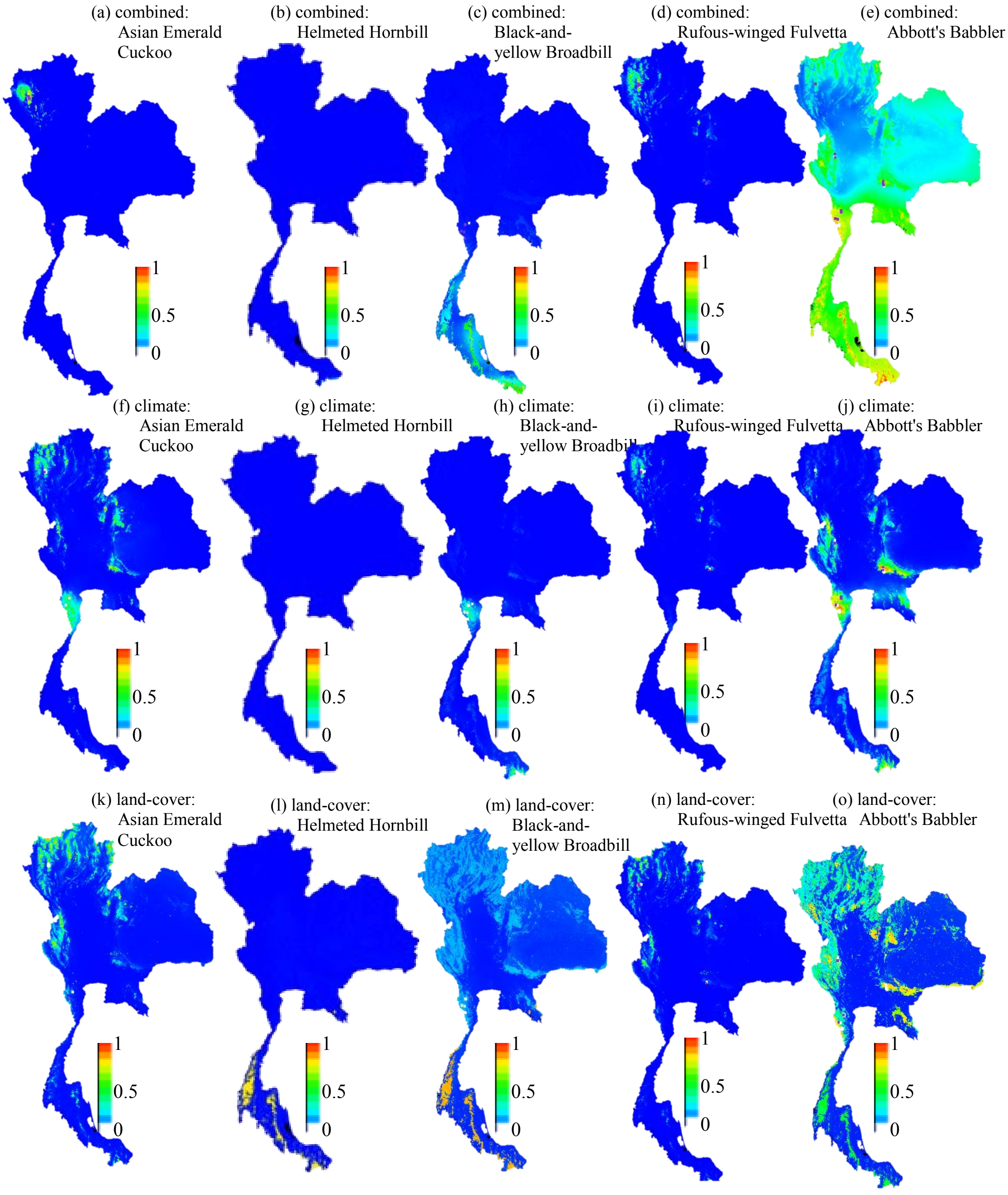


Figure 3.2 Species distribution models for five example bird species based on (a–e) combined climate and land-cover, (f–j) climate only, and (k–o) land-cover only for a representative species of each of the five major types of distribution patterns of bird species in Thailand's evergreen forest ecosystem: (a,f,k) an Indochinese species – the Asian Emerald Cuckoo; (b,g,l) Sundaic species-the Helmeted Hornbill; (c,h,m) Lowland species-the Black-and-yellow Broadbill; (d,I,n) Montane species-the Rufous-winged Fulvetta; and (e,j,o) Widespread forest species- the Abbott's Babbler Scale 0–1 showed the probability of distribution.

3.4.2 Model performance

Most of the SDMs for all species and predictor sets performed acceptably well, however, in general, models based on land-cover only performed less well than those that included climate (Table 3.3 and Figure 3.3). The mean AUC of all species and all predictor sets was 0.951 ± 0.052 (mean±SD) and TSS was 0.691 ± 0.223 (mean±SD), although there were some significant outliers (Table 3.3 and Figure 3.3). Post-hoc multiple pairwise comparisons tests indicated that the AUC value of combined climate and land-cover models was significantly higher than for climate only (df = 608, $p < 0.05$), in contrast the TSS value of this pair was not significantly different (df = 608, $p = 0.137$). There were highly significant differences between the performances of models based on land-cover only and combined climate and land-cover, and between land-cover only and climate only (Table 3.3).

Table 3.3 The Post-hoc multiple pairwise comparisons test the difference in model performance between climate and/or land-cover input variables using both AUC and TSS model accuracy statistics for 304 forest bird species.

Predictors	df	AUC		TSS	
		t-value	P	t-value	P
Climate&land-cover: climate only	608	- 2.334	0.0198	-1.489	0.137
Climate&land-cover: land-cover only	608	-28.520	<0.001***	-10.844	<0.001***
Climate only: land-cover only	608	-26.191	<0.001***	-9.489	<0.001***

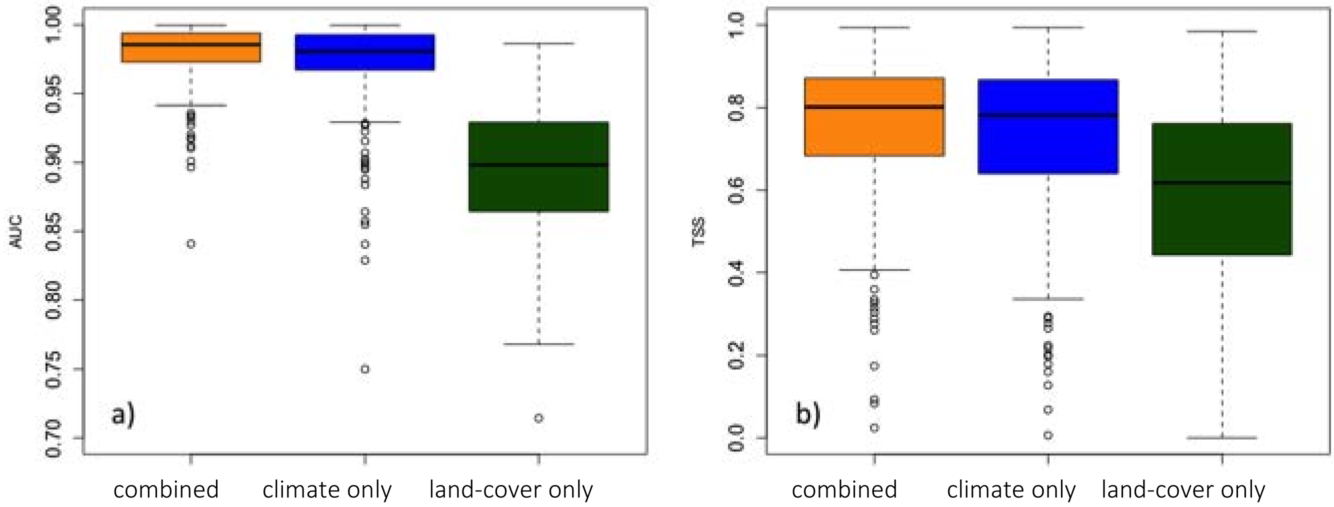


Figure 3.3 Summary model performance statistics for the species distribution models using combined climate and land-cover, climate only, and land-cover only. Box-whisker plots illustrating the mean and variability of model accuracy for each predictor set as measured by; a) AUC - Area Under Curve (AUC), and b) TSS - True Skill Statistic (see methods for more detail).

The overall pattern of comparative model performance using different predictor sets presented above in Figure 3 remained largely the same within each of the ecological subgroups (Figure 3.4). This was explored by comparing the relative model performance for each predictor set within each ecological subgroup. Overall, combined climate and land-cover and climate only models outperformed land-cover only models irrespective of habitat preferences, feeding guild, elevational range limits, biogeographic grouping, and migratory type (Figure 3.4). Generally, there was little difference between climate only and combined climate and land-cover models but land-cover only models performed less well and with wide variability especially for Sundaic species (Figure 3.4h).

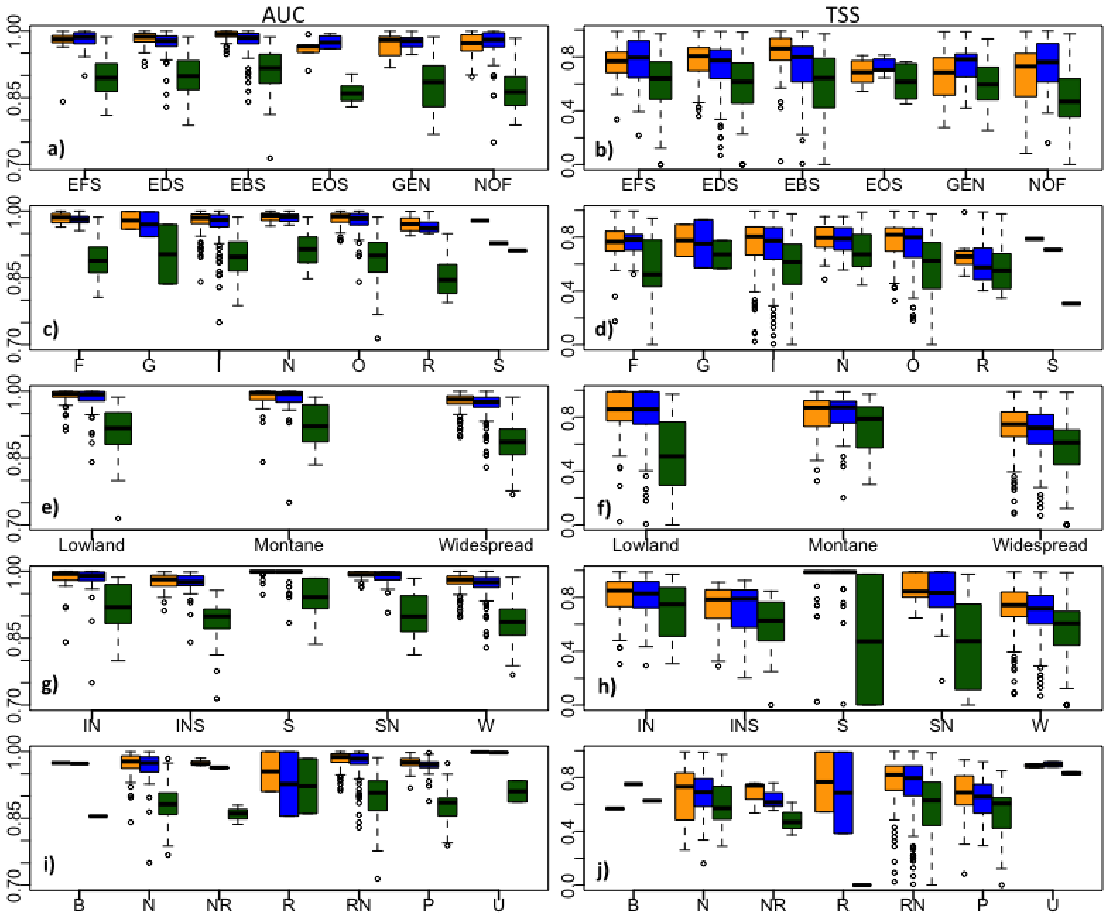


Figure 3.4 Summary model performance statistics for the species distribution models using combined climate and land-cover (orange), climate only (blue), and land-cover only (dark green). Box-whisker plots illustrating the mean and variability of model accuracy for each predictor set as measured by: (a, c, e, g, i) AUC, and (b, d, f, h, j) TSS. For the 304 species split into a variety of ecological subgroups including: (a, b) Habitat groups (EFS - evergreen forest specialist; EDS – evergreen forest specialist but occur in deciduous forest; EBS - evergreen forest specialist but occur in bamboo forest; EOS - evergreen forest specialist but occur in edge forest, open area, and other (not include forest); GEN - occur in evergreen forest but common in other forest, occur in evergreen forest but common in edge forest, open area and other (not include forest area); and NOF - never occur in evergreen forest), (c, d) Feeding guilds (F - frugivorous; G – granivorous; I – insectivorous; N – nectarivorous; O – omnivorous; R – raptor, and S - scavenger), (e, f) Elevational groups (L - lowland ; M - montane ;W - widespread), (g, h) Biogeographic subregions (IN – Indochinese; INS - Indochinese-southern cross; S – Sundaic; SN - Sundaic-northern cross; and W - widespread), and (i, j) Seasonal migratory classes (B – breeding visitor; N – non-breeding visitor; NR - mainly non-breeding visitor but maybe resident; R - resident or presumed resident; RN - mainly resident but maybe non-breeding visitor; P - mainly spring and autumn passage migrant, and U – uncertainty). See Table 3.1 for more details of number of species within each subgroups.

3.4.3 Spatial patterns of biodiversity

Utilising the individual species distributions producing in the previous section, it is possible to build maps of bird species richness and assemblage composition/diversity across the entire forest ecosystem of Thailand. The results show that in overall species richness and diversity, the western and the central part of Thailand have the highest diversity particularly in the uplands (Figure 3.5). On the other hand, the lowlands and the northeastern part of Thailand have lower biodiversity (Figure 3.5).

There is generally spatial concordance in the patterns of diversity estimated by climate only, land-cover only or combined climate and land-cover predictor sets (Figure 3.5). However, there are major differences in their resolution and predictions at more localised spatial scales. At the “whole-country” spatial scale there is little spatial difference when considering high biodiversity areas between the maps of species richness and diversity (Figure 3.5). The maps of diversity (Figure 3.5d - 5f) take into account the environmental suitability for each individual species and therefore are more smoothed and will still project lower diversity estimates into areas that are marginal that are excluded by the threshold approach used in estimating species richness.

Since there is extensive global evidence suggesting that montane species are the most vulnerable to climate change, I conducted a preliminary visualization of the diversity patterns of lowland, montane and generalist species diversity to explore spatial patterns of montane specialist diversity (Figure 3.6). The diversity of montane specialists is primarily concentrated in the northern and middle (Indochinese dominated) mountain ranges and the Western Forest Complex (Figure 3.6 and Appendix Figure E3.4).

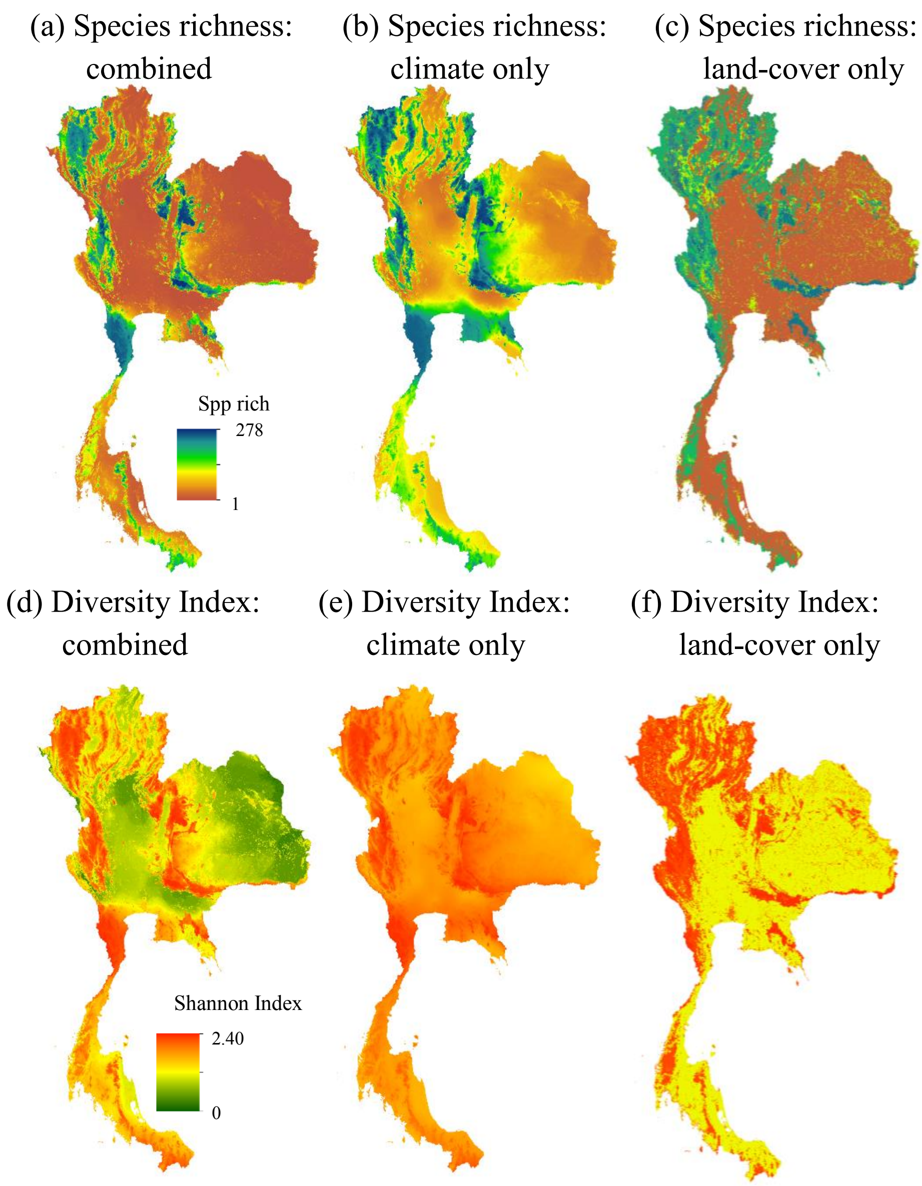


Figure 3.5 Spatial pattern of species richness (a-c) and spatial pattern of diversity index (d-f) of Thailand's forest birds predicted by (a, d) combined climate and land-cover; (b, e) climate only; and (c, f) land-cover only.

Predictably, the spatial pattern of each predefined biogeographic group showed a strong latitudinal pattern. The maps of diversity of each group presented in Appendix Figure E3.5 illustrate, for the first time, the detailed, spatially explicit pattern of where each biogeographic group makes the most contribution to overall species richness and assemblage structure. The forest avifauna of mainland Thailand is dominated by species of Indochinese origins while the assemblages on peninsular Thailand is Sundaic in origin (see methods for definition of biogeographic region subgroup). The highest diversity area at the lower part of

Western forest complex, Kaeng Krachan National Park, at the neck of the peninsular is an overlap zone with an almost equal mix of these two major zoogeographic clades (see Appendix Figure E3.2 – E3.6 for map of species richness each ecological subgroup). Surprisingly, the spatial pattern of species richness and diversity index of Sundaic–northern border species exhibits an extended distribution across Thailand (Appendix Figure E3.5).

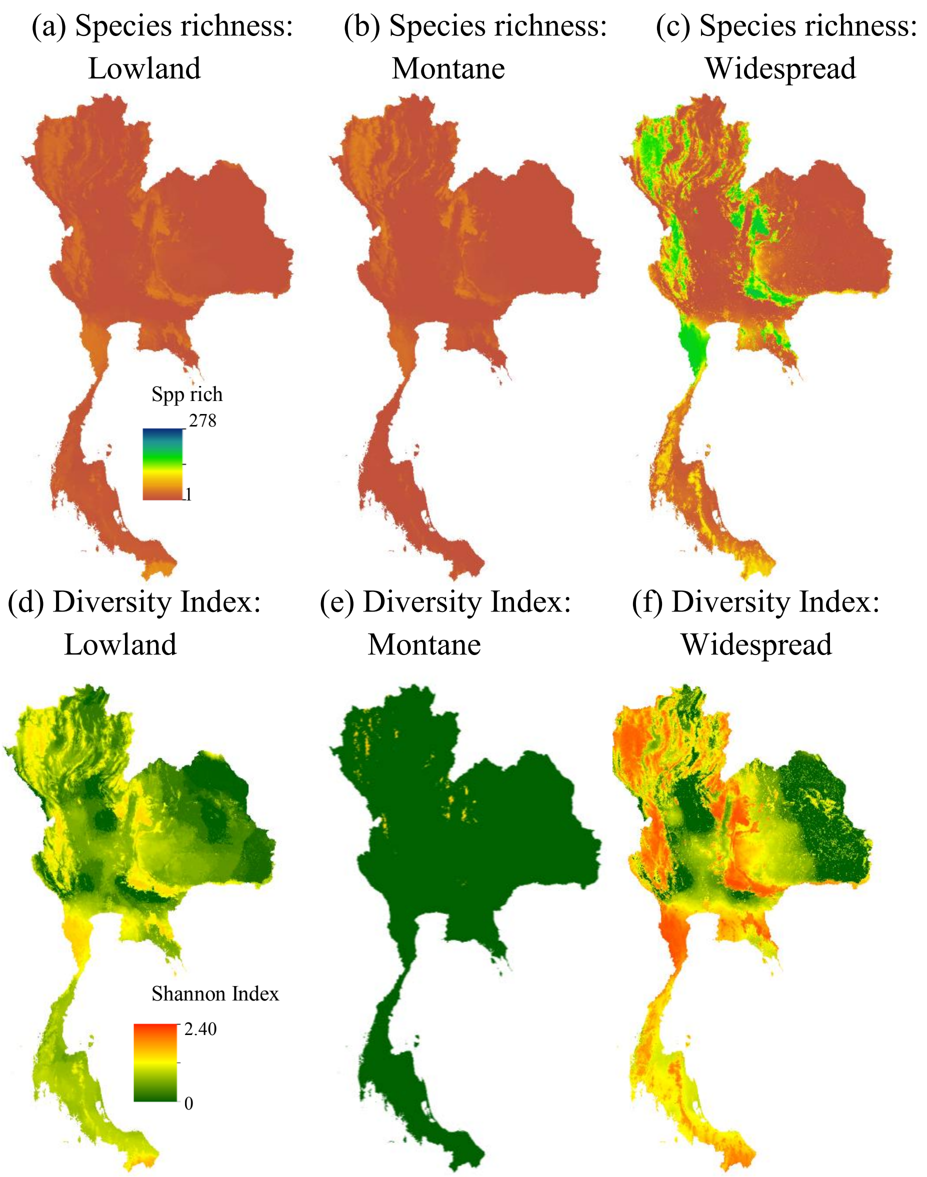


Figure 3.6 Spatial pattern of species richness (a-c) and spatial pattern of diversity index (d-f) predicted by combined climate and land-cover predictor based on subgroup of Elevational range limits: (a, d) Lowland species; (b, e) Montane species; and (c, f) Widespread species (see method 3.3.1 species data and study areas and Appendix Table 1 for more details of Elevational range limits subgroup).

3.4.4 Exploring the relative influence of climate and land-cover variables on species distributions

Overall, the distributions of evergreen forest bird species in Thailand are most consistently correlated with the combination of maximum temperature of warmest period and land-cover (Figure 3.7). Among the bioclimatic variables of both climate only model and combined climate and land-cover models, the top four variables of both models are very similar with slight differences in their relative ranking.

In climate-only models, maximum temperature of warmest period (BIO 5) was the most consistently important variable with the highest average percent contribution across species followed by mean annual temperature (BIO 1), precipitation of driest quarter (BIO 17), and precipitation of wettest quarter (BIO 16) for climate-only models. However, when land-cover was included, land-cover (LC) made the highest contribution followed by maximum temperature of warmest period was the main contributor followed by precipitation of driest quarter, precipitation of wettest quarter, and mean temperature (Figure 3.7).

The relative contribution of each environmental variable was substantially different within each functional group. These differences are summarized in Table 3.4 with full details in Appendix Figure 3.1. Mean annual temperature and maximum temperature of warmest period were the most consistently influential variable across most of functional group.

Mean temperature significantly contributed most to both climate-only models and combined climate and land-cover models for the montane, Indochinese, Indochinese – southern border and most feeding guild species, however, scavenger and granivorous species were better predicted by combined climate and land-cover model. Maximum temperature was important to all the functional groups except for scavengers and Sundaic species.

Precipitation of the wettest quarter and precipitation of the driest quarter were main contributors for most of the functional groups, with precipitation of the wettest quarter making a consistent, although small, contribution to all groups except the Scavenger and Sundaic species. In contrast, precipitation of driest quarter was the most influential to evergreen forest specialists. Other groups that were influenced by precipitation of driest quarter included most feeding guild groups, particularly the Scavenger species; lowland species, and species that had biogeographically ranges in the Sundaic, and Sundaic-northern border or resident species grouped by seasonal status.

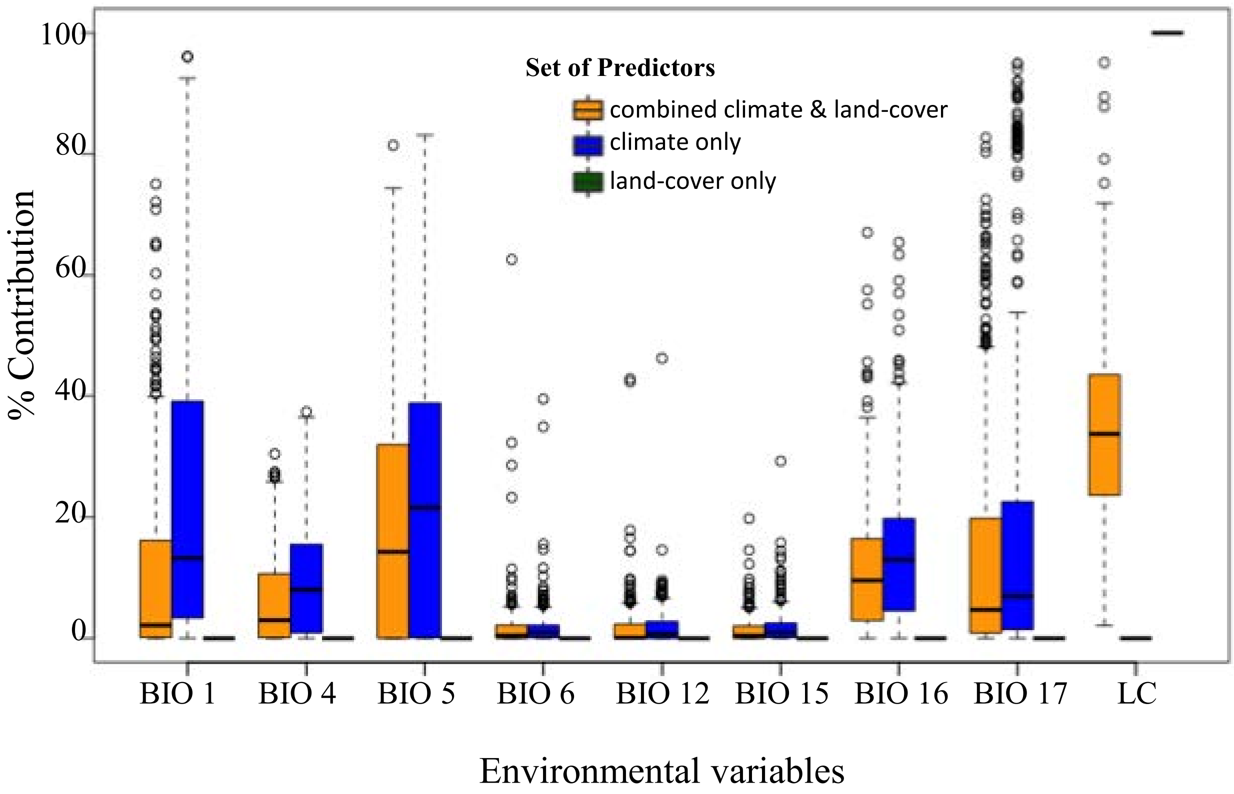


Figure 3.7 The contribution of environmental variables (mean±SD) based on combined climate and land-cover (orange), climate only (blue), and land-cover only (green): BIO 1 = mean temperature; BIO 4 = temperature seasonality; BIO 5 = maximum temperature of warmest period; BIO 6 = minimum temperature of coolest period; BIO 12 = annual precipitation; BIO 15 = precipitation seasonality; BIO 16 = precipitation of wettest quarter; BIO 17 = precipitation of driest quarter; and LC = land-cover.

Table 3.4 Summary of the influence of each climatic variable across all species distribution models within each functional group (also see Appendix Figure 3.1).

Code	Climatic variable	Results
Bio 1	Annual mean temperature	Primary importance to all functional groups especially montane, Indochinese, Indochinese – southern border, and uncertain species, but not important to scavenger, Sundaic and resident species.
Bio 4	Temperature seasonality	Minor influence on all functional groups.
Bio 5	Maximum temperature of warmest period	Important to all functional groups, except scavenger, and Sundaic species.
Bio 6	Minimum temperature of coldest period	Minor influence on all functional groups.
Bio 12	Annual precipitation	Minor influence on all functional groups.
Bio 15	Precipitation seasonality	Minor influence on all functional groups.
Bio 16	Precipitation of wettest quarter	Important to most functional groups, in particular granivorous, and breeding visitor species, however not important to scavenger, and Sundaic species.
Bio 17	Precipitation of driest quarter	Important to most functional groups, evergreen forest specialist but occurs in bamboo forest, scavenger, lowland, Sundaic, Sundaic-northern border, and resident species.

3.4.5 The relationships between climatic variables and the projected spatial patterns of species richness

To better understand the patterns of local diversity for Thailand's forest birds, I explored the relative contribution of each climatic variable to the overall estimated spatial patterns of bird diversity in each locality (1 km^2 pixel). In general, species richness based on the combined species distribution models was higher in the cooler uplands (Figures 3.8a, 3.8c, and 3.8d) and in areas with a less harsh dry season (Figure 3.8h).

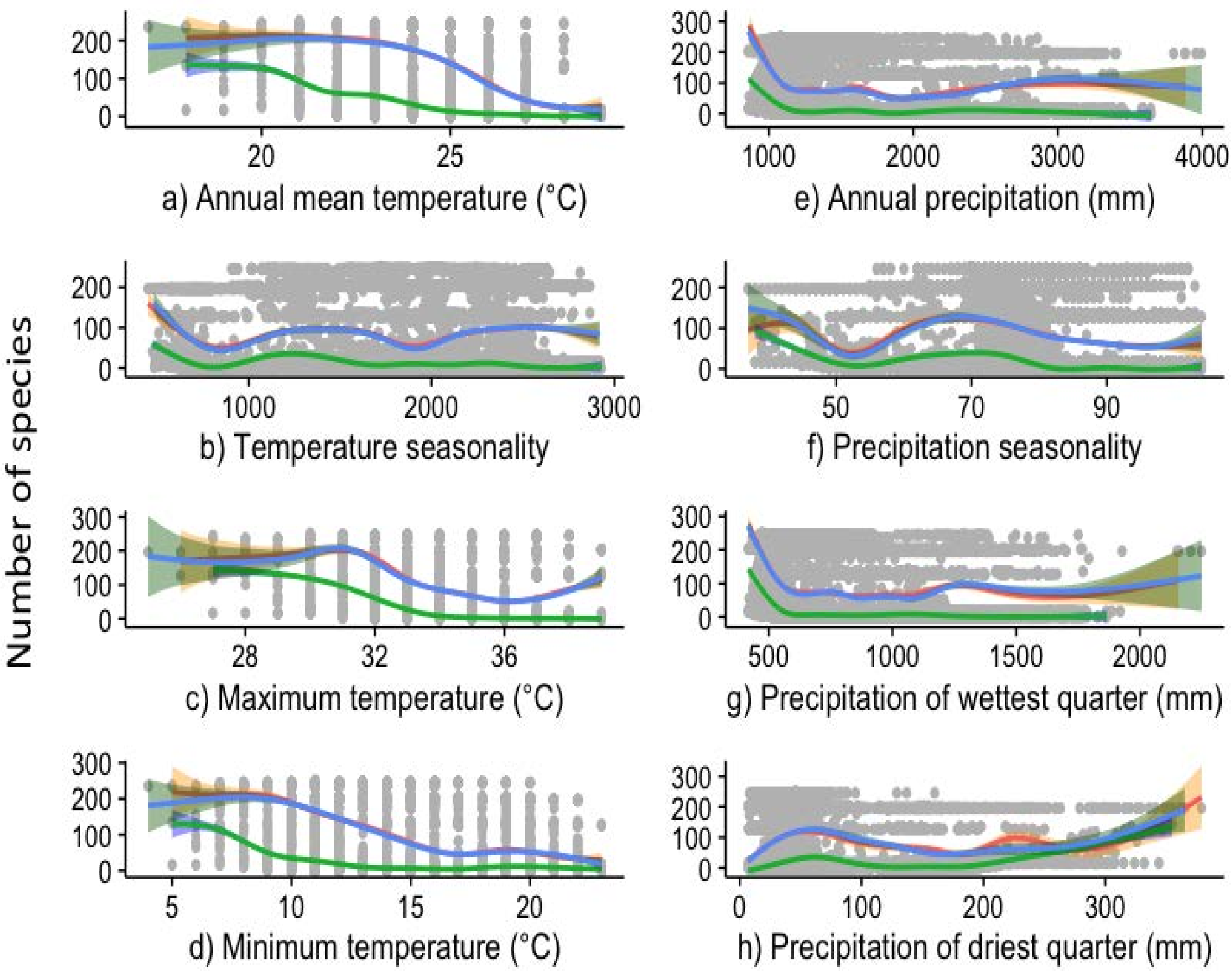


Figure 3.8 The relationship between species richness in each local area (1 km^2 pixel) as estimated from the summed distribution maps and climatic variables (± SE) based on the three different sets of predictor variables (grey dot); combined climate and land-cover (orange), climate only (blue), and land-cover only (green); (a – d) temperature variables, and (e – h) precipitation variables. Note that in this analysis there are many overlaid points and the resolution plotted is for each degree celcius and each 10 mm of rainfall.

Since elevation and temperature are inextricably linked and given the significance of temperature in understanding likely impacts of global climate change, I explored the diversity relations across elevation in more detail (Figure 3.8). Overall, the combined species distribution maps of all forest species, suggest that species richness is relatively similar across most elevations (temperature) (Figure 3.9). There is a tendency for lower species richness below 500m however this is highly variable. Patterns based on land-cover only predict slightly lower species richness than those that include climate variables

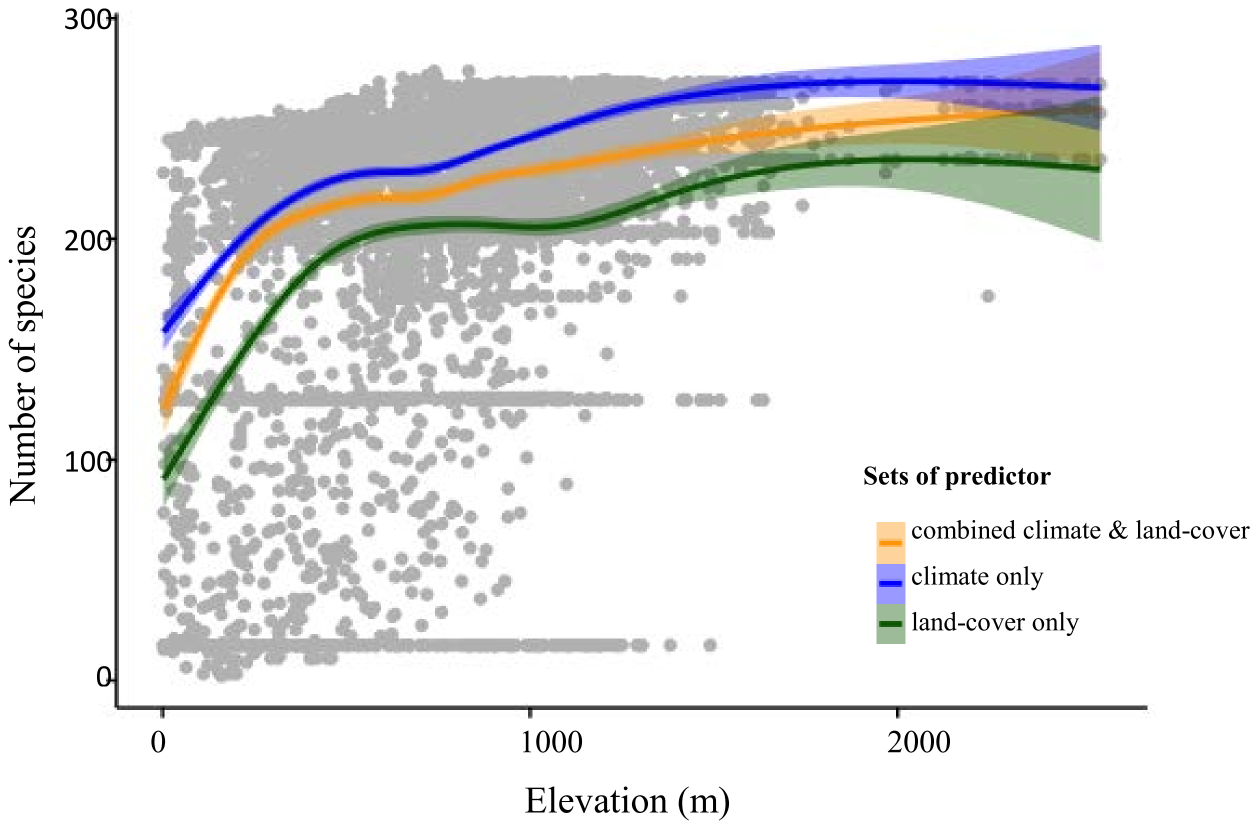


Figure 3.9 Species richness across elevation based on the three different sets of predictor variable: combined climatic and land-cover, climate only, and land-cover only. The trend line and variability for species richness is estimated as the mean number of species per pixel based on the SDMsacross all pixels in each 100m elevational band (± SE).

3.5 Discussion

This study provides the first high-resolution, comprehensive set of species distribution maps for forest birds in Thailand (Appendix Figure E3.1). The distribution maps cover the entire country, include the bulk of the bird assemblage, have a relatively high spatial resolution and are explicitely linked to relationships with environmental variables providing a vast improvement on coarse range maps. The distribution maps are based on a collation of many thousands of records from across the country combined with systematic standardized surveys across elevation, latitude and season for the whole of Thailand. By sampling across elevation and latitude the survey data covers most geographic and environmental space represented within Thailand. Moreover, this is the first spatially explicit, high-resolution map of all forest bird species that considers both climate and land-cover, the two factors generally considered to most influence distributions. This study is a valuable resource for environmental management and policy within Southeast-Asia and makes a significant contribution to avian biogeography and biodiversity science in the region.

3.5.1 Relative role of climate and land-cover on species distributions and biodiversity spatial patterns

This study suggests that climate variables produce species distribution models with the best overall performance, as measured by model performance statistics (Table 3.2). The number of variables within each model type (climate only, land-cover only, combine climate and land-cover) is not equal, so the difference between the performance of land-cover only and climate-only models could conceivably be partially due to the inclusion of more variables. However, the addition of land-cover variables to climate-only modelsdid not improve the models significantly. Therefore, it seems likely that the difference in explanatory power is real and not just the affect of the inclusion of more variables. However, the inclusion of land-cover still improved overall model performance. This study intimates that although broad distributions or range limits are best defined by climate, the higher resolution (local scale) distribution is significantly improved when land-cover is included, a conclusion supported by previous studies (Thuiller et al., 2004a, Luoto et al., 2007, Howard et al., 2015). This makes intuitive sense as the presence of a forest bird in a local area will first be influenced by the suitability of overall climate but then at the local scale it still requires suitable forest habitat to be present. Not surprisingly, the combination of climate and land-cover provides the best spatial pattern matching with expert opinion and what is observed in the field (Lekagul and Round, 1991, Napheethapat et al., 2012). Forest extent has been heavily modified across Thailand (RFD, 2015) so, in general, this study demonstrates that species distribution models and resulting biodiversity patterns should be based on both climate and land-cover whenever possible although climate alone is adequate for large scale biogeographic analyses. Therefore, this validates the idea that including land-cover variables into bioclimatic distribution models may provide essential information to capture the environmental conditions used by species and to project its distribution in the future particularly at the fine spatial scales required by conservation managers (Luoto et al., 2007, Barbet-Massin et al., 2012). These findings highlight the need to include land cover into climate models (Luoto et al., 2007, Barbet-Massin et al., 2012) so that more accurate assessments of the effects of global change on tropical birds species and biodiversity can be projected.

Without doubt, the local accuracy or these distribution models could be improved by more detailed vegetation descriptions and other habitat structure information, however, these types of data are rarely available over extended geographic areas. There is great potential for conservation managers to combine the potential climatic/land-cover models produced here with higher resolution local coverages to provide more accurate localised maps for specific species at specific locations.

Spatial patterns of biodiversity produced by SDMs can be useful to examine many questions about the patterns and processes of biodiversity or for making predictions about future changes. Although the performance of individual species distribution models varied significantly depending on the environmental predictors used (Table 3.3), at the scale of the entire country, there was little difference in the overall patterns of species richness and diversity predicted using climate only or climate/land-cover models. The results presented here enable more detailed examination of both latitudinal and elevational patterns, both important patterns in the context of understanding the future impacts of increasing temperature. However, examining species richness is inadequate as we are often more concerned about the impacts on specific groups of greater conservation significance than in absolute levels of species richness. For example, previous studies show that montane specialists inhabiting narrow elevational are the most vulnerable to climate change (McCain, 2009b, McCain and John-Arvid, 2010).

Species richness and diversity is lower in the lowland and concentrated in the higher elevation areas particularly in the central and northern regions of Thailand (Figure 3.5). This result indicates that climate and forest-cover determining species distribution increase from lowland to upland also increase from southern to northern Thailand. Furthermore, the forest avifauna of mainland Thailand is dominated by species of Indochinese origins while the assemblages on peninsular Thailand are primarily Sundaic in origin (Round et al., 2003). This study shows clearly that the Sundaic-northern border species are distributed more widely across Thailand at than previously thought (Round et al., 2003). Both models and empirical field records show 24 Sundaic species occurring as far north as 13º - 13º30'N extending the previously described lattudinal distribution limits described in Round et al. (2003) for these species to higher latitudes (~20ºN). The results of this study may therefore be showing that either these species are more widely distributed than previously recorded or there has already been a significant range shift of tropical bird species to the north, as many studies have already recorded (Deutsch et al., 2008, Jump et al., 2009, Post et al., 2009, Bonebrake and Mastrandrea, 2010, Jiguet et al., 2010, VanDerWal et al., 2013, Gibson-Reinemer et al., 2015, Ferrarini et al., 2017).

Describing and understanding the spatial patterns of biodiversity is useful in prioritising areas of high biodiversity conservation significance. I found that there is an overlap zone between two major zoogeographic clades centred on Kaeng Krachan National Park resulting in the highest avifauna diversity in Thailand. Protecting and managing biodiversity rich areas such as Kaeng Krachan National Park should be a key component of environmental protection in Thailand, especially given contribution of biodiversity ecosystem processes and general resilience (Klorvuttimontara et al., 2011, Nakao et al., 2013, Beale et al., 2013, Thomas and Gillingham, 2015, Gaüzère et al., 2016, Regos et al., 2016). In addition, given the expectation that species distributions will shift latitudinally as global climates change and the subsequent necessity of maintaining a spatially dynamic approach to conservation planning, Kaeng Krachan is also a critical link between peninsula Thailand and mainland areas. Without doubt, my results confirm that Kaeng Krachan is vitally important as a reservoir of high species richness, an overlap zone between Sundaic and Indochinese biogeographic groups and as a stepping-stone in potential future bird distribution shifts from the peninsular to central Thailand.

The interaction impacts between future land-cover change and climatic change has often been discussed as one of the most significant future threats to global biodiversity (Oliver and Morecroft, 2014, Williams et al., 2017). The results presented in this chapter highlight the need to include land-cover and climate in species distribution models to assess future impacts of climate change and supports previous recommendations that this is vitally important (Luoto et al., 2007, Barbet-Massin et al., 2012, Martin et al., 2013, Sirami et al., 2017). I will explore this topic in greater detail in Chapter 5.

3.5.2 Relative influence of climate and land-cover variables to contribute species distributions

When both climate and land-cover is included in the species distribution models, land-cover is the most consistently important variable, followed closely by temperature and dry season rainfall (Figure 3.7). However, it is also clear from the analyses and model evaluation statistics that, in general, climate provides a better spatial delineation of the true spatial distribution of most species. This conclusion is based on the model evaluations (Figures 3.7 and Table 3.4) that compare the modeled distribution to the coverage of the empirical data points. This contrasts somewhat with previous studies that show that climate is usually more influential than land-cover in determining species distributions (Thuiller et al., 2004a, Luoto et al., 2007). It is clear that both are important, climate is probably the most important variable limiting the distribution extent, while land-cover is the most significant variable predicting the spatial pattern of distribution within the range.

The point of the different groups is simply to explore the relative importance of different environmental variables within different ecological subgroups, though each subgroup contain different number of species. Therefore, the separate exploration of ecological subgroups supports the patterns found for overall species that maximum and mean annual temperature are of paramount importance to bird distributions, especially montane, Indochinese, and uncertain seasonal status species (Table 3.4 and Appendix Figure 3.1). These results agree with prior studies in temperate regions showing that temperature is more influential on species occurrence than precipitation (Howard et al., 2015, Pearce-Higgins et al., 2015) and is of clear importance in predicting and managing the impacts of increasing global temperature. However, my analyses also show a consistent importance of dry season rainfall, or rainfall seasonality, in the species distribution models of a high proportion of species (Table 3.4 and

Appendix Figure 3.8). The analyses of model contributions by each environmental variable demonstrate that many forest species particularly forest specialists, granivorous, lowland, Sundaic, and resident species prefer lower seasonality in rainfall, that is, a more consistent rainfall across the year. This matches well with previous research in the forests of the Australian Wet Tropics birds where rainfall seasonality is a significant variable related to spatial pattern of bird abundance, range size, and population size (Williams and Middleton, 2008). The results presented here support the hypothesis that rainfall seasonality is an important factor in determining the distributions and diversity patterns in the topics as suggested in a number of other studies (Chadwick et al., 2015, Kent et al., 2015, Feng et al., 2013), Thus, predicted future changes in rainfall seasonality pose a significant threat to some populations and communities of tropical birds even in large tracts of protected habitat (Brawn et al., 2016).

The analyses presented here provide further evidence that temperature is potentially more important than rainfall in limiting species distributions. Exploring the relationships between climatic variables and spatial patterns of species richness in all these approaches (climate-land cover, climate only, land cover only) showed that maximum temperature, annual mean temperature, and dry season rainfall are the most consistent influence on Thailand's forest birds community. There is higher species richness in cooler areas at high elevation, also in the wetter areas. Obviously the importance of temperature, especially maximum temperature, has implications for vulnerability to increasing temperature under climate change (Laurance et al., 2011, Forero-Medina et al., 2011a, Forero-Medina et al., 2011b, Freeman and Class Freeman, 2014). These results also emphasize that changes in the intensity and frequency of dry season conditions (rainfall seasonality) in the future might also produce significant impacts on tropical forest birds as predicted elsewhere (Williams and Middleton 2008, IPCC, 2012, Barros et al., 2017).

Chapter 4:

Impacts of climate change on Thailand's forest birds: projected changes in species distributions, abundance, diversity, and threat status

---

4.1 Abstract

Projected climate change over the next 50 years, is predicted to lead to significant range contractions and population decline in more than 200 species (>85%) of Thailand's forest birds. These impacts would result in more than two thirds of all forestbird species being threatened by 2070. I assessed the vulnerability of birds by projecting the exposure of 304 species of forest birds across the whole of Thailand for the current time and for 2050 and 2070. Maximum Entropy Algorithm (MaxEnt) was employed to project future species distributions based on presence-only data of birds for each of five global circulation models and four representative concentration pathways (RCPs) scenarios of future climate. Changes in national threat status were assessed using the IUCN Red List Criteria: B1 as continuing decline of extent of occupancy, and A3 as the future reduction in population size projected. There is geographic variation in the impacts with less severe impacts being predicted for the assemblages in the lowlands, migratory species and the Sundaic biogeographic assemblages.

Overall, the projections predict a massive loss in habitat quality for many species rather than a decline in distribution area. Using an index of total population size (criteria A3) based on summed environmental suitability for each species distribution model, I predict that over 85% of bird species assessed will become threatened within Thailand, while only 5% become threatened using purely range size criteria (B1). This has significant implications for the widespread use of range size in projecting future vulnerability of biodiversity to climate change and I emphasize that indices of total population size are more biologically meaningful and provide a more sensitive and realistic assessment of vulnerability. Not surprisingly, impacts are greatest in high elevation assemblages across Thailand. These results suggest that mitigation is vitally important in reducing impacts on Thailand amazing biodiversity and that an extended protected area network of highland forests will be critical in order to minimize the impacts of climate change.

4.2 Introduction

Anthropogenic changes in the world's climate have significant implications for biodiversity with impacts on population abundance, species distributions and invasions, potentially resulting in significant levels of extinction among the world's biota (Parmesan and Yohe, 2003, Williams et al., 2003, Thomas et al., 2004). Thus, understanding how species will respond to project future climate change is vital for predicting species vulnerability and the design of efficient conservation management strategies for protecting biodiversity (Hannah et al., 2002, Williams et al., 2008, Dawson et al., 2011, Reside et al., 2012b). The IUCN Red List Criteria is the most widely recognized scheme to assess species vulnerability, although it is only recently being used to assess vulnerability to climate change using quantitative criteria based on population size, rate of population decline and range of distribution decline (IUCN, 2001). (Thomas et al., 2004, Bomhard et al., 2005, Shoo et al., 2005a, Maclean and Wilson, 2011, Stanton et al., 2015, Meng et al., 2016)

Birds represent excellent organisms for studying the effects of climate change, since they are species-rich, relatively easily monitored and can respond to environmental shifts rapidly due to their high potential for movement (Sodhi et al., 2011, Şekercioğlu et al., 2012). Climate change has already led to shifts in bird distributions (Parmesan, 2006, La Sorte and Jetz, 2010a, Chen et al., 2011, Freeman and Class Freeman, 2014). There is already convincing evidence that recent changes in climate have affected birds (Crick, 2004, Beaumont et al., 2006, Beaumont et al., 2007, Gregory et al., 2009, Beaumont et al., 2011). For example, many temperate species have shifted their distributions poleward (VanDerWal et al., 2013) and tropical birds have reacted to current climate change by shifting their geographic ranges to cooler climates (La Sorte and Jetz, 2010a). To confirm that temperature is an important factor driving elevational distribution of tropical forest birds (La Sorte and Jetz, 2010a) used species distribution models and showed that tropical birds have shifted their breeding ranges to higher elevations.

Population declines and major reproductive declines have been serious consequences attributed to climate change for many species of birds around the globe (Crick, 2004, Both et al., 2006, Wormworth, 2006, Beaumont et al., 2011). Bird population responses to climate change have received less study than distribution, however, there are some studies on long term observations (Flousek et al., 2015, Both et al., 2010, Both and te Marvelde, 2007, Jiguet et al., 2010, Gregory et al., 2009, Møller et al., 2008, Reif et al., 2008, Beaumont et al., 2011), or projecting from species distribution models (Jenouvrier, 2009, VanDerWal et al., 2009a, Aiello-Lammens et al., 2011, Barbraud et al., 2011, Sun et al., 2016). However, there are few data on population changes due to future climate change in tropical birds (Gasner et al., 2010) This particularly worrying as there has been a number of studies suggesting that tropical birds already live near their maximum thermal tolerance (Tewksbury et al., 2008, Laurance et al., 2011).

Evaluating extinction risk to climate change is a critical aspect of conservation management. There are many ways to assess species vulnerability and estimate extinction risk with many previous studies using species distribution models that predict future distributions under a variety of future climate scenarios (Williams et al., 2003, Thomas et al., 2004, Evangelista et al., 2011). Some approaches combined projecting distribution range with quantitative specie-specific life history traits (Huey et al., 2012, Foden et al., 2013, Carr, 2014, Meng et al., 2016, Reside et al., 2016). Very few studies utilized approaches that predict relative changes in population size rather than distribution area, despite research demonstrating that population size is more effective and the widespread use of changes in population size as a measure of vulnerability (Shoo et al., 2005b).

Birds of tropical forests will be particularly vulnerable to increasing extinction risk due to both climate induced range shift and habitat decline (La Sorte and Jetz, 2010a, Sekercioglu et al., 2008, Şekercioğlu et al., 2012). For instance, in north-eastern Australia, 74% of rainforest birds are predicted to become threatened (including 26 critically endangered species) as a result of projected mid-range warming projected within the next 100 years (Shoo et al., 2005a). Increasing extinction risk of bird biota is further exemplified in Costa Rican and Panamanian forest birds, where increasing temperature is predicted to cause 50% forest bird species to decline and result in local extinctions of the region's mountaintop endemic species (Gasner et al., 2010). A similar story was suggested for high-elevation birds of Indonesia, with the white-eared myza (*Myza sarasinorum*) and Sulawesi leaf-warbler (*Phylloscopus sarasinorum*) highly threatened (Harris et al., 2014). In the Australian Wet Tropics rainforests, 50% of the bird species have already declined and their distributions retracted to higher elevations (Williams et al., 2016).

Tropical mountains harbour a significant proportion of global avian biodiversity (Şekercioğlu et al., 2012), and Thailand is no exception, with 1,011 species recorded (Napheethapat et al., 2012). Although the magnitude of warming is predicted to be greater at high latitudes, tropical species may already be living closer to their maximum thermal tolerances and therefore even small changes could have disproportionally large impacts (Deutsch et al., 2008, Tewksbury et al., 2008, Laurance et al., 2011). Despite this, there is a paucity of information regarding impacts of climate change on tropical birds (Şekercioğlu et al., 2012), and little is known about the potential extent of climate change impacts on the natural ecosystems in Thailand (Trisurat, 2011). Coupled with this lack of information, there has already been an increase in average air temperature of 0.95°C between 1955 and 2009 in the region, exceeding the average increase of world temperature (Limsakul, 2011). To date, the only documented impact of climate change on Thailand's birds has been on the lowland Siamese Fireback (*Lophura diardi*), a species that has significantly increased in abundance at a higher-altitude site, formerly only inhabited by the highland Silver Pheasant (*L. nycthemera*). Temperature increase was attributed as most likely cause for this shift in distribution (Round and Gale 2008).

Currently there has been no quantitative assessment of the vulnerability of Thailand's avian biodiversity to future climate change. The Thailand Red Data List of birds has previously estimated extinction risk but this list is entirely based on expert opinion only (Sanguansombat, 2005). Therefore, there is an urgent need to collate the necessary empirical data and to objectively assess the future impact of climate change on biodiversity in Thailand in order to understand the changes that are occurring and subsequently manage the anthropogenic and natural threats to this avifauna-rich region.

In this chapter, I examine the potential impacts of future climate change on spatial patterns of species distributions, species richness, and abundance, and evaluate species vulnerability due to climate change for more than 300 species of forest birds in Thailand. I use distribution models for 304 species to (1) estimate the potential impact of climate change on pattern of species richness, distribution range, and population size, and (2) evaluate the vulnerability of individual species using the IUCN Red List Criteria B1 as continuing decline of extent of occupancy (distribution size), and also Criteria A3 using estimates of changes in total population size.

4.3 Methods

4.3.1 Species data and study areas

The dataset I collated provides a comprehensive representation of the avifauna of tropical evergreen forest ecosystems in Thailand. The data consists of two main elements: (1) My own standardized surveys from 2013 to 2015 and (2) Data collated from a variety of other sources including individual ornithologists, bird clubs, the Department of National Park (DNP) and universities (see Appendix Table 1 for list of species collated from these sources). From the combined dataset, there were 313 species with greater than 10 geographically-unique records across 461 geographic locations which I used in this study for species distribution modeling. Of this 313, 304 species models were high qulaity and were used in subsequent analyses as discuss in Chapter 3. The dataset covers most of the geographic and environmental space occupied by evergreen forest in Thailand and represents the first quantitative, nation-wide summary of an entire ecosystem avifauna in Thailand. These data will be of considerable ongoing value to ornithology and conservation management in Thailand. In order to better understand the patterns of bird biodiversity and ecological relationships between species and the environment, I classified bird species in five ways for additional pattern exploration: habitat preferences, feeding guilds, elevational range limits, biogeographic, and migratory status (see Chapter 3 for more details).

I also compiled species conservation status, as vulnerable, endangered, and critically endangered, as currently listed in Thailand (Sanguansombat, 2005), and internationally (IUCN, 2001) (see Appendix Table 1 for details of each species).

This study was focused on the evergreen forest (20°28′N 99°57′E and 5°37′N 101°8′E), occupying nearly one-quarter of Thailand (RFD, 2015) that most of Thailand’s remaining evergreen forest occurs in protected areas (Figure 4.1) (Faculty of Forestry, 2012).

Forest Complexes of Thailand

1 = Lum Num Pai-Salawin

2 = Sri LannaKhun Tan

3 = Doi Phuja-Mae Yom

4 = Mae Ping-Om Koi

5 = Phu Meang-Phu Thong

6 = Phu Khiew-Nam Naew

7 = Phu Parn

8 = Phanom Dongrak-Phatam

9 = Dong Phayayen-Khao Yai

10 = Eastern

11 = Western

12 = Kaeng Krachan

13 = Chumporn

14 = Klong Saeng-Khao Sok

15 = Khao Luang

16 = Khao Bantad

17 = Hala-Bala

18 = Mo Kho Similan-Peepee-Andaman

19 = Mo Kho Ang-Thong-Ao Thai

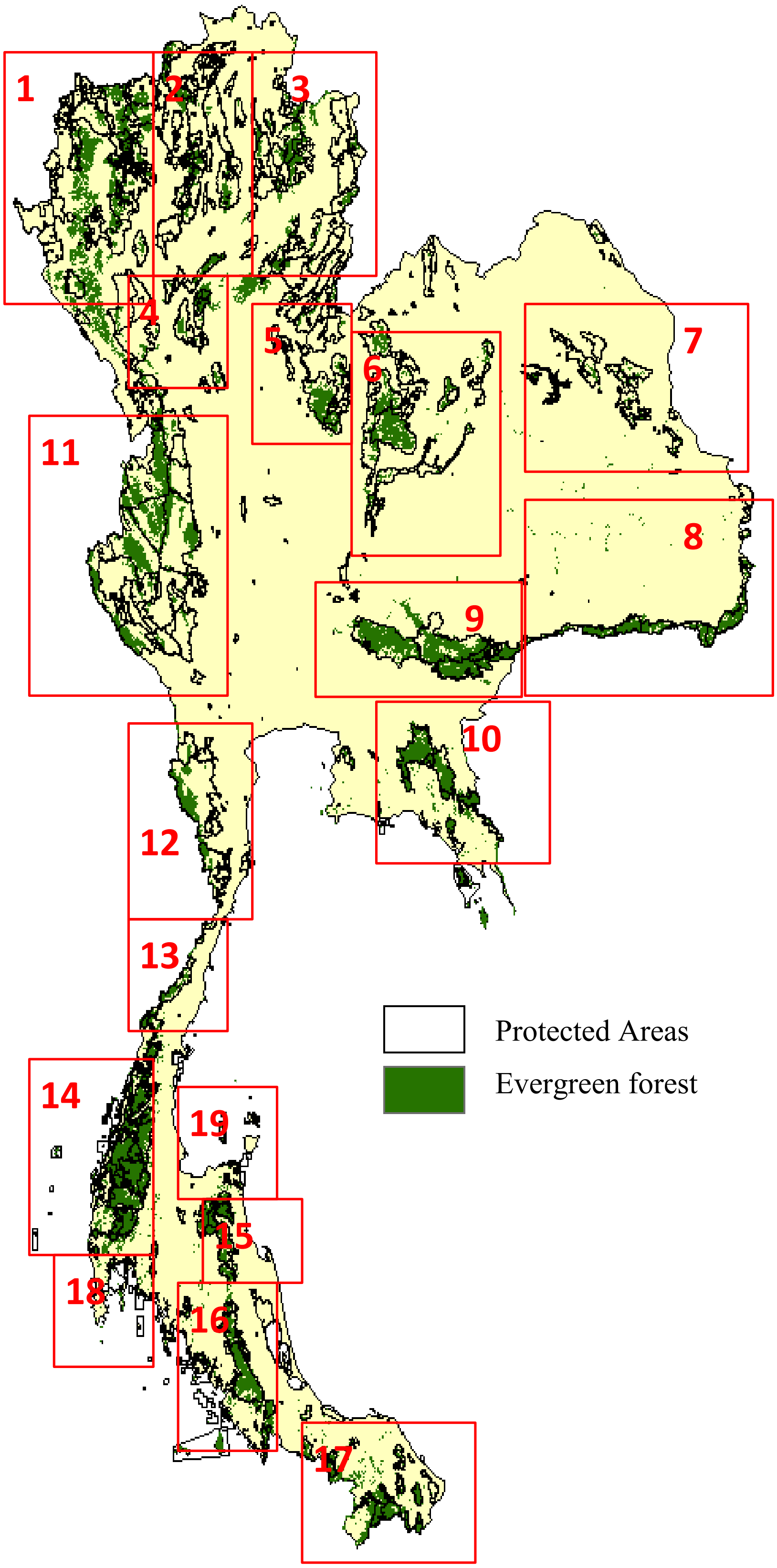


Figure 4.1 Map of the current extent of evergreen forest within 19 forest complexes in Thailand (red squares) (Faculty of Forestry, 2012).

4.3.2 Climatic data

Species distribution models (SDMs) utilize spatial coverage of environmental variables especially bioclimatic variables representing average and extreme values of temperature and rainfall for all locations. Current climate data covering 19 bioclimatic variables was downloaded from the WorldClim database based on climate averages over ~1960 - 1990 at 1x1 km^2 resolution, which was the highest resolution available for the entire study area (Hijmans et al., 2005). In this study I used eight of these standard, commonly used bioclimatic predictors of temperature and precipitation, representing the annual average, quarterly maximum/minimum period value and annual variability (seasonality) as used in a number of studies in the Australian Wet Tropics (Table 3.1): (Williams et al., 2003, Williams et al., 2010, VanDerWal et al., 2009a, VanDerWal et al., 2009b).

To represent potential future climates (2041 – 2060 and 2061 - 2080) I used data from WorldClim at 1x1 km^2 resolution (Hijmans et al., 2005), which provides downscaled projections from the general circulation models (GCMs) as CIMP5-coupled model intercomparison project phase five, corresponding to the fifth IPCC assessment report (IPCC, 2013). To limit computing time, I selected a subset of nine complementary GCMs that are suitable for Thailand (SEACLID, 2016): ACCESS1-0, CCSM, CNRM-CM5, GISS-E2-R, GFDL-ESM 2M, HadGEM2-AO, IPSL – CMSA-LR, MIROC5, and MPI-ESM-LR (Hijmans et al., 2005, SEACLID, 2016). Four representative concentration pathways (RCPs) of greenhouse gas scenarios from the IPCC Fifth Assessment Report (AR5) were considered: RCP2.6 - representing a lowest emission; RCP4.5 - medium emission based on stabilization of radiative forcing shortly after 2100; RCP6.0 - medium emission scenario; and RCP8.5 – business as usual rising greenhouse gas emission scenario(van Vuuren et al., 2011).

I extracted these variables for as all of Thailand and converted them into Raster ASCII grids (.asc) format as required for distribution modeling using maximum entropy algorithm (Maxent). The projection of all variables was set to GCS_WGS_1984 using ArcGIS version 10.2 with a resolution of 0.01-degree grid (1x1 km^2).

4.3.3 Projecting distributions

To model species distributions, I employed the maximum entropy algorithm (MaxEnt) version 3.1.3 (Phillips et al., 2006). MaxEnt models the relationship between species occurrence (presence-only) and spatially - explicit environmental predictors to estimate the spatial distribution of all target species.

To describe the current distributions, I projected species distribution models for all 304 species into climate space for the current time period (~1960 – 1990; 2000s), using the WorldClim data at 1x1 km^2 resolution (Hijmans et al., 2005). I also projected models into 68 future climate scenarios that reflect different combinations of available representative concentration pathways (four RCPs), and nine GCMs, describing climate projections for two future average time periods as 2050 (average for 2041-2060) and 2070 (average for 2061 – 2080). These current and future models are all based on the same eight standard bioclimatic variables described above and used in similar climate change impacts studies (Williams et al., 2003, Graham et al., 2006, VanDerWal et al., 2009a, VanDerWal et al., 2009b, Williams et al., 2010).

In order to identify optimal setting for all models, I set up a default to evaluate the predictive performance of the SDMs for each species of each models as a random subset of 75% of the data to generate the species distribution model, while the remaining 25% was kept as independent data to test the accuracy of each model (random test percentage = 25) (Kramer-Schadt et al., 2013, Velásquez-Tibatá et al., 2013). Furthermore, to minimise biases in distribution models I used a target group background, that is, background points in the model are based on the occurrence points of all bird records in our dataset (target group) (Phillips, 2008, Fourcade et al., 2014). By default, maximum number of background points as 10,000 are randomly selected from the whole rectangular study area (Fourcade et al., 2014). A cross – validation with a 10-fold partitioning procedure was implemented to define the calibration and evaluation datasets provided as an average percentage (Kramer-Schadt et al., 2013).

Therefore, in this chapter I projected 207,024 models for 304 forest birds in Thailand ((68 future models x 304 species x 10 fold) + 304 current models), then, I used consensus forecast to average predictions across GCMs (Barbet-Massin et al., 2012, Reside et al., 2012b). This process results in four future prediction grids for each species in each period, one for each

RCP (RCP2.6, RCP4.5, RCP6.0, and RCP8.5). Using the RASTER package (Hijmans et al., 2015) and the SDMTool (VanDerWal et al., 2011) in R to perform all projections. In order to transform the probable consensus distribution to a presence/absence distribution, I treated the suitability values for pixels above the balancing training omission rate, predicted area and logistic threshold as presence, and set the suitability for pixels under the threshold to zero as absence (VanDerWal et al., 2009a, Reside et al., 2010).

4.3.4 Model evaluation

I used the area under the receiver-operating characteristic (ROC) curve (AUC) and the true skill statistic (TSS) to evaluate the predictive performance of the SDMs for all species distribution models (current, 2050, and 2070). AUC has widely been used to estimate the predictive accuracy of species distribution models (Reside et al., 2010, Barbet-Massin et al., 2012, Bucklin et al., 2015). AUC is the area under the receiver-operating characteristic (ROC) curve, which measures the probability that a model ranks a randomly selected presence site higher than a randomly selected absence site (Liu et al., 2013). The AUC values for each model were received from the MaxEnt Results output file, models that have a value of AUC less than 0.5 = 'poor'; 0.5-0.6 = 'no discrimination'; 0.6-0.7 = 'discrimination'; 0.7-0.8 = 'good'; 0.8 – 0.9 = 'very good'; and 0.9 – 1.0 = 'excellent' (Phillips et al., 2006).

The use of AUC as a tool on its own is considered insufficient for measuring the accuracy of predictive models, therefore, I also utilised True Skill Statistic (TSS) as an additional measure of model accuracy (Allouche et al., 2006, Barbet-Massin et al., 2012, Bucklin et al., 2015). TSS is a measurement of prevalence of the performance independent variable, and was computed from the proportion of correctly classified presences (sensitivity) plus the proportion of correctly classified absences/pseudo absences (specificity) minus 1 (sensitivity + specificity -1) (Allouche et al., 2006). TSS values can be assigned into three categories: less than 0.2 - 'poor'; between 0-2 and 0.6 as 'fair'; and greater than 0.6 as 'good' (Jones, 2012).

Based on these model performance statistics, 304 of the 313 species distribution models were suitable for further analysis. The performances of these models were excellent within the AUC values (0.956 ± 0.094) (Phillips et al., 2006) and "good" using the true skill statistic (TSS) criteria (0.731 ± 0.192). Model accuracy of all four RCPs was similar with good performances (Figure 4.2).

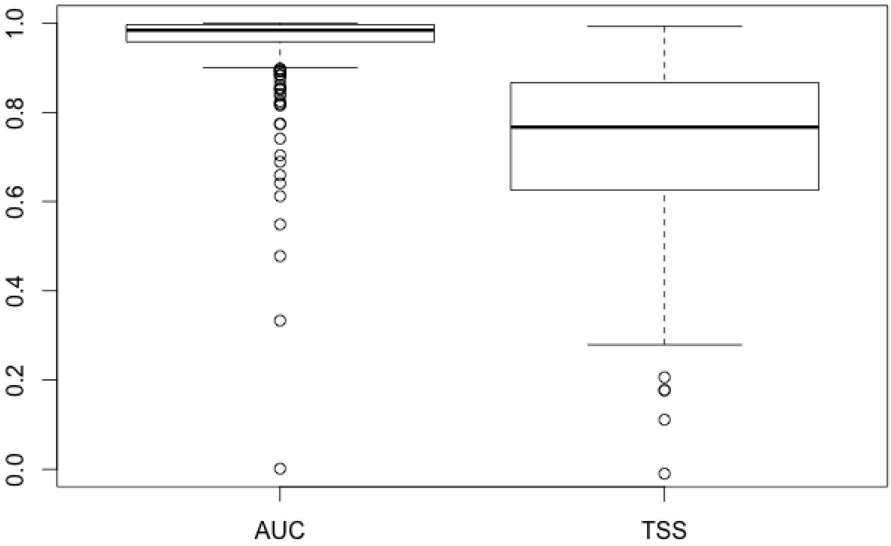


Figure 4.2 Mean of model performance of all 304 bird species distribution, models across the four RCPs, nine GCMs, and two time periods in total 207,024 SDMs with 10-fold cross – validation. Model performance is represented by two statistics: AUC - Area Under Curve, and TSS - True Skill Statistic (see methods for more detail).

4.3.5 Predicting change in species richness

To obtain maps of estimated species richness, I first transformed the SDM maps obtained from MaxEnt and the mean of the model consensus across GCMs to a presence/absence distribution (VanDerWal et al., 2009a, Reside et al., 2010). I then summed across all species distributions considered as presence distribution that transformed the probable consensus distribution to a presence/absence distribution using stacked continuous models method to reduce the over prediction (Distler et al., 2015). Future changes in species richness was deduced from the difference between estimates of current richness and future richness in each grid cell for each comparison, based on four RCPs scenarios and three time periods. The SDMTool package (VanDerWal et al., 2011) and the MASS package (Venables and Ripley, 2002) in R were used to calculate species richness.

4.3.6 Predicting change in distribution range

To calculate geographic range size of each species for current and future distributions for each future scenario (RCPs) and at each time period (2050 and 2070), I first transformed the SDM maps obtained from MaxEnt and the mean of the model consensus across GCMs, to a presence/absence distribution (VanDerWal et al., 2009a, Reside et al., 2010). I then calculated the range size and the propotion of range gain and loss for each projection of future species distribution. The range size was analyzed as the ratio between the number of grid cells where species were predicted to be present and the total number of grid cell in the study area of the current and future projections of each scenarios. Also the change in range size calculated as the ratio of the total number of grid cells in the study area of the future projection compared to the total number of grid cells of the current projection in the study area (Reside et al., 2012).

To assess future distributions range change in individual bird species, I evaluated by overlaying the current projection and the future projection of each species, then calculation the ratio of grid cells where: (1) current distribution predicted absence but future distribution predicted presence as “range gain”, (2) current distribution predicted presence but future distribution predicted absence as “range loss”, (3) both current and future distribution predicted presence as “range stable”, and (4) both current and future distribution predicted absence as “unsuitable range”.

I employed the R program with packages grid (Murrell, 2005), gplots (Gregory et al., 2016) sp (Edzer et al., 2016), ROCR (Tobias et al., 2015), vcd (David et al., 2015), boot (Angelo and Ripley, 2016), raster (Hijmans et al., 2016), and rgdal (Bivand et al., 2016) to calculate the number of grid cells.

I also used these measure to examine an average change in distribution range using multiple linear models with ANOVA tables for each ecological subset of birds classified by habitat preference, feeding guilds, elevational range limit, biogeography, and seasonal status (as described above).

4.3.7 Predicting change in total population size

The concept that the environmental suitability for each pixel predicted using Maxent is a reasonable predictor of total population size, that is, it provides an index of maximum abundance for that pixel given the environment present was tested using large datasets in the Australian Wet Tropics (Shoo et al. 2005b; VanderWal et al 2009a). Therefore, to predict changes in total population size for each species between current and future patterns of distribution and abundance, I followed the recommendations of VanDerWal et al. (2009a) that showed an index of total population size can be obtained from the summed environmental suitability across all grid cells in the species distribution model. Proportional changes in total summed environmental suitability provide an index of changes in total population size. Employing R packages: grid (Murrell, 2005), ggplots (Gregory et al., 2016), sp (Edzer et al., 2016), ROCR (Tobias et al., 2015), vcd (David et al., 2015), boot (Angelo and Ripley, 2016), raster (Hijmans et al., 2016), and rgdal (Bivand et al., 2016).

I also determined an average percentage of change in population size using multiple linear models with ANOVA tables for each ecological subset as described above: birds classified by habitat preference, feeding guilds, elevational range limit, biogeography, and seasonal status.

4.3.8 Assessing vulnerability impact of future climate change on threaten status

In order to estimate the threat status of birds under climate change I used two different approaches as used under the IUCN Red List Criteria. The first is based on declines in range size (Criteria B1) and the second is based on changes in population size (Criteria A3) (IUCN, 2001, AkÇAkaya et al., 2006). I applied the the red listing criteria to future range size estimates for each species from projected future SDMs in each time slot (2050, 2070) within Thailand. Defined criteria are: if a species has continuing decline in habitat or range from the current, and it has a restricted range size (i) lower than 100 km^2, will be classified as "Critically Endangered" (CR); (ii) 100 – 5000 km^2, will be the "Endangered" (EN); and (iii) 5000 – 20000 km^2 will be "Vulnerable" (VU) (IUCN, 2001, AkÇAkaya et al., 2006) and “Near threatened” (NT) as those where range size is predicted to decline below 20000 km^2. Furthermore, species that have increased range size will be "Increasing" species (IN); species which do not change their range, are "No Change" species (NO).

The second criteria considered to assess the predicted change in conservation status within Thailand is the loss of population size: IUCN Red List Criteria A3, that is, future change in population size, based on an index of abundance, or drop in occupied habitat range or habitat quality (IUCN, 2001, AkÇAkaya et al., 2006). Thus, I projected future change in abundance across time; I then applied these estimated rates of population change to assess the threatened status for each species in the year 2050 and 2070. Threat categories are defined as: (i) more than 80% decline in population size from the current: "Critically Endangered" (CR); (ii) 50 – 80 % decline will be “Endangered” (EN); and (iii) 30 – 50% decline will be “Vulnerable”

(VU) (IUCN, 2001, AkÇAkaya et al., 2006) and potentially threatened species (Near Threatened – NT) as those where population size is predicted to decline below 30% (AkÇAkaya et al., 2006). I also classified species that have increased population size will be "Increasing" species (IN); species which do not change their population size, are No Change species (NO). Species are considered "Threatened" if they meet any of the criteria for Vulnerable, Endangered, and Critically Endangered (TT).

4.4 Results

4.4.1 Spatial patterns of species richness

The spatial patterns of both current and future species richness for Thailand's forest bird species are illustrated in Figure 4.3. This richness pattern is based on the overlaid species distribution models of 304 bird species and projected across Thailand for an average across GCMs and all RCP scenarios. I showed in Figure 4.3a that the current richness pattern of Thailand's forest bird peaks in the higher latitudes and areas with higher elevation in protected areas and forest complexes along the northern, western, central, and southern region. Lower latitudes support many fewer species (Figure 4.3a). By 2050, projected richness is highest in the west especially the Lum Num Pai-Salawin, Sri Lanna-Khun Tan, Mae Ping-Om Koi, Phu Meang-Phu Thong, Phu Khiew-Nam Naew, Dong Prayayen-Khao Yai, Eastern, Western, and Kaengkrachan Forest Complex (Figure 4.3b–4.3e). Declines in overall bird diversity are especially evident by 2070 in the more severe emission scenario (RCP 8.5, Figure 4.3i) although there is a consistent and gradual shrinkage of high diversity areas with increasingly severe emission scenarios and time. Another important, although unsurprising, result highlighted in Figure 4.3 is a steady decline in diversity in lowland areas and an increased diversity in the uplands as species distributions shrink into cooler upland forest.

In summary, this results predict that species richness is likely to decline most in the lower elevation forests as species distributions contract upslope. As could be expected, the severity of these changes increases with the severity of the future emission scenario. There is an increased concentration of species in the more northern regions of the country where there are higher elevation forest complexes. Forest complexes that primarily increase in the concentration of species are particularly noticeable in the Mae Pin-Om Koi, Dong Prayayen-Khao Yai, Phu Meang-Phu Thong, Phu Khiew-Nam Maew, Western, Kaeng krachan, and Hala-Bala Forest Complex.

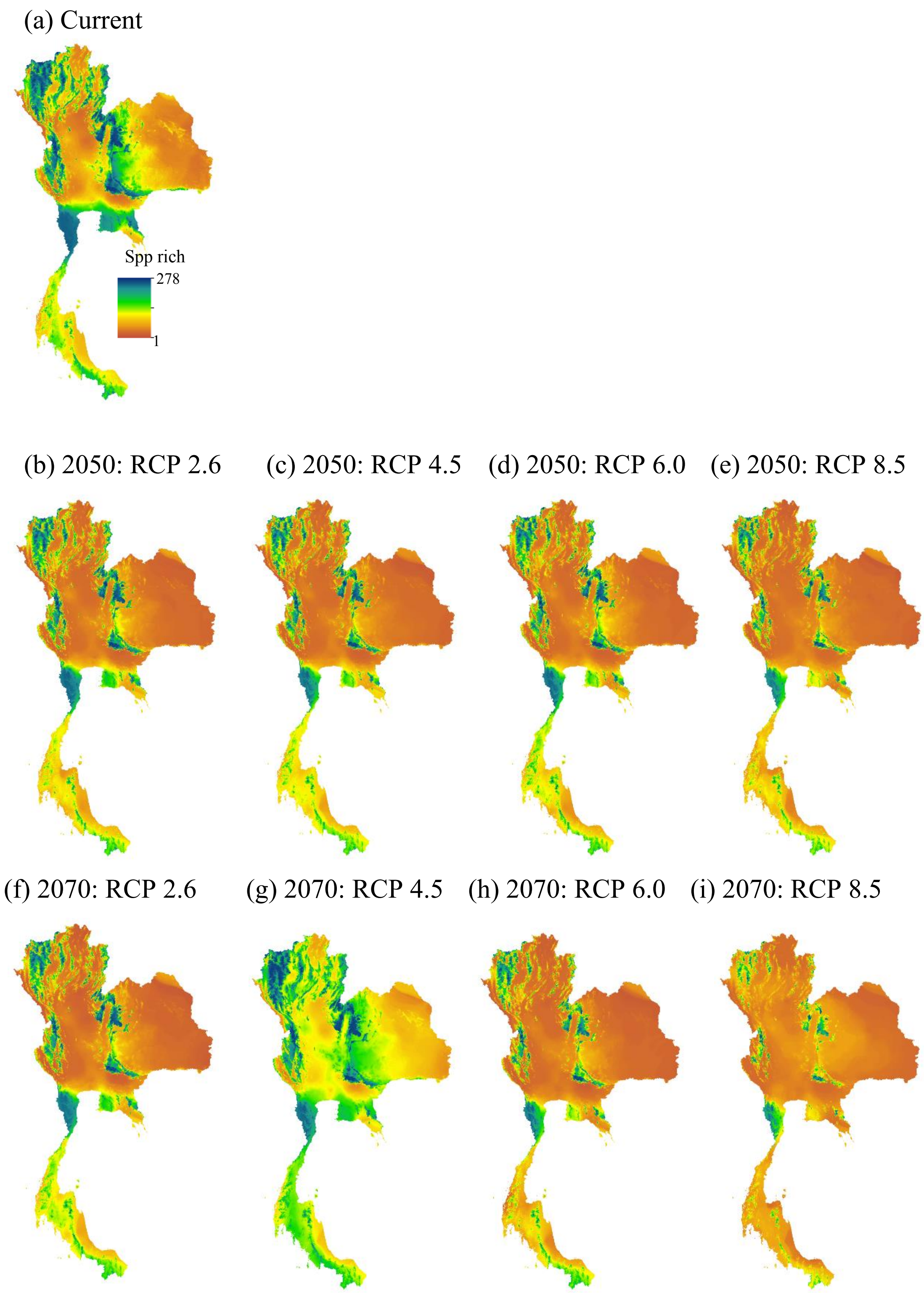


Figure 4.3 The estimation of current and future of spatial pattern of species richness of Thailand's forest birds. Maps are derived from 304 overlaid species distribution models for each of the RCP emission scenarios in each of three time periods (current, 2050, 2070): (a) the current pattern; (b) – (e) 2050; and (f) – (i) 2070.

4.4.2 Predicting change in geographic distribution for individual species

I have modeled the predicted change in distribution for each of the 304 species of forestbirds with sufficient data for current, 2050 and 2070 under the four different emission scenarios, using nine different global circulation models. The results for each individual species, with responses ranging from increase, through no change, to severe declines are observed across many different species and scenarios (207,024 SDMs). The full details of all species, times, GCMs and scenarios are included in Appendix Figure E1. An example of a declining species (*Malacocincla abbotti)* is illustrated in Figure 4.4. The maps show that, for this species, there are large areas of decline that increase with increasing emissions and also a large area where no significant change is predicted (Figure 4.4).

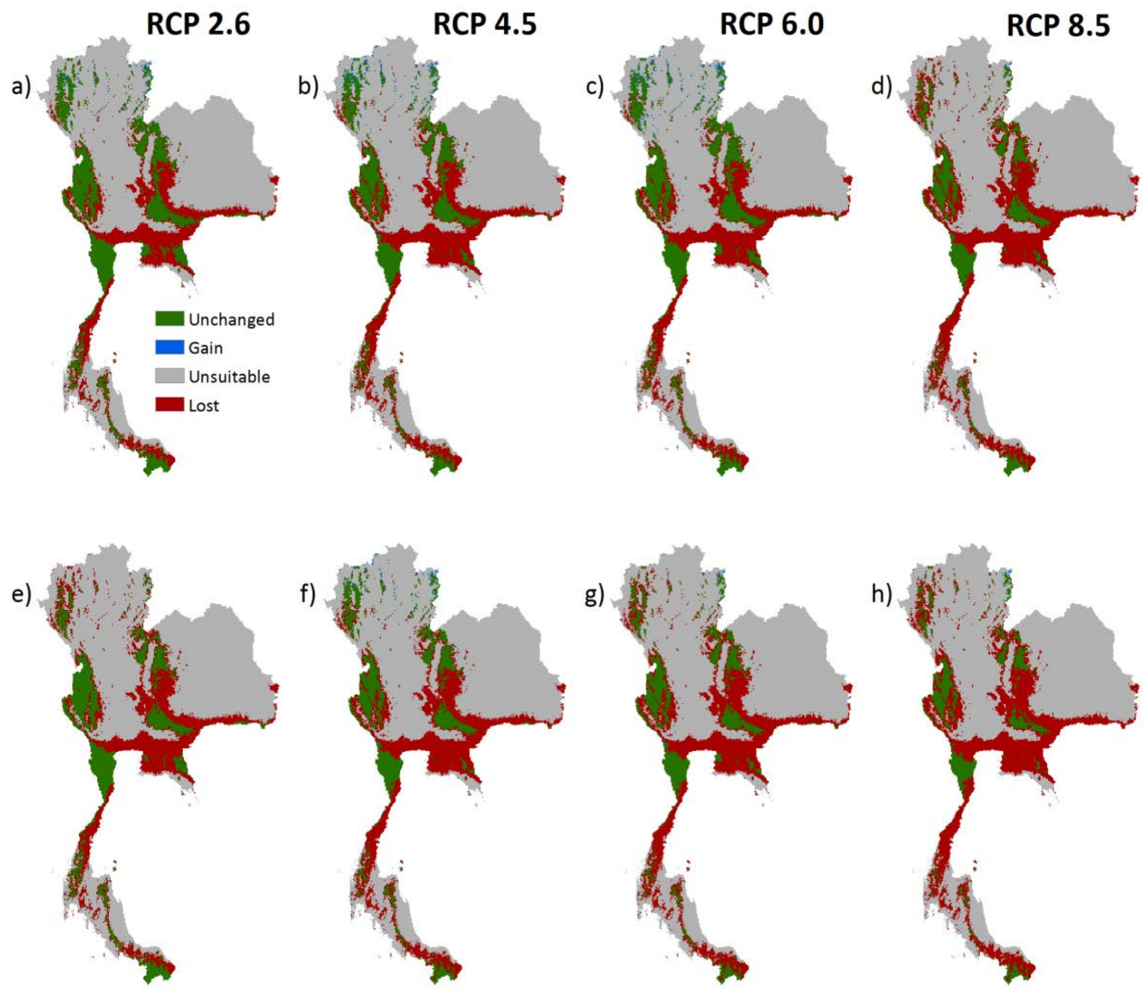


Figure 4.4 Example of predicted change in geographic distribution (*Malacocincla abbotti*) between the current distribution and the predicted distribution in 2050 and 2070, across each RCP scenario: a) – d) in the current (2000) and 2050, e) – h) in the 2000 and 2070. The green color shows areas that are suitable in both current and future models, blue shows areas suitable in the future but not currently, grey shows area that are unsuitable in all three periods, and red highlights areas that are suitable in current climates but predicted to be unsuitable in the future.

As could be expected, individual species responses vary across time and scenarios, with significant differences between the lowest mitigation scenario (RCP 2.6) and the most severe emission scenario (RCP 8.5) (Figure 4.5). The distribution of responses is bimodal with a consistently increasing impact over time on the vast majority of species, while a much smaller number of species increase (Figure 4.5). More than 85% of the 304 species of Thailand's forest birds are projected to experience declines in their suitable climate space under future climate warming, while around 10 – 20 % of species are expected to benefit from future climate (Figure 4.5, Appendix Table E2 and Appendix Figure E1).

In the lowest mitigation scenario (RCP 2.6), the suitable habitat ranges of 265 species are projected to decrease by an average of 37% by 2050 and by 44% for 265 species by 2070. s. In contrast, 39 species are projected to increase their range by an average of 66% by 2050 and 74% 2070 (Figure 4.5a). These trends are more noticeable as the emission scenarios become more severe through to the business-as-usual scenario (RCP8.5) (Figure 4.5). Under RCP8.5 up to 87% of all species will have experienced an average of more than 50% loss of range area with some species declining by as much as 80% (Figure 4.5).

To further estimate species responses to future climate and to assess whether predicted impacts are consistent within different ecological subgroups of the assemblage I examined the response within groups of species defined by habitat preferences, feeding guild, elevational limits, biogeographic regions and migratory type (Figure 4.6). There were significant differences in the mean predicted response of species across the species in all ecological subgroups. Each subgroup shows an average decline in range size of about 40% with some outlier species that increased. Lowland species consistently showed little decline while mid elevation and upland species consistently show a severe decline in range size of more than 50% (Figure 4.6c). Species responses did vary significantly across the different biogeographic groupings (Figure 4.6d). Species within the Sundaic-northern biogeographic group were highly variable in their response but had on average a no change response, while the Sundaic group largely consisted of species that increased their range size. All of the species groups defined by migratory type showed a significant estimated decline except for the migratory species, which on average increased their range size (Figure 4.6e).

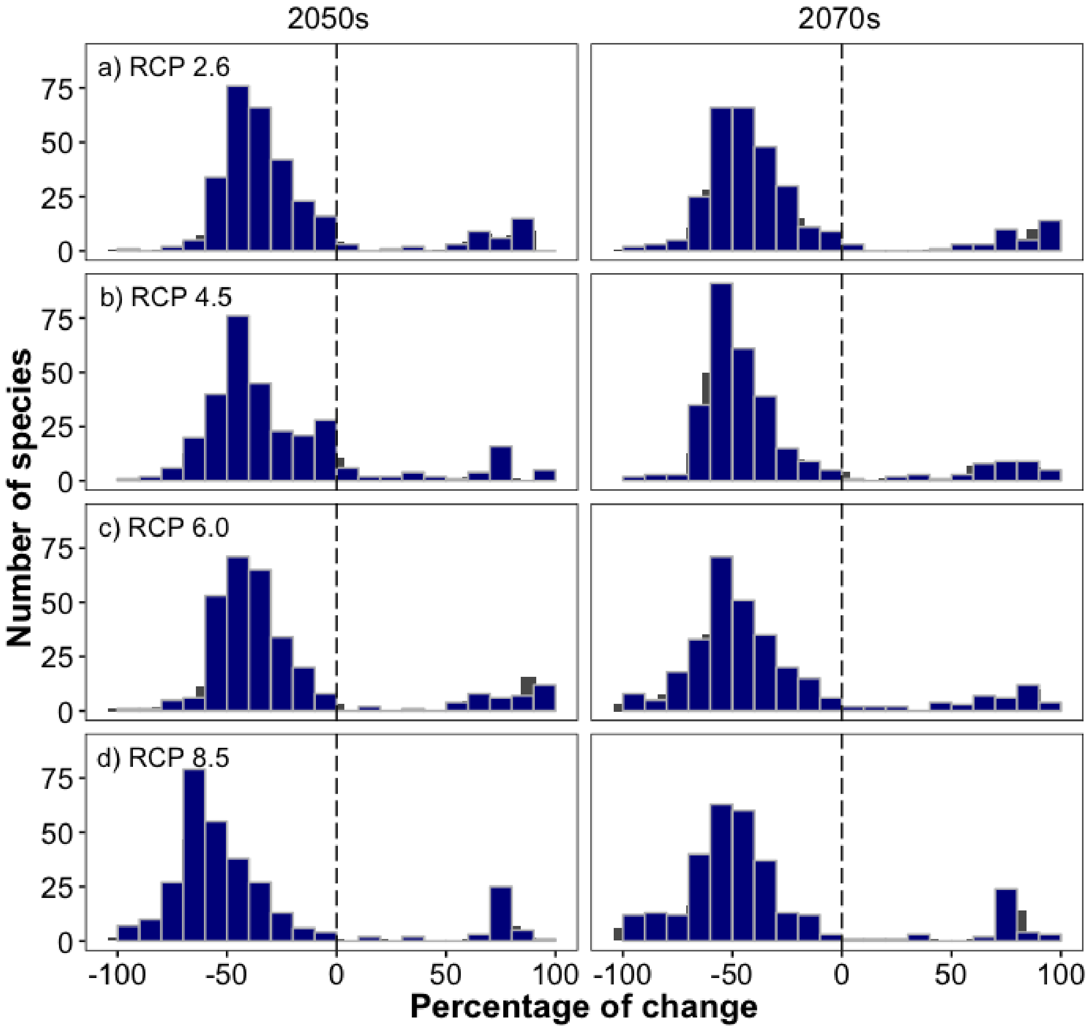


Figure 4.5 Frequency histogram presenting the relative change in range size across all 304 species from current range size to projected range size in 2050 and 2070 for each RCP emission scenario: a) RCP 2.6; b) RCP 4.5,; c) RCP 6.0; and d) RCP 8.5.

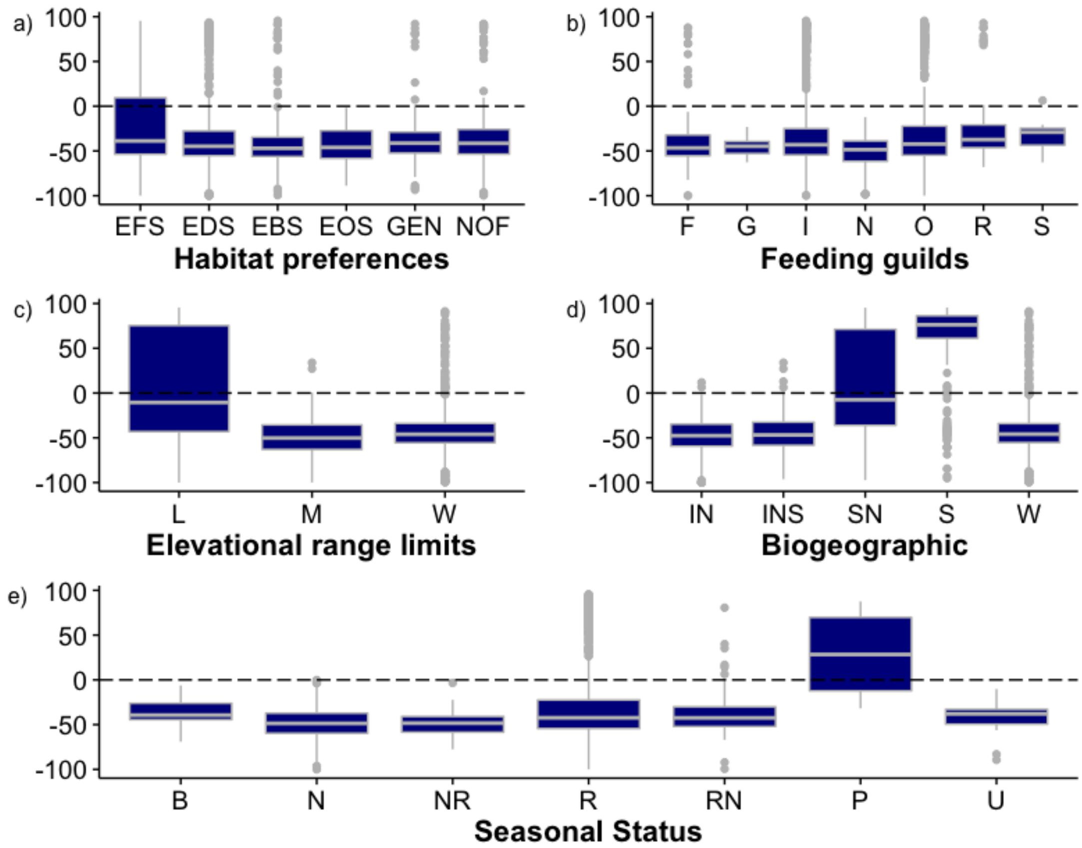


Figure 4.6 Relative change in the mean and variance in species range size from current range size to projected range size in 2050 and 2070 for the 304 species split into a variety of ecological subgroups including: a) Habitat groups (EFS - evergreen forest specialist; EDS – evergreen forest specialist but occurs in deciduous forest; EBS - evergreen forest specialist but occurs in bamboo forest; EOS - evergreen forest specialist but occurs in edge forest, open area, and other (not including forest); GEN - occurs in evergreen forest but common in other forest, occurs in evergreen forest but common in edge forest, open area and other (not including forest area); and NOF - never occurs in evergreen forest), b) Feeding guilds (F - frugivorous; G – granivorous; I – insectivorous; N – nectarivorous; O – omnivorous; R – raptor, and S - scavenger), c) Elevational groups (L - lowland ; M - montane ;W - widespread), d) Biogeographic subregions (IN – Indochinese; INS - Indochinese-southern cross; S – Sundaic; SN - Sundaic-northern cross; and W - widespread), and e) Seasonal migratory classes (B – breeding visitor; N – non-breeding visitor; NR - mainly non-breeding visitor but maybe resident; R - resident or presumed resident; RN - mainly resident but maybe non-breeding visitor; P - mainly spring and autumn passage migrant, and U – uncertainty). See Table 3.1 of Chapter 3 for more details of number of species within each subgroup.

4.4.3 Predicting change in total population size

Many schemes aimed at assessing species vulnerability rely on changes in total population size over time. Previous studies have emphasized that estimates of population size are a much more sensitive indicator of impacts of a changing climate than range size (e.g. Shoo et al. 2005). VanDerWal et al. (2009a) demonstrated that summed environmental suitability can provide an effective estimate of total population size making it possible to produce more robust estimates of changes in population size under different potential future climates. Using this approach, I have estimated the changes in population size between the current and 2050 and 2070 for each of the 304 species across each combination of emission scenarios (RCPs) and each different GCM (as described in previous sections).

Population size change predictions differed significantly between the emission scenarios (RCP 2.6, RCP 4.5 and RCP 8.5). (Figure 4.7). Overall, these analyses suggest that more than 85% of 304 Thailand's forest bird species are projected to decrease their population size with an average decline of 73%. Conversely, 10 – 20% of species will have an increase in population size with an average increase of 86% (Figure 4.7 and Appendix Table E2). The full distribution of species responses for each RCP, perspective future environmental change, and period is presented as a frequency histogram (Figure 4.7). The number of species and the relative severity of these declines increase with the severity of the emission scenario with RCP8.5 being significantly worse (Figure 4.7).

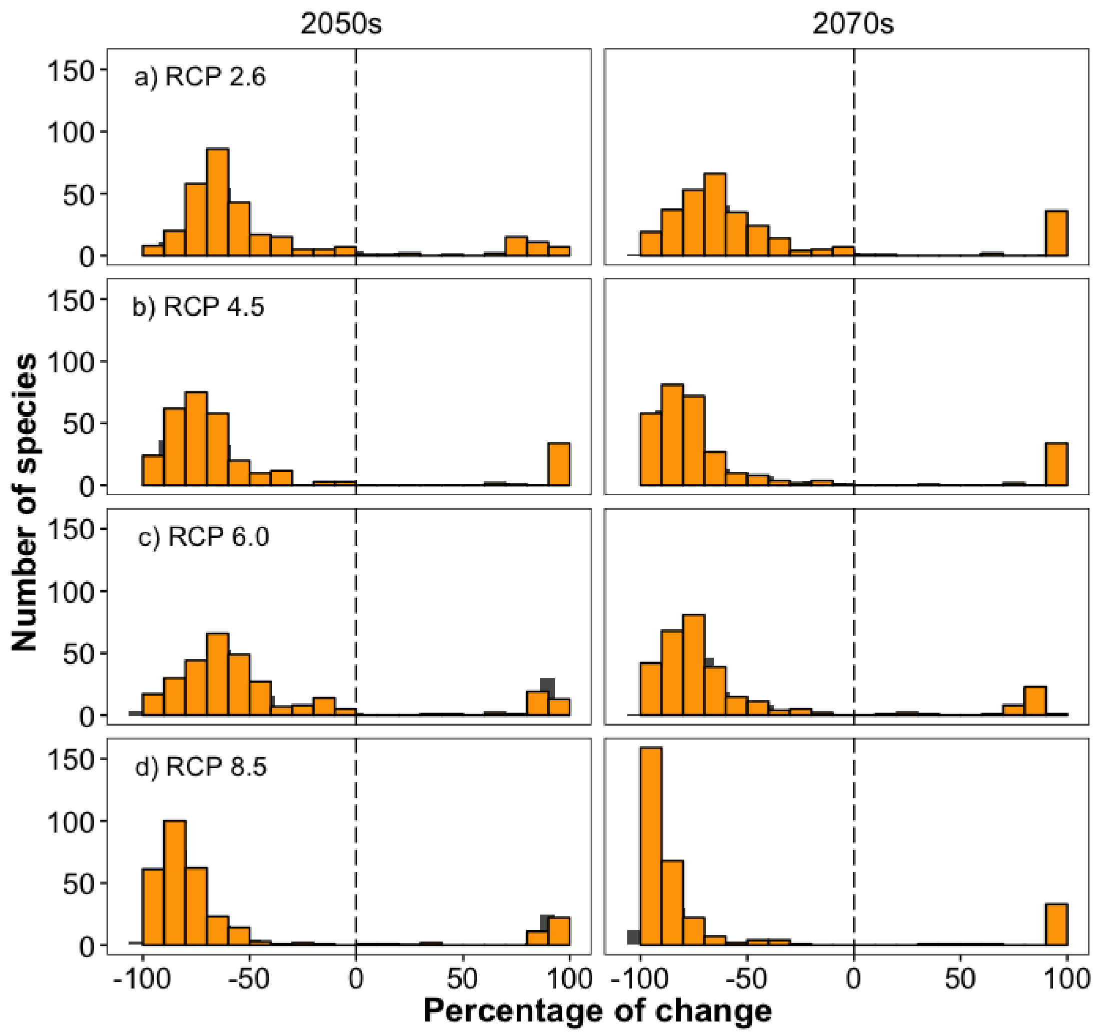


Figure 4.7 Frequency histogram presenting the relative change in total population size for each species under each RCP emission scenario expressed as the percentage change from current to 2050 and 2070: (a) RCP 2.6; (b) RCP 4.5; (c) RCP 6.0; and (d) RCP 8.5.

To examine in more detail in each ecological subgroups on change in total population size to projected future climate change, I examined the response within groups of species defined by habitat preferences, feeding guild, elevational limits, biogeographic regions and migratory type (Figure 4.8). Found that most of all subgroups were estimated to decline, while lowland species grouped by elevational range limit, Sundaic-northern border and Sundaic species grouped by biogeographic range, and winter migrant species grouped by seasonal status were estimated to increase in total population size (Figure 4.8).

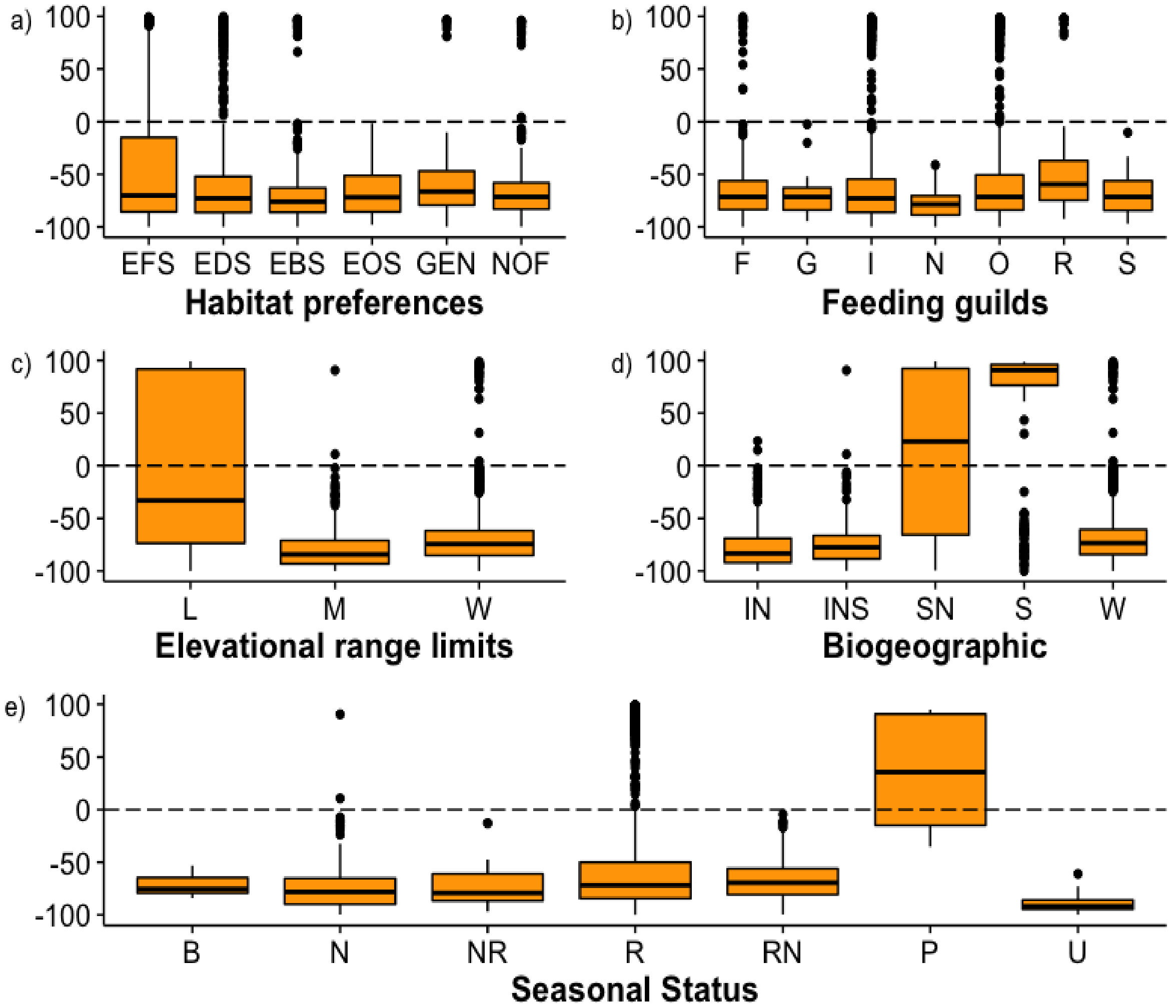


Figure 4.8 Relative change in the mean and variance in population size from current population size to projected population size in 2050 and 2070 for the 304 species split into a variety of ecological subgroups including: a) Habitat groups (EFS - evergreen forest specialist; EDS – evergreen forest specialist but occurs in deciduous forest; EBS - evergreen forest specialist but occurs in bamboo forest; EOS - evergreen forest specialist but occurs in edge forest, open area, and other (not including forest); GEN - occurs in evergreen forest but common in other forest, occurs in evergreen forest but common in edge forest, open area and other (not including forest area); and NOF - never occurs in evergreen forest), b) Feeding guilds (F - frugivorous; G – granivorous; I – insectivorous; N – nectarivorous; O – omnivorous; R – raptor, and S - scavenger), c) Elevational groups (L - lowland ; M - montane ;W - widespread), d) Biogeographic subregions (IN – Indochinese; INS - Indochinese-southern cross; S – Sundaic; SN - Sundaic-northern cross; and W - widespread), and e) Seasonal migratory classes (B – breeding visitor; N – non-breeding visitor; NR - mainly non-breeding visitor but maybe resident; R - resident or presumed resident; RN - mainly resident but maybe non-breeding visitor; P - mainly spring and autumn passage migrant, and U – uncertain). See Table 3.1 of Chapter 3 for more details of number of species within each subgroups.

4.4.4 Assessing species vulnerability to climate change: What will be the broad outcome of the predicted changes in distribution area and population size for the conservation status of Thailand's forest birds?

Climate change poses a major threat to the bird species of Thailand's evergreen forest complexes. Currently there are 12 species of forest bird that considering to be threatened. Applying the IUCN criteria (IUCN 2001) to assess national conservation status based on changes in range size (Criteria B1) to the projected species distribution models described in this chapter, there would be up to 30 threatened species by 2070 including 7 endangered species and 5 critically endangered species (see Appendix Table E2 for full species details).However, using the more sensitive and robust estimates of population size and applying IUCN Criteria A3 for declines in population size the predictions are much more dire. Estimated changes in population size predict up to 266 species becoming threatened with almost 75% (227 species) of these being critically endangered (see Appendix Table E2 for full species details).

Figure 4.9 summarises in more detail the changes in the number of species in each threat category and compares the relative outcomes estimated by using either range size or population size. Population size changes predict much more dramatic increases in threat status because they are based on the environmental suitability of each individual pixel in the landscape whereas range size simply assumes the species will occupy all areas within the distribution equally. All evidence from previous studies suggest that the estimates based on Criteria A3 (population size) will be the most robust and provide the best estimate of future impacts (Shoo et al., 2005a, Both et al., 2006, Reif et al., 2008, Both et al., 2010, Jiguet et al., 2010, Jenouvrier, 2013, Flousek et al., 2015, Bestion et al., 2015).

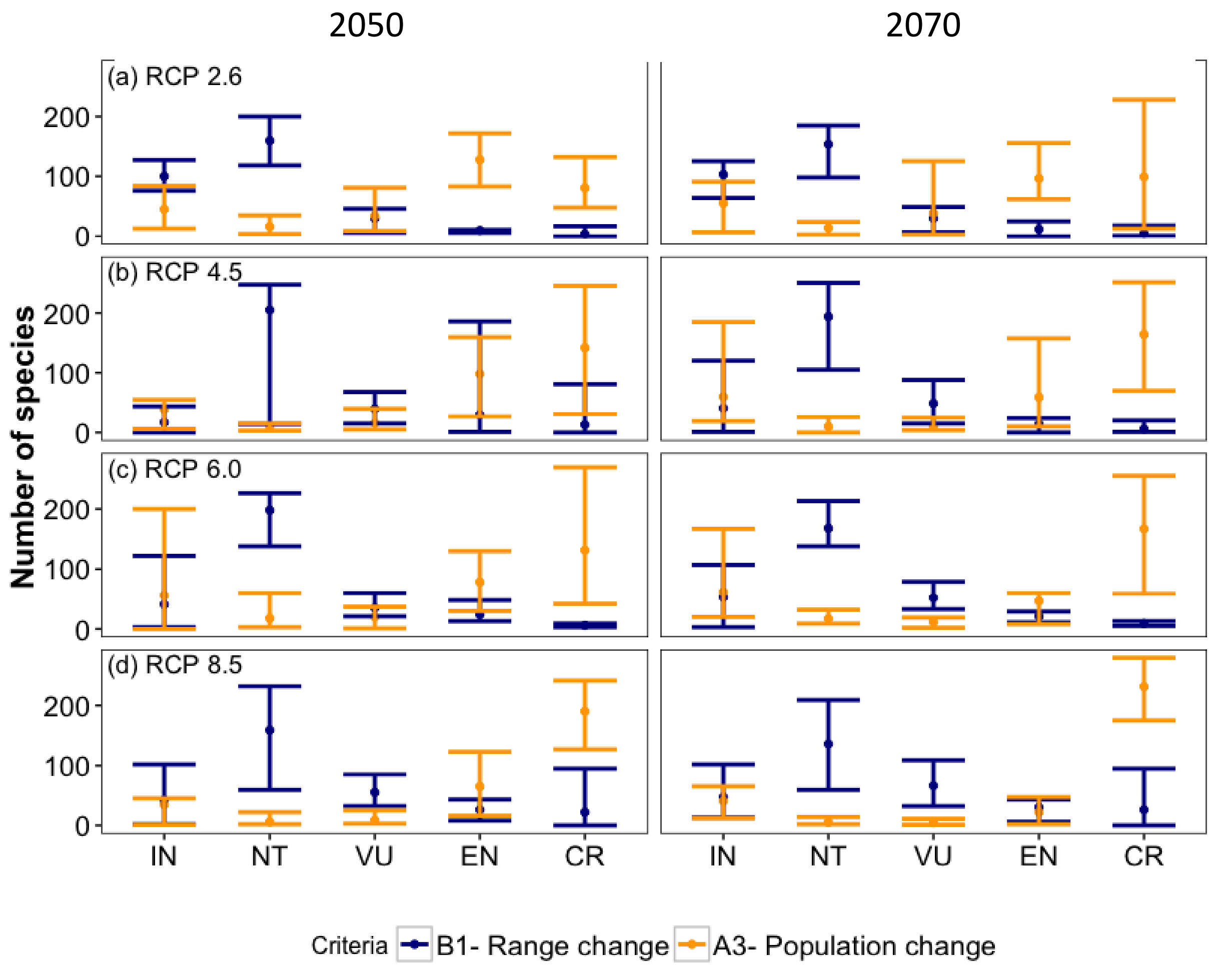


Figure 4.9 Projections of the future variation in the number of species within each conservation status category within Thailand based on the IUCN criteria B1- continuing decline in occupancy range and criteria A3- future reduction of population size by 2050s and 2070s Plots represent the mean across nine GCMs within each emission scenario (see methods for details): (a) RCP 2.6; (b) RCP 4.5; (c) RCP 6.0; and (d) RCP 8.5. **:** IN = increasing population size or extent of occupy; NT = Near Threatened species; VU = Vulnerable; EN = Endangered species; and CR = Critically Endangered species.

Therefore, many more species are predicted to become threatened based on changes in population size rather than range size: this massive difference is summarized in Figure 4.10. A full detail of the responses of each species under each future scenario is included in Appendix Table E2. In contrast to the prediction of declines, the numbers of species predicted to *increase* under future climate change is similar using either range size or population size as the assessment criteria.

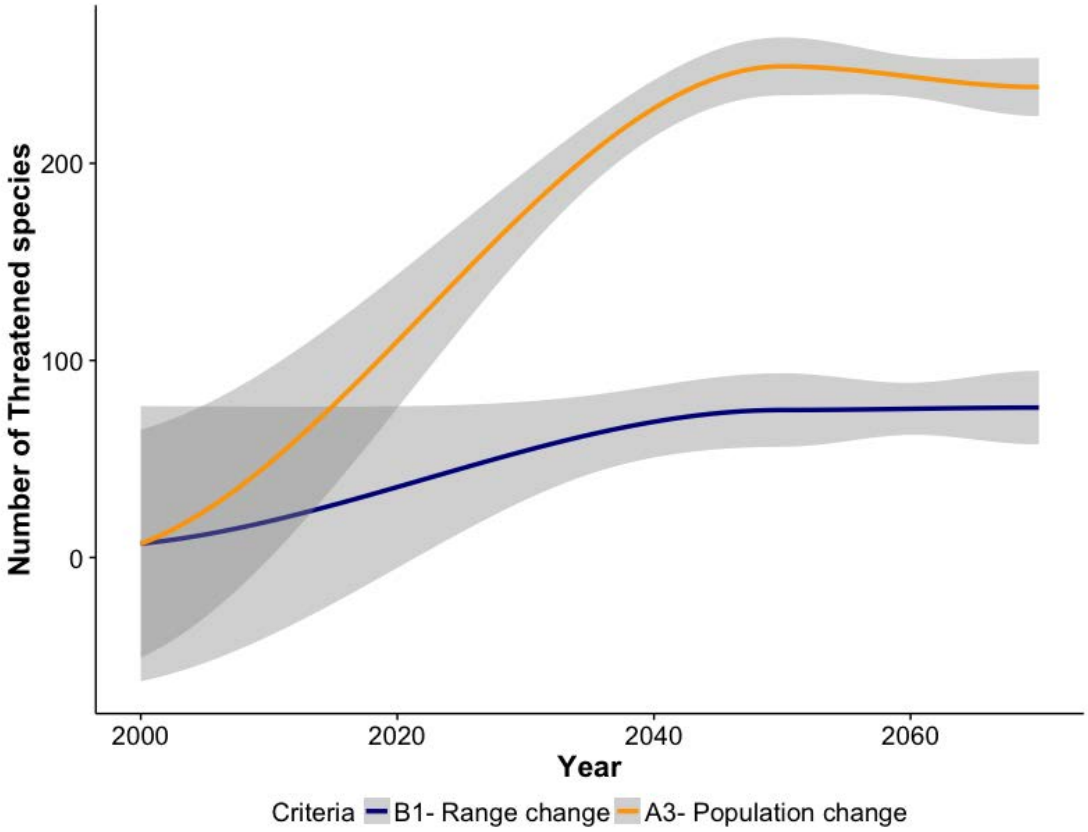


Figure 4.10 Future trend in the number of species predicted to become threatened within Thailand based on the IUCN criteria B1- continuing decline in occupancy range (blue) and criteria A3- future reduction of population size (orange). Projections based on mean across four future climate scenarios (RCPs) and nine global climate models (GCMs) (± SE).

4.5 Discussion

This study presents the first comprehensive projection of the impacts of climate change on Thailand. The analyses not only use a collation of all available bird occurrence data but also include a systematic standardized survey program designed to maximize the coverage of elevational and latitudinal gradients representing most of the geographic and environmental space in Thailand. Additionally, I have used each of the potential future emission scenarios and multiple global climate models to provide information on the variability and uncertainty inherent in making comprehensive vulnerability assessments (IPCC, 2014). As such the results provide the most robust assessment of the future climate change impacts on the patterns of species distributions and diversity of forest birds in Thailand.

4.5.1 Projected changes in the spatial patterns of species richness

Overall, the general projected trend in the spatial pattern of species richness is a loss of richness in lowland areas and a concentration of richness into upland areas. This is not surprising as all evidence would suggest that as each species shifts uphill to maintain its preferred climate there will be a spatial concentration of species at higher elevations and a decline in lowland richness. This should not be confused with the pattern predicted in this study of lowland species being less impacted in general than upland species.This pattern is consistent with previously documented responses to climate change, as tropical lowlands are predicted likely to decrease in richness and highland areas will slightly increase in species richness due to upslope movement (Williams et al., 2003, Parmesan, 2006, Colwell et al., 2008, La Sorte and Jetz, 2010a, Harris et al., 2011, Sodhi et al., 2011, Şekercioğlu et al., 2012). It is beyond the scope of this project to predict whether new species will move into this projected lowland species vacuum. The implication of species concentration in the uplands is also difficult to assess. The complex changes in species biotic and abiotic interactions that will result from concentrated species richness are impossible to predict in analyses presented here that are based entirely on the additive patterns produced by modeling each species individually. However, there will likely be significant negative impacts on the more specialized upland endemics due to the increased competitive pressure for resources from lowland generalists being pushed into these higher elevations.

Given the general expected trend of species moving into higher elevation areas it is fortunate that many of the upland areas are already protected. The projections of concentrated species richness in these areas suggest that in the future it will be critical to manage these protected areas for biodiversity under climate change (Regos et al., 2016, Gaüzère et al., 2016, Thomas and Gillingham, 2015, Thuiller et al., 2014). This will be examined in more detailin Chapter 5.

Given the relatively uniform pattern of species richness across environmental gradients demonstrated in this study (see Chapters 2 and 3), it is not surprising that the spatial patterns of absolute levels of richness do not dramatically change in many places. Although the predicted shift of lowland species into the uplands results in a contracted spatial pattern of richness in upland areas as discussed above, there is only marginal increases in overall richness in uplands and a decrease in the lowlands. Therefore the implication is that many upland endemic species are predicted to disappear from these higher elevations. The predicted changes in the spatial pattern of richness obscures the significant impacts on species distributions and population size.

The analyses based on projected changes to species distribution size and total population size tell a dramatically different story to the species richness patterns discussed above, with predictions of significant declines (mean 73% loss) for the majority (85%) of species. Projected losses are much more severe when based on losses in population size rather than range size. This conclusion is similar to previous studies that have examined predicted losses based on population size rather than simply considering range size although the majority of these studies have been conducted in more temperate regions in Europe, North America and Australia (Crick, 2004, Shoo et al., 2005a, Both et al., 2006, Wormworth, 2006, Jenouvrier, 2009, Aiello-Lammens et al., 2011, Barbraud et al., 2011, Peery et al., 2012, Sun et al., 2016).

Utilising an index of total population size, as provided by summed environmental suitability (VanDerWal et al. 2009) isa significant improvement on total range size in making more robust assessments of the future vulnerability of a species: it takes into detailed consideration both habitat extent and quality and does this in a realistic, spatially-explicit way by taking into consideration the environmental suitability across the range of the species and how this suitability changes under future climatic changes. This study extends previous findings into the tropics of Asia and provides strong support that tropical biodiversity is going to be severely impacted (Williams et al., 2003, Gasner et al., 2010). The results here also suggest that the global meta-analysis conducted by Urban (2015) could be significantly underestimating the potential impacts in South-east Asia.

However, the analyses clearly show that there will also be some species who are winners, with up to 15% of species projected to increase both in range size and total population size (see Appendix Table E2 for the species in each vulnerability category). Examination of the relative impacts across a variety of ecological and biogeographical subgroups of species sheds some light on commonalities between groups of species. Species that increased their range or population size were primarily either lowland generalists or lower latitude species within the Sundaic/Sundaic-northern biogeographic groups. Similar patterns have been shown in central European montane bird assemblages (Flousek et al. 2015) and in Central America (Gasner et al. 2010). It is hardly surprising that these groups of species that are adapted to hotter environments are predicted to take advantage of expanding warmer climates and will likely shift their ranges further north and upwards in elevation ((Shoo et al., 2005b, La Sorte and Jetz, 2010b, Laurance et al., 2011, Reside et al., 2012b, Velásquez-Tibatá et al., 2013). There has potentially already been northerly shifts in the distribution of the Sundaic species as described by Round et al. (2003) with my surveys recording many Sundaic species much further north than previously thought (see Chapter 3), however, the lack of systematic, standardised baseline monitoring makes it impossible to be sure (see chapter 3). Chen et al. (2011) has described the distributions of many terrestrial species shifting to higher latitudes and higher elevations with temperature increases. Latitudinal shifts, both observed and predicted, have been widely discussed in the global change literature and the results from this study are concordant with most global studies from a variety of ecosystems. One exception is my prediction that migratory species are likely to increase their range and population size. Studies in Europe on migratory birds suggest that they will undergo more significant declines than resident species (Beaumont et al., 2006, Both et al., 2006, Both et al., 2010, Lemoine et al., 2007, Saino et al., 2011, Chambers et al., 2014, Flousek et al., 2015). The potential for impacts on migratory species is more difficult to assess than resident species as they can have very different climatic niches in breeding versus non-breeding times of year and the analytical approach here is potentially not ideal to examine migratory species so caution is recommended in interpreting this result and a more detailed examination of migratory species is recommended in future. The overall conclusion from my analyses, and other studies on tropical birds (Sekercioglu et al., 2008, Sodhi et al., 2011, Reside et al., 2012b, Şekercioğlu et al., 2012), is that most tropical forest bird species will be severely impacted by climate change. Given the importance of tropical biodiversity and its recognized vulnerability, it is critical to evaluate the future conservation status and trends of these species in order to inform environmental management and policy.

4.5.2 Assessing the future conservation status of Thailand's forest birds

Current assessment of the conservation status of birds for the Thailand Red List status was evaluated based on expert knowledge (Sanguansombat, 2005). This study represents the first quantitative assessment of the vulnerability of Thailand's forest birds to climate change and is based on both a systematic survey across Thailand, collation of existing data and detailed spatially-explicit modelling of future changes incorporating the uncertainty of future global emissions and climate models. Given the data and analyses from this study, it is now possible to make a more objective, comprehensive and spatially-explicit prediction of the future conservation status of forest bird species in Thailand. Using previously tested methodology (AkÇAkaya et al., 2006)for projecting both range size and population size, I applied the information of change in range extent and population size to evaluate threaten status based on the IUCN Red List criteria (IUCN, 2001, AkÇAkaya et al., 2006, Rodriguez et al., 2015, IUCN, 2017).

My results suggest that many species will become highly threatened within Thailand, for example by 2070 under a business-as-usual emission scenario (RCP 8.5) that approximately 2/3 of the birds species will be critically endangered (Figure 4.9). This is an incredibly serious problem, potentially resulting in the extinction of many species in one of the highest biodiversity regions of the world and suggests even more dire consequences than previous studies that emphasized the threat to tropical biodiversity (Williams et al. 2003, Sekercioglu et al., 2008, La Sorte and Jetz, 2010a, La Sorte and Jetz, 2010b, Sodhi et al., 2011, Şekercioğlu et al., 2012). This study demonstrated that the number of threatened species predicted by analyses based on population size is approximately three-times higher than predictions based on range size/extent (Figure 4.10). The huge difference in the predictions of threatened status depending on the use of either range extent or population size (combination of both habitat extent and quality) and highlights the importance of considering population size as originally suggested by Shoo et al. (2005). A further sobering consideration is the fact that these analyses assume unlimited dispersal and that species can disperse to maintain their preferred climate. Dispersal limitation is likely to be an important factor in future vulnerability (Keith et al., 2008, Williams et al., 2008, Marini et al., 2009, Reside et al., 2012b, Pacifici et al., 2015). Given the highly modified and fragmented nature of the landscapes across Thailand, the results presented here are potentially a significant underestimate of what the true impacts will be. Ongoing changes in land cover are expected to further exacerbate historical habitat loss and degradation and will undoubtedly increase the impacts predicted in this chapter. A more detailed analysis of the combined impacts of both future climate and land cover change will be explored in the next chapter (Sekercioglu et al., 2008, La Sorte and Jetz, 2010a, La Sorte and Jetz, 2010b, Sodhi et al., 2011, Şekercioğlu et al., 2012).

4.5.3 Implications for conservation and management

Clearly, a large proportion of the forest birds of Thailand are highly vulnerable to future climatic change and there will likely be significant impacts, particularly on upland endemic species. Conservation policy and management needs to consider these patterns in order to make informed decisions. As many as 200 species (listed in Appendix Table E2) are likely to become critically endangered and it will be important to protect the future habitat distributions of as many of these species as possible to help increase their resilience and minimize the impacts as much as possible. The projected distributions of these species of high priority can be used in systematic conservation planning (Pressey et al., 2007) to identify the most strategically important areas to direct the allocation of conservation resources (Gaüzère et al., 2016). Protecting the areas that will maintain the highest biodiversity could be important to conservation management goals based on the potential to protect greater functional roles and to support greater ecosystem wellbeing (Vieilledent et al., 2013, Gaüzère et al., 2016, Regos et al., 2016). In this context, this study highlighted nine main forest complexes that are of high importance, including Lum Num Pai-Salawin, Sri Lanna-Khun Tan, Mae Ping-Om Koi, Phu Meang-Phu Thong, Phu Khiew-Nam Naew, Dong Prayayen-Khao Yai, Eastern, Western, and Kaeng Krachan Forest Complex.

Chapter 5:
Global environmental change and the future of Thailand's forest birds: the combined impact of climate and land-cover

----

5.1 Abstract

Changes in climate and land-cover are key threats to global biodiversity and ecosystem health. However, little is known of how these two important drivers of change on ecosystems will combine in the future to further threaten biodiversity. This is of particular importance in the tropics, where global biodiversity is concentrated and there is ongoing habitat modification. This study examined the impacts of both land-cover and climate change on the spatial pattern of species richness, distribution, and population size for 304 species of Thailand's forest birds. The study then evaluates the vulnerability to global change of individual species under a range of future climate and land cover scenarios. Species distribution models for each species in each combination of future scenario were constructed using Maximum entropy modeling (MaxEnt) based on three conbinations: climate change only, land-cover change only, and climate change combined with land-cover change. Four scenarios of future climate change were used (representative concentration pathways - RCP 2.6, 4.5, 6.0, and 8.5) from the Fifth IPCC Assessment Report (AR5). Four future scenarios of land cover change were used that vary based on a combination of predicted on population and economic policy (mild, moderate, severe, and most severe) were used for land-cover based on the Thailand strategic planning for the next 20 years.

The combination of both climate and land cover change was the most severe and largely, although not completely, additive with a small percentage of impact being overlaping in either method. Summarising the threat levels across all species within Thailand using IUCN Red List Criteria, it was revealed that 30 – 95 % of Thailand's forest birds would become threatened by the combination of climate change and land-cover change. This is more severe than climate change only (20 – 80%) and land-cover change only (9 – 12%). This study provides the first evidence to show that future climate and land-cover change could produce significant reduction in the distribution and population size of tropical species and the importance of managing these impacts if significant biodiversity loss is to be avoided. The combination of business-as-usual global emissions combined with ongoing land cover change

could be devastating with approximately 85% of all forest birds species becoming critically endangered and potentially extinct in Thailand.

The results suggest that under climate change only, a large decrease in species richness was predicted for lowland areas of Thailand and increased species richness was predicted in some highland areas of western Thailand. This was associated with the maintenance of forest cover in protected areas, concomitant with a shift in species distributions into higher elevation areas. Climate change models predicted much larger negative impacts on species richness, species distributions and population size than did land-cover change models.

The analyses identify species and geographic areas that are most vulnerable and areas where protection of upland refugial forest cover will provide some resilience to some species. It is imperative that environmental management and policy makers utilise this information to strategically plan the most effective adaptation actions aimed at maintaining functional ecosystems in the face combined and individual effects of climate and land-cover change, combining global emission reduction, adaptive forest management and the design of spatially protected area networks to help compensate for the high number of species at risk in a rapidly changing world.

5.2 Introduction

Potentially the most important threat to global biodiversity is the synergistic interactions between climate change and human pressures (Brook et al., 2008, Asner et al., 2010, Brodie et al., 2012, Martin et al., 2013). Yet most studies reporting effects of climate change (Williams et al., 2003, Root et al., 2003, Thuiller et al., 2004b, Thomas and Williamson, 2012) or land-cover change, habitat loss, habitat fragmentation and disease on biodiversity (Andren, 1994, Yamaura et al., 2009) studied each stressor in isolation. However, a single stressor prospective is inadequate when ecosystems and species are threatened by multiple, and cumulative stressors (Jetz et al., 2007, Lemoine et al., 2007, Mora et al., 2007, Brook et al., 2008, Darling et al., 2010, Heikkinen et al., 2010, Williams et al., 2017). For example, studies on European biodiversity focusing on effects of climate and land use change separately showed that climate change was more important for birds than land-use change (Vermaat et al., 2017). Similarly, in Finland, waterbirds are predicted to decrease in population size due to climate change, whereas land-use change impacts to landbirds especially forest birds have likely suffered from native habitat loss, but urban species have probably benefited from land-use change (Fraixedas et al., 2015). A study by Jetz et al. (2017) concluded that although climate would have severe impacts on biodiversity, in the near future habitat loss may lead to a greater threat to birds than climate change for tropical birds (Jetz et al., 2007). A study on endemic birds in Indonesia predicted that mid-elevation endemic birds could face large declines in population due to climate change, and that high-elevation endemics are predicted to face more severe population declines due to climate change than deforestation (Harris et al., 2014). However, most of these studies do not explicitely analyse the combined impacts of climate and land-cover change.

Species response to the combined effects of climate and land-use change could be purely additive or greater than the sum of the two (synergism) or less (overlapping or antagonistic impacts) (Oliver and Morecroft, 2014). Synergistic interactions between climate and land-use change could represent one of the most important threats to global biodiversity (Brook et al., 2008, Bellard et al., 2012, Ordonez et al., 2014, Oliver and Morecroft, 2014, Trisurat et al., 2014, Radinger et al., 2016, Sirami et al., 2017). Most studies thus far, focus on European biotas (Barbet-Massin et al., 2012, Fox et al., 2014, Radinger et al., 2016, Sirami et al., 2017). One study investigated these synergistic impacts on tropical birds in the Brazilian Amazon, suggesting that losses of biodiversity greater than the sum of the contribution from each individual threatening process (Brodie et al., 2012). Approximately 400 – 550 tropical birds were predicted to become extinct by 2100 depending on temperature and land use (Sekercioglu et al., 2008). The combination of climate change and habitat loss (land-cover change) may explain the extinction rate of tropical birds better than either variable on its own, however, it is poorly understood how species will respond to climate change in combination with land-cover change globally in particular Southeast-Asia and Thailand (Hughes et al., 2012, Mantyka-pringle et al., 2012). Southeast-Asia is a globally significant biodiversity hotspot, but has been severely impacted by habitat degradation resulting in high threat levels to the regions biodiversity (Myers et al., 2000, Sodhi et al., 2010a, Koh et al., 2013). Further investigation into the combined impacts of climate change and other stressors is essential so that managers and policy makers can make the best decisions possible on adaptation actions aimed at minimising future impacts.

The evaluation of synergistic impacts of multiple drivers to species loss, especially climate change and land-cover change on ecosystems, has been a challenge to conservation action throughout the 21st century (Sala et al., 2000, Brook et al., 2008, Brodie et al., 2012, Mantyka-pringle et al., 2012, Mantyka-Pringle et al., 2015). Southeast-Asia, and particularly Thailand, is of great conservation interest as a globally significant biodiversity hotspot (Myers et al., 2000, Sodhi et al., 2010a, Koh et al., 2013), but few have attempted to examine synergistic impacts of deforestation and climate change on biodiversity (Hughes et al., 2012). Only one study on forest mammals assessed the combined effects of land use and climate change in Thailand (Trisurat et al., 2014) and concluded that the combination of land use and climate change could produce more severe losses than individual factors and suggested that land-use change and habitat loss would be a more severe impacts than climate change. This study also argues that change in climate and land use are important to conservation management and supports the need to obtain more information in other species of Thailand (Trisurat et al., 2014).

Identifying extinction risks by future climate and land use change is important to prioritizing conservation (Maggini et al., 2014, Zhang et al., 2016). However, the current assessments for conservation of organisms in Thailand depends heavily on expert knowledge (Sanguansombat, 2005, ONEP, 2007). Only one study has applied the information of distribution range assessed with IUCN Red List Criteria B1 (decline in range size) to evaluate conservation status of a Thailand bird speciesand recommended changing the status of Tickell's and Austen's brown hornbill from Vulnerable to Endangered (Sanguansombat, 2005). The study also suggested changing the status of the Helmeted hornbill from Endangered (Sanguansombat, 2005) to Vulnerable in Thailand (Trisurat et al., 2013), further illustrating how using spatial distribution can improve accuracy of an evaluation on conservation status of a species, which is particularly important in identifying and prioritizing conservation in a rapidly changing world. There are profound knowledge gaps on the interactions and combined impacts of multiple stressors to biodiversity loss with projected climate change, land-cover change and combined change in climate and land-cover in regards to tropical birds (Harris et al., 2011, Laurance et al., 2011, Sodhi et al., 2011, Brodie et al., 2012, Urban, 2015). In order to help fill these existing knowledge gaps, I examined the potential impacts of mutiple scenarios of future change in both climate and land cover on spatial patterns of species distributions, species richness and abundance, and evaluated species vulnerability in regards to future environmental change. I did this for more than 300 species of forest birds in Thailand according to three impact assessments of future environmental changes based on (1) future land-cover change, (2) future climate change, and

(3) future land-cover change combined with climate change. I used distribution models for 304 species to: (1) investigate the change in pattern of species richness; (2) predict changes in geographic distribution range; (3) estimate changes in total population size; and (4) estimate the potential impact of future environmental change on individual species. This approach assesses the vulnerability of each species within Thailand based on both range extent and population size. Species vulnerability is estimated using the IUCN Red List Criteria B1 as continuing decline of extent of occupancy (distribution size) and also Criteria A3, using estimates of changes in total population size. I expected that the use of future climate change combined with future land-cover change in the models might alter the projection on species richness, distribution and populations size more severely than each individual driver.

5.3 Methods

5.3.1 Species data and study areas

The dataset I collated provides a comprehensive representation of the avifauna of tropical forest ecosystems in Thailand. From the combined presense-only dataset of bird sampling and existing data, there were 313 species, with greater than 10 geographically unique records, across 461 geographic locations, which I used in this study for species distribution modeling. Of this 313, 304 species models were high qulaity and were used in subsequent analyses as discuss in Chapter 3. In order to further explore detailed relationships between ecological subsets of the avifauna and the environment, I explored relationships within a number of species groups, including habitat preferences, feeding guilds, elevational groups defined on published elevational range limit, biogeography, and seasonal status (more details in Chapter 3).

I also compiled species conservation status, as vulnerable, endangered, and critically endangered, as currently listed in Thailand (Sanguansombat, 2005), and internationally (IUCN, 2001) (see Appendix Table 1 for details of each species).

I also compiled species conservation status, as vulnerable, endangered, and critically endangered, as currently listed in Thailand (Sanguansombat, 2005), and internationally (IUCN, 2001) (see Appendix Table 1 for details of each species).

This study was focused on the tropical evergreen forest (20°28′N 99°57′E and 5°37′N 101°8′E), occupying nearly one-quarter of Thailand (RFD, 2015). Evergreen forest is a forest where most, or all, trees retain foliage all year round and includes tropical forest, dry evergreen forest, hill evergreen forest and coniferous forest. Most of Thailand's remaining evergreen forest occurs in protected areas (Figure 5.1).

5.3.2 Environmental predictors

i) Climatic data

Species distribution models (SDMs) utilize spatial coverage of environmental variables especially bioclimatic variables representing average and extreme values of temperature and rainfall for all locations. In this study I used eight standard, commonly used bioclimatic predictors of temperature and precipitation, representing the annual average, quarterly maximum/minimum period value and annual variability (seasonality) as used in a number of studies in the Australian Wet Tropics (Table 3.1; (Williams et al., 2003, VanDerWal et al., 2009a, VanDerWal et al., 2009b, Williams et al., 2010). Current climate data originated from the WorldClim database based on data covering from 1960 – 2000 (Hijmans et al., 2005).

To represent potential future climates (2041 – 2060 and 2061 - 2080) I used data from WorldClim at 1x1 km^2 resolution, which was the highest resolution available for the entire study area (Hijmans et al., 2005), which provides downscaled projections from the general circulation models (GCMs) as CIMP5-coupled model intercomparison project phase five, corresponding to the fifth IPCC assessment report (IPCC, 2013). To limit computing time, I selected a subset of nine complementary GCMs that are suitable for Thailand: ACCESS1-0, CCSM, CNRM-CM5, GISS-E2-R, GFDL-ESM 2M, HadGEM2-AO, IPSL – CMSA-LR, MIROC5, and MPI-ESM-LR (Hijmans et al., 2005, SEACLID, 2016). Four representative concentration pathways (RCPs) of greenhouse gas scenarios from the IPCC Fifth Assessment Report (AR5) were considered: RCP2.6 - representing a lowest emission; RCP4.5 - medium emission based on stabilization of radiated forcing shortly after 2100; RCP6.0 - medium emission scenario; and RCP8.5 – business as usual rising greenhouse gas emission scenario (van Vuuren et al., 2011) (see Appendix Table 5.2 for more details).

I extracted these variables for as all of Thailand and converted them into Raster ASCII grids (.asc) format as required for distribution modeling using maximum entropy algorithm

(Maxent). The projection of all variables was set to GCS_WGS_1984 using ArcGIS version 10.2 with a resolution of 0.01-degree grid (1x1 km^2).

ii) Land-cover data

I simplified land-cover data of the year 2000 from the Royal Forest Department on the forest cover classification based on satellite imagery from the Landsat 5^{TM} at a resolution 1x1 km^2 (Appendix Figure 5.1) (RFD, 2001). The current land-cover data classified based on satellite imagery downloaded from the Landsat 8^{TM} of dry season (January – May 2012) (https://landsat.usgs.gov/landsat-data-access), then interpolated images into four classes as (1) agriculture area, (2) total forest area, (3) urban area, and (4) others areas (Figure 5.1) (Campbell and Wynne, 2011). Validation with published data with the Land Development Department (LDD, 2014) for the correction of agriculture features, and validated with the Royal Forest Department (RFD, 2014) for the correction of forest features. I then employed the Conversion of Land Use and its Effects at Small regional extent (CLUE-s Model) to project future land-cover change (Verburg and Overmars, 2009a). The CLUE-s model is a tool to explicitly simulate land use change using empirically quantified relations between location suitability combined with a dynamic simulation of competition and interactions between the spatial and temporal dynamics of alternative land use systems (Verburg and Overmars, 2009a). Here, I projected future land-cover change based on four scenarios that covered a broad range of potential changes in socio-economic, environmental planning and development policy according to the Thailand strategic planning for the next 20 years (2017-2038) (Trisurat et al., 2014, NESDB, 2017):

1. **Mild scenario: *Sustainable development and limited resources degradation scenario (SD).*** A lower rate of land conversion is assumed due to low population growth and limited deforestation. Anticipating effective protection of remaining forest in all existing and proposed protected areas (Appendix Figure 5.2);
2. **Moderate scenario: *Sustainable poverty and stable resources scenario (SP).*** A relative land conversion rate applies for agriculture area. Limited forest encroachment for agriculture outside protected areas and assumed the along inner and outer buffer zone of protected areas is low population growth (Appendix Figure 5.3);
3. **Severe scenario: *Low economic decline and localized resource degradation (LD).*** It is predict that the continuous high agriculture product prices and high population

growth make it profitable to transform large forest area (excluding existing protected areas) and bare soil to paddy field and economic crops (Appendix Figure 5.4); and

4. **Most severe scenario:** ***Unsustainable economic development and serious resource degradation (UD).*** A continuation of land transformation of recent year (2000 – 2012) is foreseen. The recent land-cover change detection revealed that only limited encroachment restricted in the protected areas (Appendix Figure 5.5).

In order to project the potential future outcomes into a more distant future to compare with potential climatic change scenarios, it was assumed for each separate development scenario that policy would continue.

Forest Complexes of Thailand

1 = Lum Num Pai-Salawin
2 = Sri LannaKhun Tan
3 = Doi Phuja-Mae Yom
4 = Mae Ping-Om Koi
5 = Phu Meang-Phu Thong
6 = Phu Khiew-Nam Naew
7 = Phu Parn
8 = Phanom Dongrak-Phatam
9 = Dong Phayayen-Khao Yai
10 = Eastern
11 = Western
12 = Kaeng Krachan
13 = Chumporn
14 = Klong Saeng-Khao Sok
15 = Khao Luang
16 = Khao Bantad
17 = Hala-Bala
18 = Mo Kho Similan-Peepee-Andaman
19 = Mo Kho Ang-Thong-Ao Thai

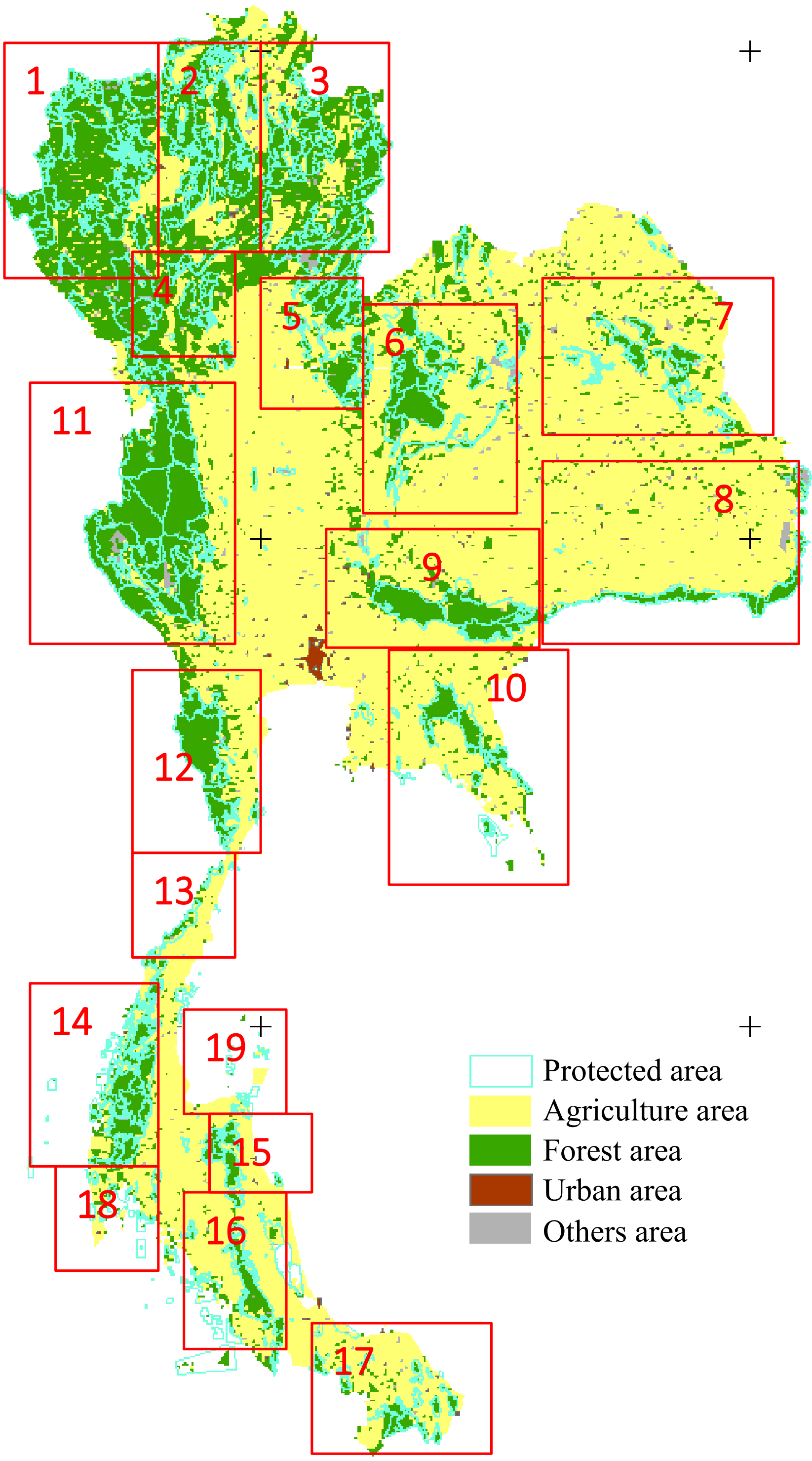


Figure 5.1 Map of the current land-cover and boundary of protected areas (blue) within 19 forest complexes in Thailand (red squares) (Faculty of Forestry, 2012). Current land-cover features agriculture area (yellow); forest area (green); urban area (dark red); and others area (grey) classified by Satellite image Landsat 8TM at 2012.

5.3.3 Projecting future species distributions

To model species distributions, I employed the maximum entropy algorithm (MaxEnt) version 3.1.3 (Phillips et al., 2006). MaxEnt models the relationship between species occurrence (presence-only) and spatially - explicit environmental predictors to estimate the spatial distribution of all target species.

In order to identify optimal setting for all models, I set up a default of each model in the MaxEnt for each predictor and ran 10 cross-validations, with 75% of the data sample points to generate a species distribution model. The remaining 25% was kept as independent data to test the accuracy of each model (random test percentage = 25); regularization multiplier = 1 (Kramer-Schadt et al., 2013, Velásquez-Tibatá et al., 2013). To minimise biases in distribution models I used a target group background, that is, background points in the model are based on the occurrence points of all bird records in our dataset (target group) (Phillips, 2008, Fourcade et al., 2014). By default, maximum number of background points as 10,000 are randomly selected from the whole rectangular study area (Fourcade et al., 2014).

For each species I projected distribution models based on three combinations of potential future scenarios of environmental change as;

1. **Land-cover change (LCC)**: I projected models into eight scenarios with four future land-cover scenarios and two time periods (2050 and 2070);
2. **Climate change (CC)**: I projected models into 68 scenarios with nine GCMs, four RCPs, and two time periods. Then I averaged all GCMs for each RCP within each period; and
3. **Combined climate and Land-cover change (CCLC)**: I projected models into 272 scenarios with nine GCMs, four RCPs, two periods, and four land-cover change scenarios. Then I averaged all GCMs to each RCP and each Land-cover scenario within each period.

Therefore, in this chapter I projected 1,067,040 distribution models for 304 forest bird species in Thailand including three scenarios for current distributions ((8 LCC + 68 CC + 272 CCLC + 3 current) x 304 species x 10 fold). Then, I used consensus forecast to average predictions across general circulation models (Barbet-Massin et al., 2012, Reside et al., 2012b). This process resulted in 28 future prediction grids for each species in each period, four of land-cover changes, four for climate changes, and 16 of climate change combined with land-cover changes. Using the RASTER package (Hijmans et al., 2015) and the SDMTool (VanDerWal et al., 2011) in R version 3.2.2 to perform all projections.

In order to transform the most probable consensus distribution to a presence/absence distribution, I treated the suitability values for pixels above the balancing training omission rate, predicted area and logistic threshold as presence and set the suitability for pixels under the threshold to zero as absence (VanDerWal et al., 2009a, Reside et al., 2010).

5.3.4 Model evaluation

I used the area under the receiver-operating characteristic (ROC) curve (AUC) and the true skill statistic (TSS) to evaluate the predictive performance of the SDMs for all species distribution models (current, 2050, and 2070) (see chapter 3 for more detail). Based on these model performance statistics, 304 of the 313 species distribution models were suitable for analysis. The performances of all three prospective were excellent according to AUC, while evaluated based on TSS show that the climate change and combined climate and land-cover change prospective mean accuracy measures and even most land-cover change prospective still performed reasonably well (Figure 5.2).

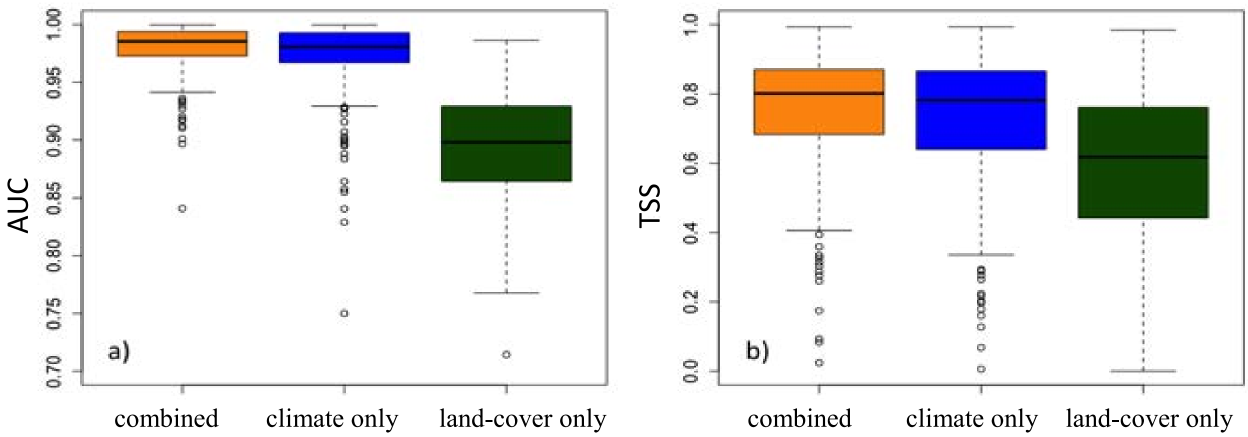


Figure 5.2 Summary model performance statistics for the species distribution models using combined climate and land-cover, climate only and land-cover only. Box-whisker plots illustrating the mean and variability of model accuracy for each predictor set as measured by: a) AUC- Area Under Curve, and b) TSS True-Skill Statistic.

5.3.5 Predicting change in species richness

To obtain maps of estimated species richness, I first transformed the SDM maps obtained from MaxEnt and the mean of the model consensus across GCMs to a presence/absence distribution (VanDerWal et al., 2009a, Reside et al., 2010). Then all species considered present in each grid cell was summed to provide an estimate of potential current richness and future richness. This method is a stacked continuous models method to help reduce over prediction (Distler et al., 2015). Future changes in species richness was deduced from the difference between estimates of current richness and future richness in each grid cell for each comparison based on three combinations of future environmental change: combined climate and Land-cover change (CCLC); climate change only (CC); and, land-cover change only (LC). The SDMTool package (VanDerWal et al., 2011) and the MASS package (Venables and Ripley, 2002) in R were used to calculate species diversity.

5.3.6 Predicting change in distribution for individual species

To calculate the species' geographic range size of each species for current and future distributions for each comparison based on the three potential futures of environmental change, I first transformed the SDM maps obtained from MaxEnt and the mean of the model consensus across GCMs for climate change only scenario, to a presence/absence distribution (VanDerWal et al., 2009a, Reside et al., 2010). I then calculated the range size and the propotion of range gain and loss for each projection of future species distribution. The range size was analyzed as the ratio between the number of grid cells where species was predicted presence and the total number of grid cell in the study area of the current and future projections of each scenarios. Also the change in range size calculated as the ratio of the total number of grid cell in the study area of the future projection compare to the the total number of grid cell in the study area of the current projection.

I employed the R program with packages grid (Murrell, 2005), gplots (Gregory et al., 2016) sp (Edzer et al., 2016), ROCR (Tobias et al., 2015), vcd (David et al., 2015), boot (Angelo and Ripley, 2016), raster (Hijmans et al., 2016), and rgdal (Bivand et al., 2016) to calculate number of grid cells of each scenario.

I used these measurements to examine different results in species distribution change from three prospective future environmental change time slots, based on a mean data set. I used the multiple linear models with the ANOVA tables to examine the interaction between range size change and prospective future environmental change. I also calculated average change in distribution range for each ecological subset of birds, classified by habitat preference, feeding guilds, elevational range limit, biogeography and seasonal status (as described above).

5.3.7 Predicting change in total population

The concept that the environmental suitability for each pixel predicted using Maxent is a reasonable predictor of total population size, that is, it provides an index of maximum abundance for that pixel given the environment present was tested using large datasets in the Australian Wet Tropics (Shoo et al. 2005b; VanderWal et al 2009a). Therefore, to predict changes in total population size for each species between current and future patterns of distribution and abundance, I followed the recommendations of VanDerWal et al. (2009a) that showed that an index of total population size can be obtained from the summed environmental suitability across all grid cells in the SDM map that I obtained from MaxEnt and the mean of the model consensus across GCMs for each scenario. Proportional changes in total summed environmental suitability provide an index of changes in total population size (VanDerWal et al. 2009). Employing packages grid (Murrell, 2005), ggplots (Gregory et al., 2016), sp (Edzer et al., 2016), ROCR (Tobias et al., 2015), vcd (David et al., 2015), boot (Angelo and Ripley, 2016), raster (Hijmans et al., 2016), and rgdal (Bivand et al., 2016) in R program.

I then calculated the population size index of each species for each prospective future environmental change of each time slot, based on mean data set. I used the multiple linear models with the ANOVA tables to examine the interaction between population size change and prospective future environmental change. I also determined average percentage of change in population size for each ecological subset as described above: birds classified by habitat preference, feeding guilds, elevational range limit, biogeography, and seasonal status.

5.3.8 Assessing the future conservation staus of Thailand's forest bird species

In order to estimate the future conservation status of birds under climate change I used two different approaches as used under the IUCN Red List Criteria. The first is based on declines in range size (Criteria B1) and the second is based on changes in population size (Criteria A3) (IUCN, 2001, AkÇAkaya et al., 2006). I applied the future range size estimates for each species from projected future SDMs in each time slot (2050, 2070) to the red listing criteria for Thailand. Defined criteria are: if a species has continuing decline in habitat or range from the current, and it has a restricted range size (i) lower than 100 km^2, will be classified as the"Critically Endangered" (CR); (ii) 100 – 5000 km^2, will be the "Endangered" (EN); and (iii) 5000 – 20000 km^2 will be the "Vulnerable" (VU) (IUCN, 2001, AkÇAkaya et al., 2006) and potentially threatened species ("Near Threatened" – NT) as those where range size is predicted to decline below 20000 km^2. Furthermore, species that have increased range size will be the "Increasing" species (IN); species which do not change their range, are the "No Change" species (NO).

The second criteria considered is the loss of population size IUCN Red List Criteria A3, that is, future change in population size, based on an index of abundance, or drop in occupied habitat range or habitat quality (IUCN, 2001, AkÇAkaya et al., 2006). Thus, I projected future change in abundance across time; I then applied these results of rate of population change to assess the threatened status for each species in the year 2050 and 2070. Threat categories are defined as: (i) more than 80% decline in population size from the current, will be classified as the "Critically Endangered" (CR); (ii) 50 – 80 % decline will be the "Endangered" (EN); and (iii) 30 – 50% decline will be the "Vulnerable" (VU) (IUCN, 2001, AkÇAkaya et al., 2006) and potentially threatened species ("Near Threatened" – NT) as those where population size is predicted to decline less than 30% (AkÇAkaya et al., 2006). I also classified species that have increased population size will be "Increasing" species (IN); species which do not change their population size, are the "No Change" species (NO). Species are considered "Threatened" (TT) if they meet any of the criteria for Vulnerable, Endangered, or Critically Endangered.

I then examined how different prospective future environmental change resulted in contrasting projections of IUCN criteria classified Threatened species across time.

5.4 Results

5.4.1 Predicting changes in species richness

Predicted changes in species richness over time varied dependent on prospective future environmental changes models (Figure 5.3 and Appendix Figure 5.6 – 5.8). In general, species richness is predicted to decrease more than increase. As I showed in Chapter 4, the most severe impacts on species richness was under the business-as-usual emission scenario (RCP8.5). Here I have illustrated the combined impacts of climate change and land cover change on spatial patterns of species richness using RCP 8.5 and the most serious land-cover change (UD-unsustainable economic development and serious resource degradation) (Figure 5.3). However, the results of all combinations of model scenarios are included in Appendix Figure E5.1 – E5.4.

Using the combined climate and land-cover change (RCP8.5+UD) scenarios, lowland areas in the northern, southern and uplands in the south were projected to face the largest decrease in species richness with an 80 - 90% decrease in species richness across time. In contrast, there are slight increases in species richness (56 - 59%) in the uplands where forest cover survives in protected areas (Figure 5.3a - 5.3c). Projections based on climate only using RCP 8.5, resulted in lower projected loss of species richness (79 - 84%) than that obtained when using combined climate and land-cover change although the spatial patterns of loss were very similar. Some lowland areas in the north and central Thailand and upland areas in the south were projected to increase in species richness (19 - 32%) (Figure 5.3d - 5.3f) when using the land-cover change only (UD) (Figure 5.3g - 5.3i).

In summary, species richness is predicted to decline most in the lower elevation forests as species get pushed higher up the mountains and the severity of these changes increases with the severity of the future emission scenario (as could be expected). There is an increased concentration of species in the more northern regions of the country where there are higher elevation forest complexes with more intact land cover. Forest complexes that primarily increase in the concentration of species are particularly noticeable in the Mae Pin-Om Koi, Dong Prayayen-Khao Yai, Phu Meang-Phu Thong, Phu Khiew-Nam Maew, Western, Kaeng krachan, and Hala-Bala Forest Complex (Figure 5.1 and Figure 5.3).

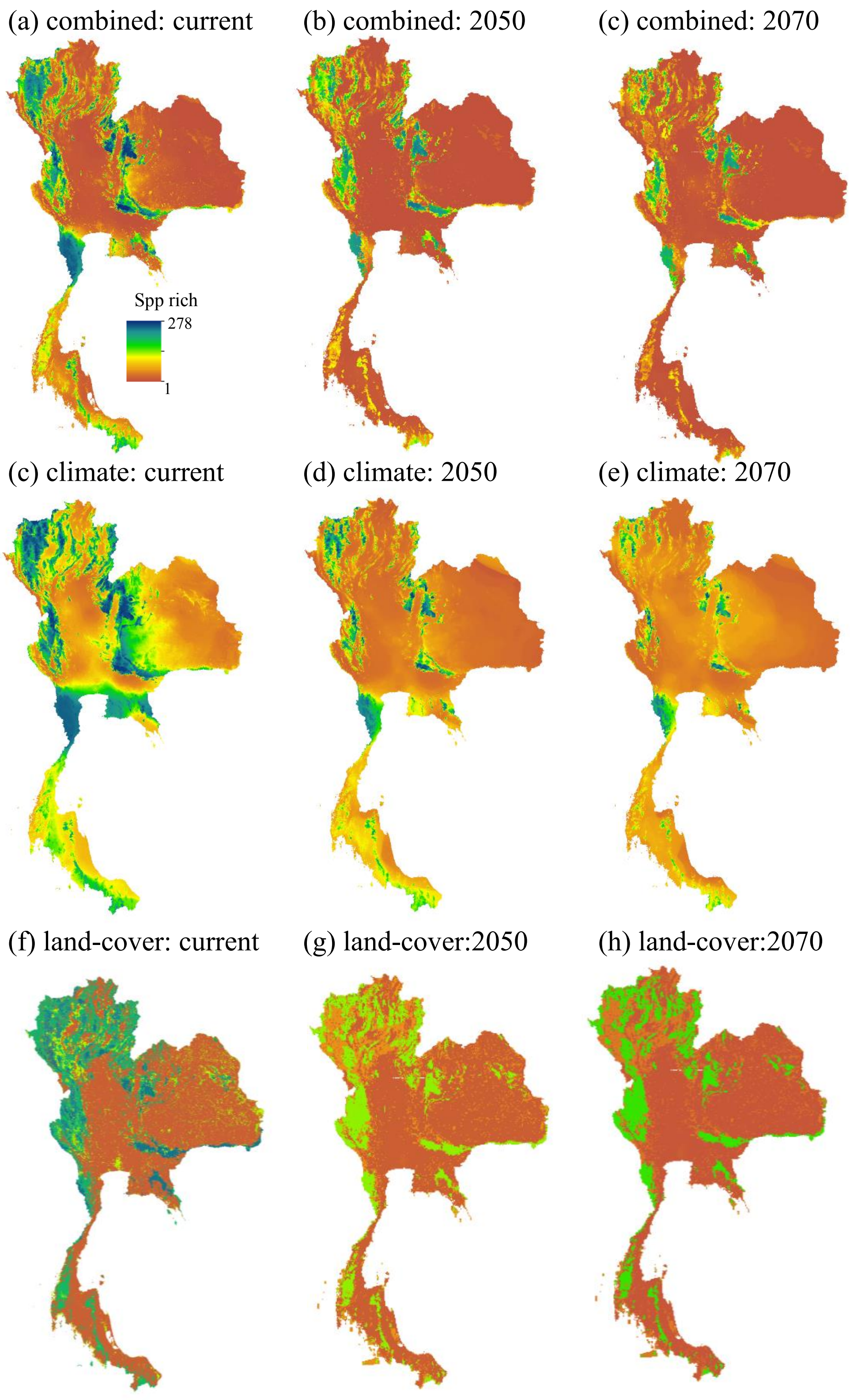


Figure 5.3. The estimation of current and future of spatial pattern of species richness of Thailand's forest birds. Maps are derived from 304 overlaid species distribution models for each of based on the most severe of future prospective scenarios: (a-c) combined climate and land-cover (RCP8.5+UD), (d-f) climate change only (RCP 8.5), and (g-i) land-cover change only (UD).

5.4.2 Predicting changes in distribution for individual species

I have modeled the predicted change in distribution for each of the 304 species of forest birds with sufficient data for the current time, 2050 and 2070 under three combinations of projected future environmental change: 1) combined climate and land-cover change, 2) climate change only, and 3) land-cover change only (a total of 1,098,630 SDMs). As could be expected, individual species responses vary across time and scenarios, ranging from increasing through to no change to severe declines/potential extinctions. Here I have illustrated the prediction of distribution changes based on all RCPs and the most serious land-cover change (UD-unsustainable economic development and serious resource degradation). (see results of each species and each scenario Appendix Table E2).

In general, the distribution of responses is bimodal with a consistently increasing impact over time on the vast majority of species while a smaller number of species increase in distribution size (Figure 5.4). More than 85% of the 304 species of Thailand's forest birds were projected to experience declines in their suitable environmental space under all scenarios of future environmental change, while around 10 – 20 % of species are expected to benefit from future environmental change. However, combined climate and land-cover change scenario predicted most severe decrease in distribution change over time (Figure 5.4).

The average range change measures significantly differed between each perspective future environmental changes, showing that the combined climate and land-cover change prospective predicted the most severe declines in distribution size (Figure 5.4). Comparison across RCPs found that, as expected, RCP8.5 predicted significantly higher negative in distribution size than other RCPs for both combined climate and land-cover and climate only combinations. RCP6.0 also forecasted significantly more severe declines in range size than RCP2.6 with climate change only (Figure 5.4). However, change in distribution size within land-cover change scenarios also significantly differed as only the most severe scenario (UD) predicted significantly most severe decrease range size than other that I have presented here (Figure 5.4) (See Appendix Figure 5.9a for distritribution change of all land-cover scenarios). Considering the combined climate and land-cover change (UD), the RCP2.6 combined with and land-cover change (RCP2.6+UD) predicted the suitable habitat ranges of 267 species are projected to decrease by an average of 46% by 2050 and by 56% for 266 species by 2070. In contrast, 37 species are predicted to increase their range by an average of 65% by 2050 and 62% 2070 (Figure 5.4a). These trends are more noticeable as the emission scenarios become more severe through to the business-as-usual scenario (RCP8.5+UD) (Figure 5.4a). Under RCP8.5+UD, up to 85% of all species will have experienced an average of more than 50% loss of range area with some species declining by as much as 80% (Figure 5.4a). Overall combined change models predicted that by 2070 most species would decrease distribution size by an average of 60% from the current size, while species that inrease will do so by approximately 63% (Figure 5.4a).

Under climate change only, the lowest mitigation scenario (RCP2.6) projected suitable habitat ranges of 265 species decrease by an average of 37% by 2050 and by 44% by 2070. In contrast, 39 species are predicted to increase their range by an average of 66% by 2050 and 74% by 2070 (Figure 5.4b). These trends are more noticeable as the emission scenarios become more severe through to the business-as-usual scenario (RCP8.5). Under RCP8.5 up to 85% of all species will have experienced an average of more than 50% loss of range area with some species declining by as much as 80% (Figure 5.4b). Thus, almost 85% of these species were predicted to decline in range size an average of 50% by 2070, with increase in range size average of 70% (Figure 5.4b).

Using the land-cover change scenario (UD), the suitable habitat ranges of 267 species are projected to decrease by an average of 27% by 2050 and by 31% by 2070. In contrast, 37 species are predicted to increase their range by an average of 57% by 2050 and 61% by 2070 (Figure 5.4c).

However, there are some species that benefit from future environmental change (Figure 5.5). I explored this in more detail by examining different ecological subgroups of the assemblages and examined the response within groups of species defined by habitat preferences, feeding guild, elevational limits, biogeographic regions and migratory type (Figure 5.5). I found that all species grouped by habitat preference and feeding guilds are expected to decline in distribution size across time and environmental change scenarios. Conversely, Sundaic (S) and Sundaic-northern border (SN) species grouped by biogeographic region; winter migrant (P) grouped by seasonal status; and lowland species grouped by elevational range limit were the groups predicted to increase in distribution size in response to future environmental change (Figure 5.5).

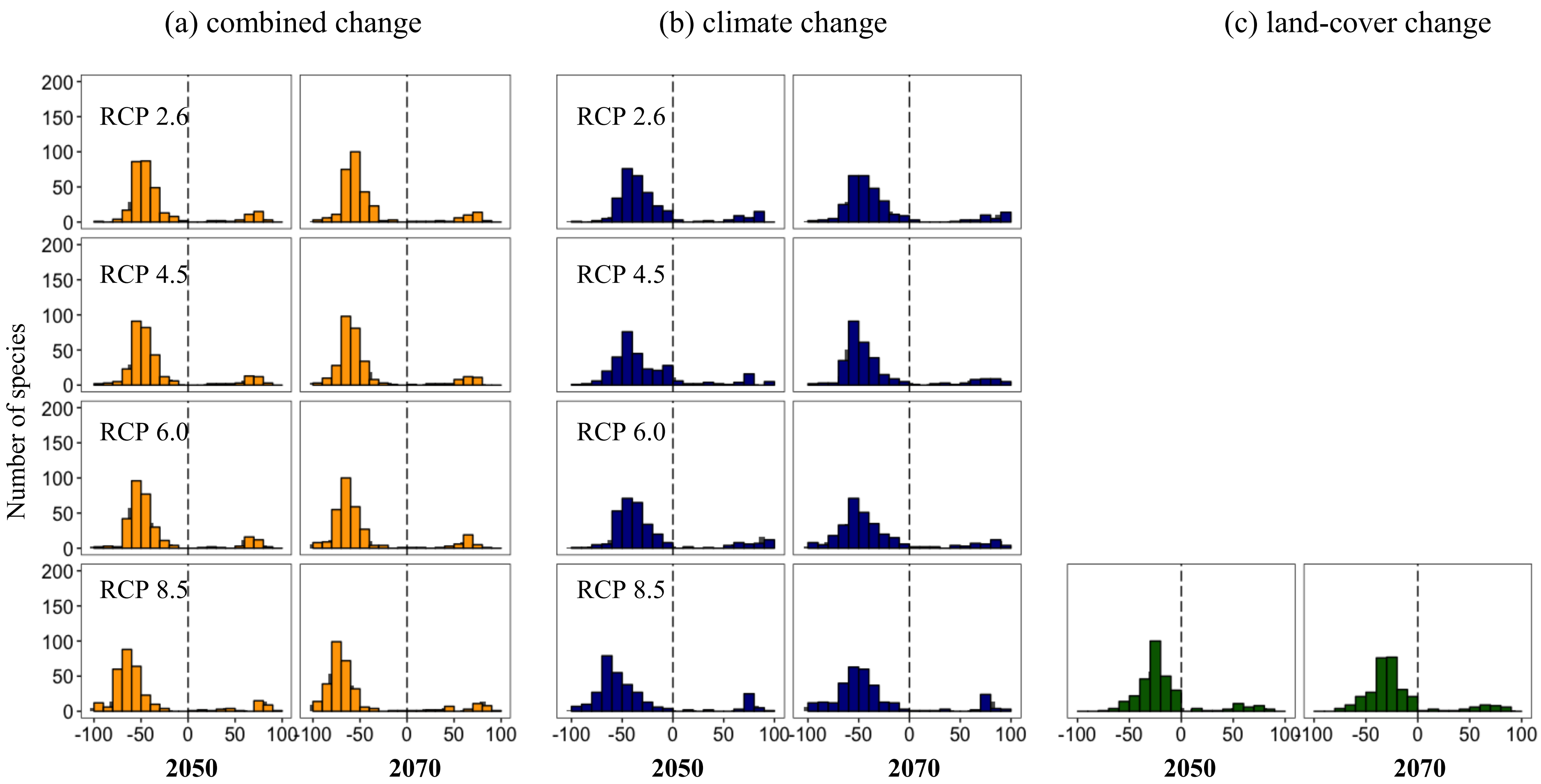


Figure 5.4. Frequency histogram presenting the relative change in range size across all 304 species from current range size to projected range size in 2050 and 2070 for each RCP emission scenarios according to prospective future environmental change: (a) Combined climate and land-cover change (RCPs+UD) (orange); (b) Climate change (blue); and (c) Land-cover change (UD) (green).

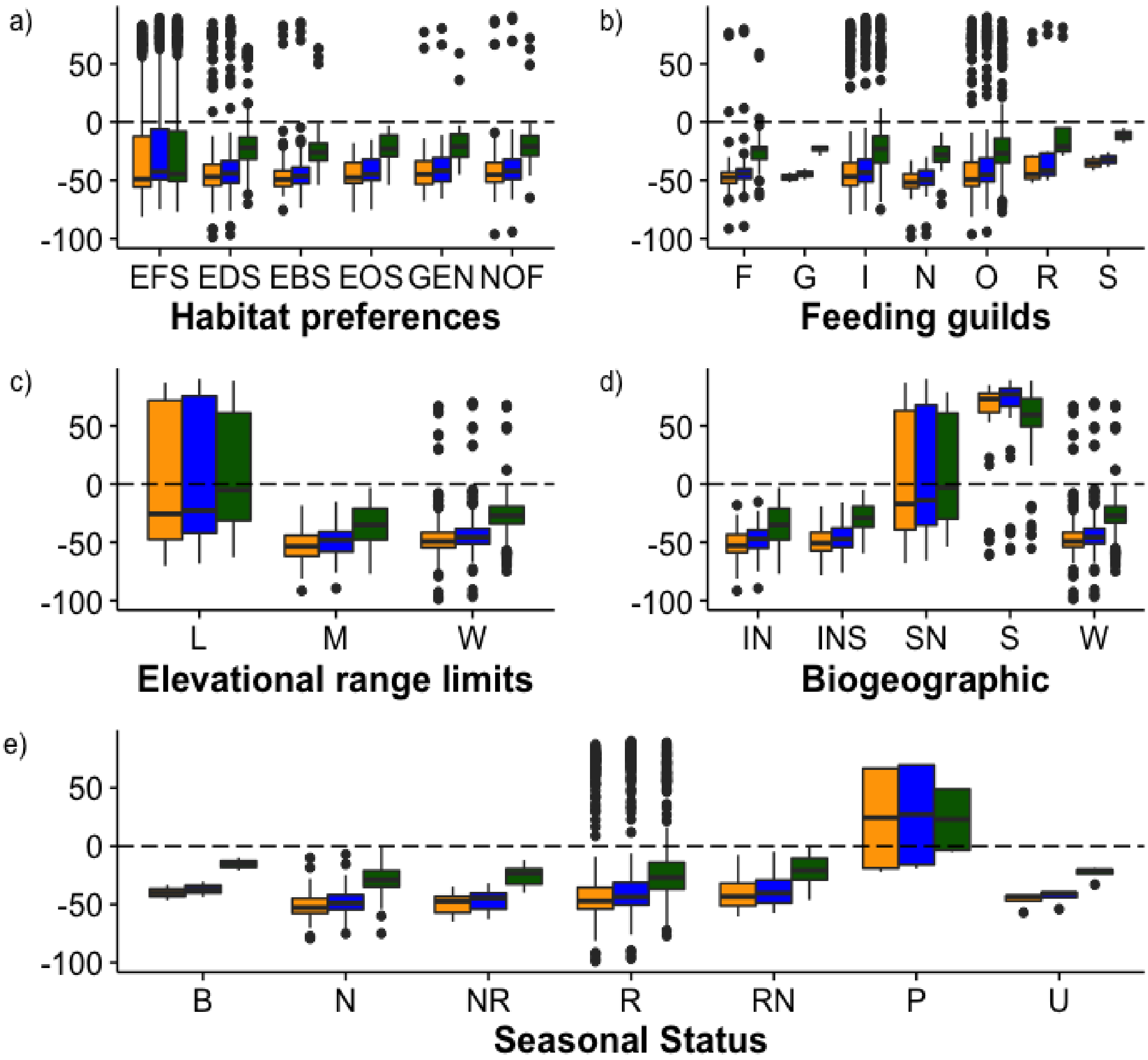


Figure 5.5 Relative change in the mean and variance in species range size from current range size to projected range size in 2050 and 2070 based on combined climate and land-cover change prospective (orange), climate change prospective (blue), and land-cover change prospective (green) for the 304 species split into a variety of ecological subgroups including: a) Habitat groups (EFS - evergreen forest specialist; EDS – evergreen forest specialist but occur in deciduous forest; EBS - evergreen forest specialist but occur in bamboo forest; EOS - evergreen forest specialist but occur in edge forest, open area, and other (not include forest); GEN - occur in evergreen forest but common in other forest, occur in evergreen forest but common in edge forest, open area and other (not include forest area); and NOF - never occur in evergreen forest), b) Feeding guilds (F - frugivorous; G – granivorous; I – insectivorous; N – nectarivorous; O – omnivorous; R – raptor, and S - scavenger), c) Elevational groups (L - lowland ; M - montane ;W - widespread), d) Biogeographic subregions (IN – Indochinese; INS - Indochinese-southern cross; S – Sundaic; SN - Sundaic-northern cross; and W - widespread), and e) Seasonal migratory classes (B – breeding visitor; N – non-breeding visitor; NR - mainly non-breeding visitor but maybe resident; R - resident or presumed resident; RN - mainly resident but maybe non-breeding visitor; P - mainly spring and autumn passage migrant, and U – uncertainty). See Table 3.1 of Chapter 3 for more details of number of species within each subgroups.

5.4.3 Predicting changes in total population size of individual species

Many schemes aimed at assessing species vulnerability rely on changes in total population size over time. Previous studies have emphasized that estimates of population size are a much more sensitive indicator of impacts of a changing climate than range size (e.g. Shoo et al. 2005). VanDerWal et al. (2009a) demonstrated that summed environmental suitability from a species distribution model can provide an effective relative index of total population size making it possible to produce estimates of change in population size under different future climate scenarios. Using this approach I have assessed the changes in population size between the current and 2050 and 2070 for each of the 304 species across each combination of emission scenarios (RCPs), each different GCM and each prospective future environmental change (as described in previous sections). Here I have illustrated the prediction of changes in population size based on all RCPs and the most serious land-cover change (UD-unsustainable economic development and serious resource degradation) (see results of each species and each scenario Appendix Table E2).

Overall, these analyses suggest that more than 87% of 304 Thailand's forest bird species are projected to decrease their population size with an average decline of 70% (Figure 5.6). Conversely, 10 – 20% of species will have an increase in population size with an average increase of 79% (Figure 5.6). The full distribution of species responses for each RCP, prospective future environmental change, and periods is presented as a frequency histogram (Figure 5.6). The number of species and the relative severity of these declines increase with the severity of the emission scenario with RCP8.5 being significantly worse (Figure 5.6). However, change in population size within land-cover change scenarios also significantly differed as only the most severe scenario (UD) predicted a significantly more severe decrease in population size than other that I have presented here (Figure 5.6).

The combination strong emission reduction (RCP2.6) climate and average land-cover change (UD), (RCP2.6+UD) predicted the suitable habitat ranges of 267 species are projected to decrease by an average of 70% by 2050 and by78% for 266 species by 2070. In contrast, 37 species are predicted to increase their range by an average of 70% by 2050 and 81% by 2070 (Figure 5.6a). These trends are more noticeable as the emission scenarios become more severe through to the business-as-usual scenario (RCP8.5+UD) (Figure 5.6a). Under RCP8.5 combined with the most severe land-cover change (RCP8.5+UD) up to 90% of all species will have experienced an average of more than 70% loss of range area with some species declining by as much as 80% (Figure 5.6a). With an overall 85% of these species predicted to decline in population size by an average of 85% by 2070 (Figure 5.6a).

Under climate change only, the lowest mitigation scenario (RCP2.6) projected suitable habitat ranges of 265 species to decrease by an average of 60% by 2050 and by 73% by 2070. In contrast, 39 species are predicted to increase their range by an average of 71% by 2050 and 80% by 2070 (Figure 5.6b). These trends are more noticeable as the emission scenarios become more severe through to the business as usual scenario (RCP8.5). Under RCP8.5 up to 85% of all species will have experienced an average of more than70% loss of range area with some species declining by as much as 80%. An average of 85% of these species were predicted to decrease in population size 55% by 2070, with an average of increase population size 90% (Figure 5.6b).

While in the land-cover change only (UD), the suitable habitat ranges of 267 species are projected to decrease by an average of 50% by 2050 and by 60% by 2070. In contrast, 37 species are predicted to increase their range by an average of 60% by 2050 and 71% by 2070 (Figure 5.6c).

Within each ecological subgroups of the assemblage the patterns of change in population size were similar to the patterns based on range size changes described in the rpevious section. All species grouped by habitat preference and feeding guilds demonstrated similar, primarily negative, responses to the future changes, while Sundaic (S) and Sundaic-northern border (SN); winter migrants (P); and lowland species were predicted to increase in distribution size with future environmental change (Figure 5.7)

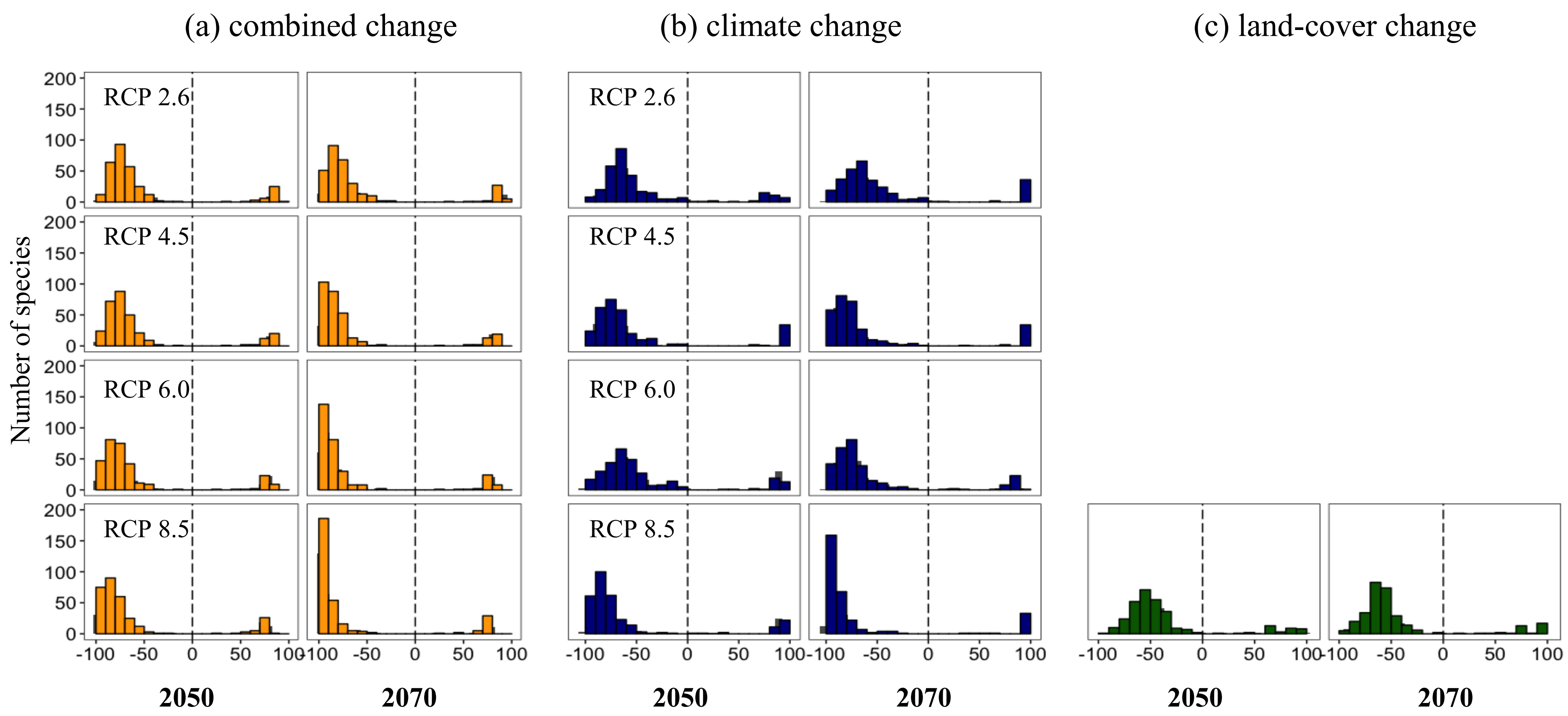


Figure 5.6 Frequency histogram presenting the relative change in total population size across all 304 species from current population size to projected future population size in 2050 and 2070 for each RCP emission scenarios according to prospective future environmental change: (a) Combine climate and land-cover change (RCPs+UD) (orange); (b) Climate change (blue); and (c) Land-cover change (UD) (green).

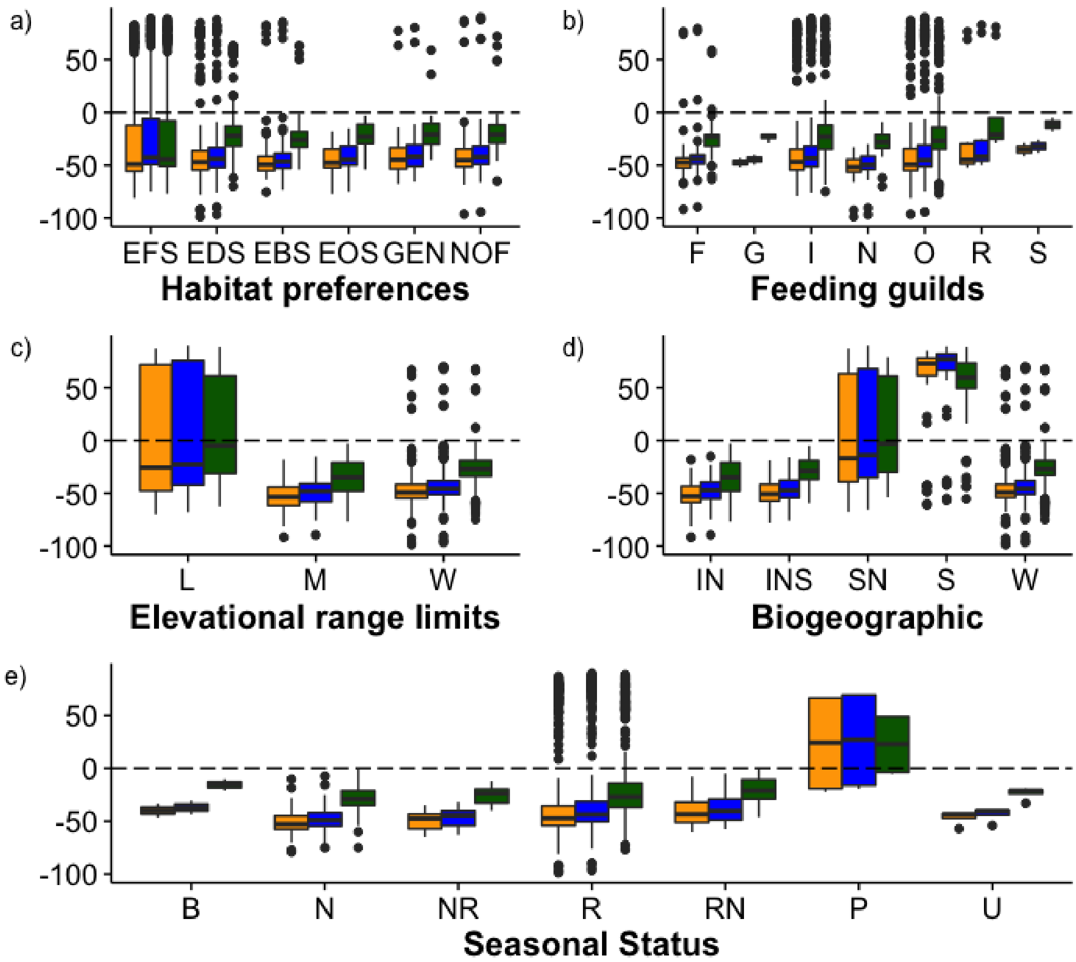


Figure 5.7 Relative change in the mean and variance in species range size from current range size to projected range size in 2050 and 2070 based on combined climate and land-cover change scenarios (orange), climate change only (blue), and land-cover change only (green) for the 304 species split into a variety of ecological subgroups including: a) Habitat groups (EFS - evergreen forest specialist; EDS – evergreen forest specialist but occur in deciduous forest; EBS - evergreen forest specialist but occur in bamboo forest; EOS - evergreen forest specialist but occur in edge forest, open area, and other (not include forest); GEN - occur in evergreen forest but common in other forest, occur in evergreen forest but common in edge forest, open area and other (not include forest area); and NOF - never occur in evergreen forest), b) Feeding guilds (F - frugivorous; G – granivorous; I – insectivorous; N – nectarivorous; O – omnivorous; R – raptor, and S - scavenger), c) Elevational groups (L - lowland ; M - montane ;W - widespread), d) Biogeographic subregions (IN – Indochinese; INS - Indochinese-southern cross; S – Sundaic; SN - Sundaic-northern cross; and W - widespread), and e) Seasonal migratory classes (B – breeding visitor; N – non-breeding visitor; NR - mainly non-breeding visitor but maybe resident; R - resident or presumed resident; RN - mainly resident but maybe non-breeding visitor; P - mainly spring and autumn passage migrant, and U – uncertainty). See Table 3.1 of Chapter 3 for more details of number of species within each subgroups.

5.4.4 Assessing species vulnerability to global change: What will be the broad outcome of the predicted changes in distribution area and population size for the conservation status of Thailand's forest birds?

Currently there are 12 species of Thailand's forest birds considered to be threatened by the IUCN Red List (Appendix Table 5.1). For all modeled future scenarios in this study, to predict national conservation status, the IUCN criterion A3 (declines in population size) was applied. The predictions are much more dire than criteria B1 (changes in range size) which across time, found that threatened species were expected to increase by time and scenarios (Figure 5.8 - 5.10). Based on both criteria B1 and A3, the largest threat to species loss is the combination of climate (RCP8.5) and land-cover change (UD) scenario that predicted up to 98% of 304 bird species will become threatened (Figure 5.8, Table 5.1, and Appendix Figure 5.10). The single effects of climate change or land-cover change on threatened species were lower than the combined effects as (i) RCP8.5 only predicted 34 - 87% would become threatened, while (ii) UD only expected 10-30% will become threatened (Figure 5.8 and Appendix Figure 5.10). These results clearly show that the combined impacts of global climate change and land cover change will severely theaten more of the species in this important ecosystem.

Climate change is predicted to be a more severe threat to biodiversity than land-cover change; however, the combination of climate and land-cover change resulted in the most severe increases in number of threatened species (Figure 5.8 - 5.10). The combined impact analyses estimating changes in range size predict up to 116 species becoming threatened with 10 species of these becoming critically endangered in Thailand. Estimates based on population size are much more severe with up to 241 species of 267 threatened species becoming critically endangered (Figure 5.9). Interestingly, the combined climate and land-cover change also predicted some species will increase their population size more than the increase predicted by either climate or land-cover change separately (Figure 5.9).

Table 5.1 The top 20 most vulnerable species due to land-cover change, climate change and combined climate and land-cover changes by 2070. Current = current conservation status (IUCN, Thai); Land-cover change = future conservation status by 2070 if land-cover change only with the most severe scenario; Climate change = future conservation status by 2070 if climate change only with RCP 8.5; and Combined change = future conservation status by 2070 if both climate and land-cover change with the most severe scenario and RCP 8.5. Range = Criteria B1; Pop = Criteria A3).

		Current		Land-cover change		Climate change		Combined change	
Common_name	**Scientific_name**	**IUCN**	**Thai**	**Range70UD**	**Pop70UD**	**Range8570**	**Pop8570**	**Range85UD70**	**Pop85UD70**
Asian Red-eyed Bulbul	*Pycnonotus brunneus*			VU	EN	EN	CR	EN	CR
Barred Cuckoo Dove	*Macropygia unchall*			NT	EN	VU	CR	VU	CR
Black-throated Laughingthrush	*Dryonastes chinensis*			VU	EN	CR	CR	CR	CR
Chestnut-tailed Minla	*Chrysominla strigula*			NT	EN	VU	CR	VU	CR
Cream-vented Bulbul	*Pycnonotus simplex*			EN	CR	CR	CR	CR	CR
Dark-backed Sibia	*Malacias melanoleucus*			NT	EN	EN	CR	EN	CR
Grey-chinned Minivet	*Pericrocotus solaris*			EN	EN	CR	CR	CR	CR
Great Hornbill	*Buceros bicornis*	NT		NT	EN	EN	CR	EN	CR
Great Iora	*Aegithina lafresnayei*			NT	EN	VU	CR	VU	CR
Indian Roller	*Coracias benghalensis*			VU	VU	EN	EN	EN	EN
Lesser Shortwing	*Brachypteryx leucophrys*			NT	EN	EN	CR	EN	CR
Racket-tailed Treepie	*Crypsirina temia*			NT	EN	VU	CR	VU	CR
Spectacled Barwing	*Actinodura ramsayi*			NT	EN	VU	CR	VU	CR
Silver-breasted Broadbill	*Serilophus lunatus*			VU	EN	EN	CR	EN	CR
Slaty-bellied Tesia	*Tesia olivea*			VU	EN	VU	CR	VU	CR
Spectacled Bulbul	*Pycnonotus erythrophthalmos*			VU	CR	CR	CR	CR	CR
Verditer Flycatcher	*Eumyias thalassinus*			NT	EN	VU	CR	VU	CR
White-chested Babbler	*Trichastoma rostratum*			NT	EN	VU	CR	VU	CR
White-tailed Robin	*Myiomela leucura*		NT	NT	EN	VU	CR	VU	CR
Yellow-bellied Warbler	*Abroscopus superciliaris*		NT	NT	EN	NT	EN	VU	CR

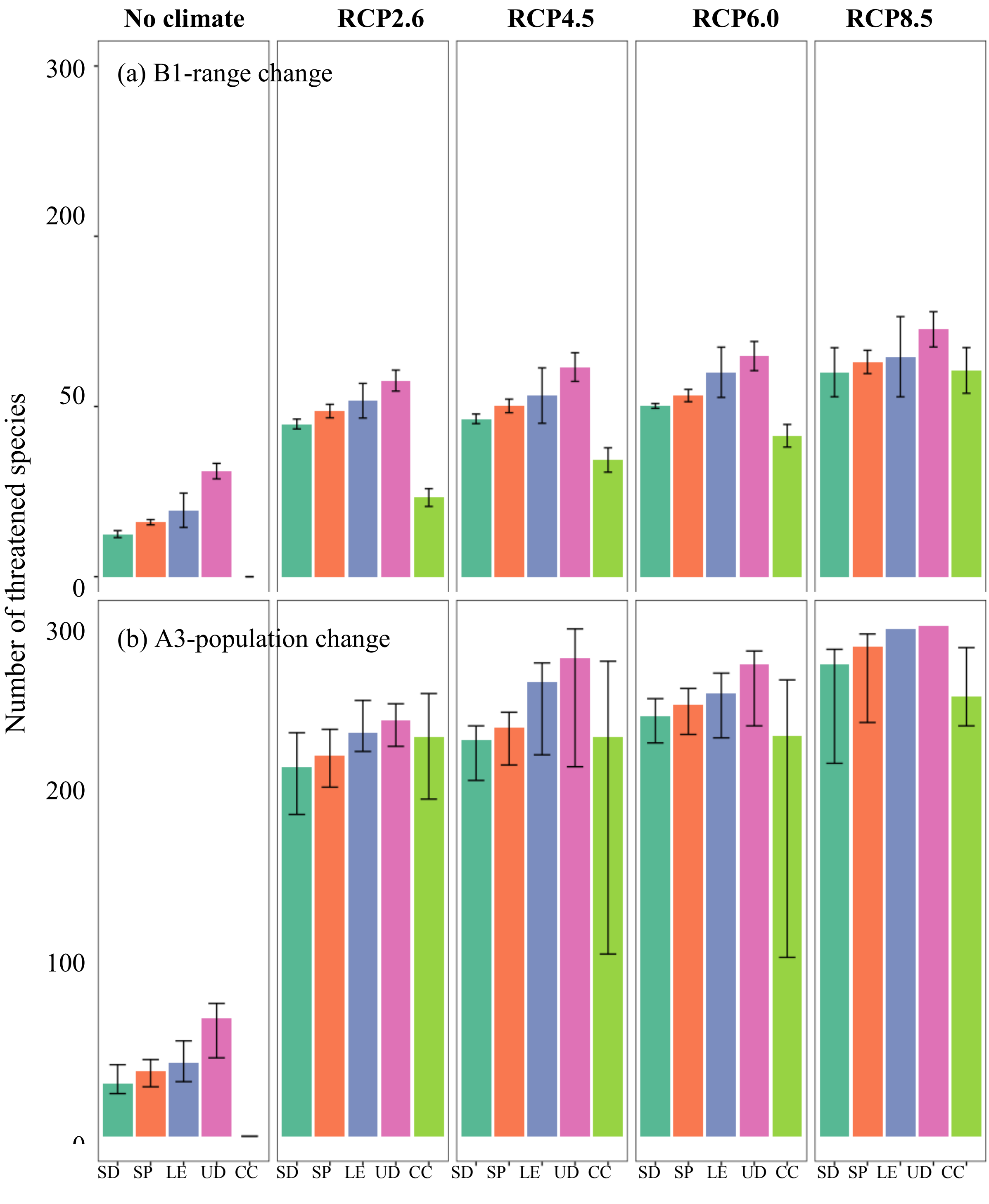


Figure 5.8 The number of threatened species within Thailand predicted by future environmental change scenarios based on the IUCN criteria (a) B1-decline in range size and (b) A3- future reduction of population size by 2070: SD = Sustainable development and limited resources degradation land use scenario; SP = Sustainable poverty and stable resources land use scenario; LE = Low economic decline and localized resources degradation land use scenario; UD = Unsustainable economic development and serious resources degradation land use scenario; and CC = Climate variables. Detailed description of scenarios is provided in the methods section 5.3.2 Environmental predictors.

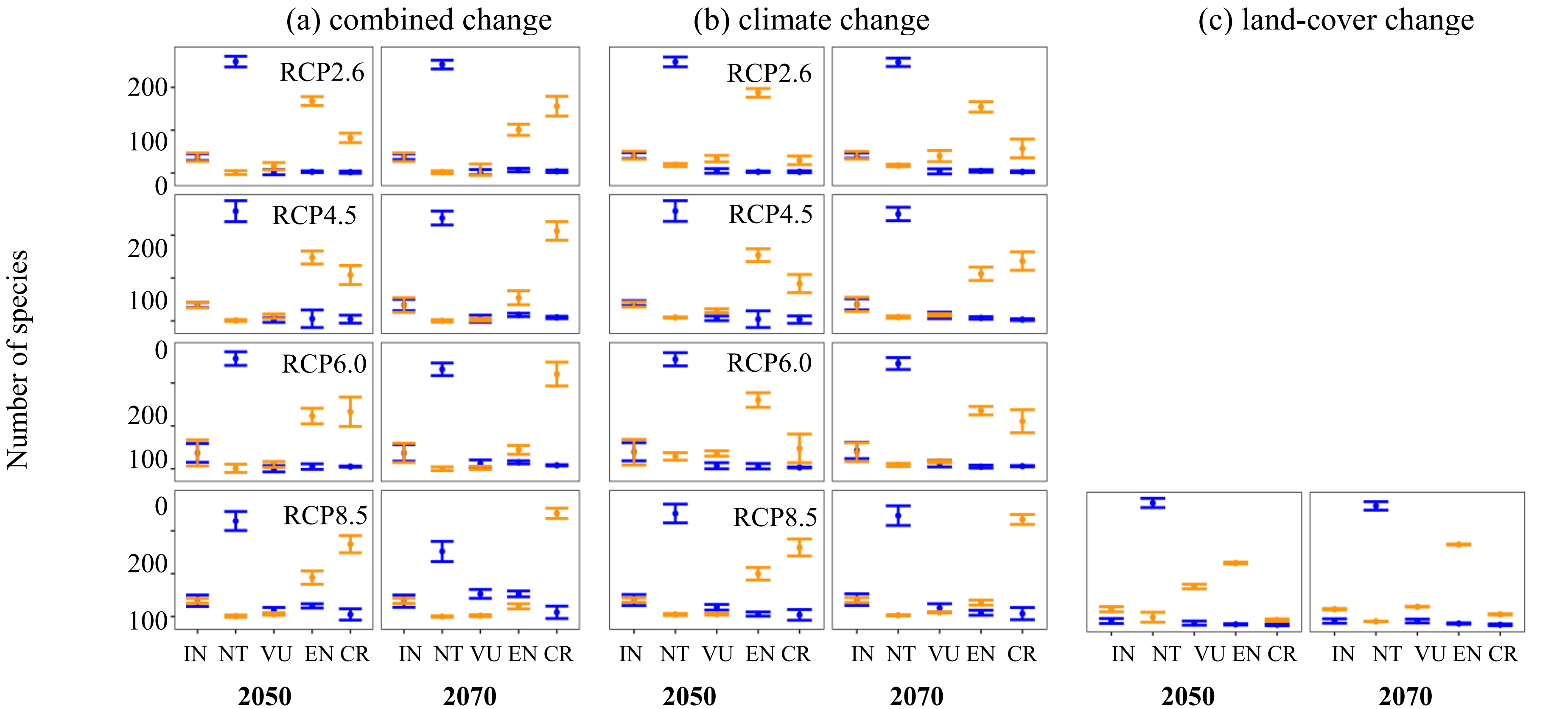


Figure 5.9 Projections of the future variation in the mean number of species (±SE) within each conservation status category within Thailand based on the IUCN criteria B1- continuing decline in occupancy range (blue) and criteria A3- future reduction of population size (orange) by 2050 and 2070. Plots represent the mean across each combinations of scenarios (see methods for details): (a) combined climate and land-cover change prospective; (b) climate change prospective; and (c) land-cover change prospective. Predicted future conservation status : IN = increasing population size or extent of occupy; NT = Near Threatened species; VU = Vulnerable; EN = Endangered species; and CR = Critically Endangered species.

Therefore, many more species are predicted to become threatened based on severe declines in their total population size rather than range size: this massive difference is summarized in Figure 5.10 and includes the mean across all scenarios and models (a total of 1,098,630 SDMs). Based on Criterion B1-change in range size it is predicted that by 2070 33 species (11%) will become threatened from land-cover change, 76 species (25%) by climate change, and 112 species (37%) will be threatened due to the combined impacts of climate and land-cover change (Figure 5.10). Criterion A3-change in population size, demonstrated that combined climate and land-cover change predicted an average 253 species (83%) would be threatened species, while 239 and 191 species (75% and 13%) would become threatened species if climate change and land-cover change respectively (Figure 5.10). Full details of the responses of each species under each future scenario are included in Appendix Table 5.1.

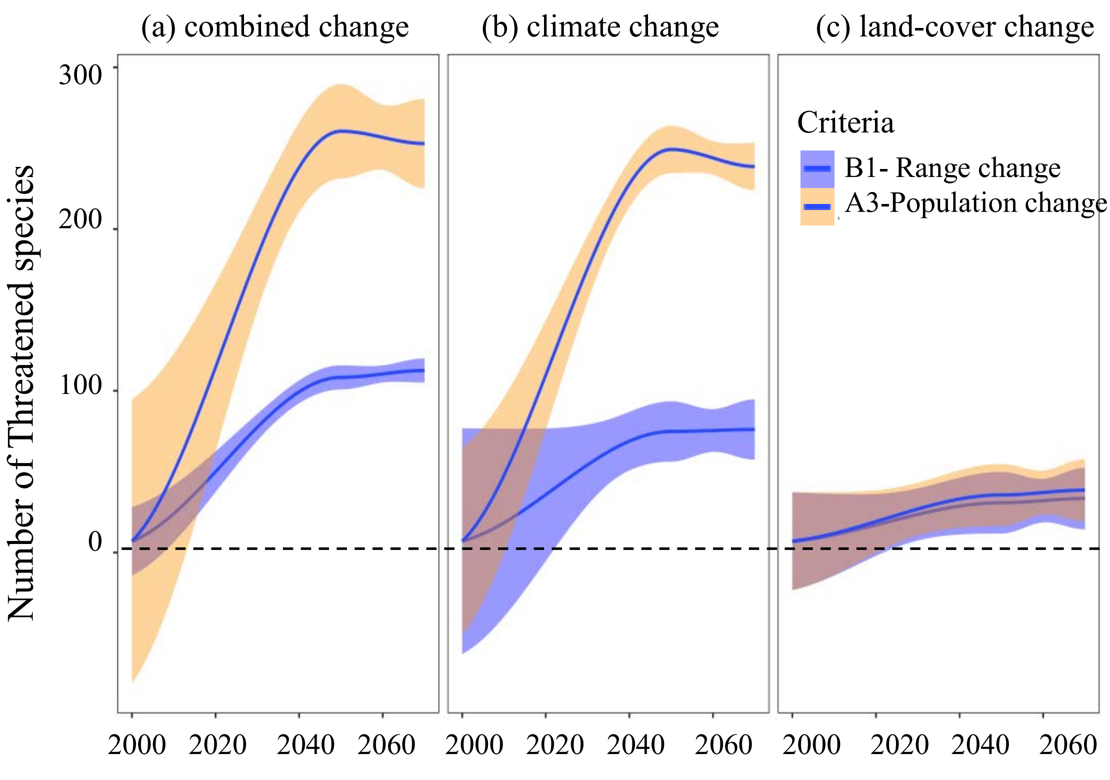


Figure 5.10 Projected changes in the number of threatened species due to changes in range size (blue) and population size (orange) based on future scenarios of land cover change, climatic change and the combination. Uncertainty is represented based on the mean and variability (±SE) across all species and all future scenarios within each category (a total of 1,067,040 SDMs).

5.5 Discussion

I present here the first quantitative assessment of the combined impacts of future climate change and land-cover change on forest birds across the whole of Thailand. Trisurat et al. (2014) conducted a similar study for mammals in one area of northern Thailand and found most of the selected mammal were predicted to lose habitat suitability due to declining forest-cover more than climate change; however, the most severe loss of suitable habitat was the combination of climate change and land-cover change. Several previous studies have been conducted on climate change impacts on some birds in specific areas (Round and Gale, 2008), or land-cover change only (Trisurat et al., 2013).

Firstly, it should be emphasized that the overall impacts on Thailand's biodiversity predicted in this study are truly catastrophic and significantly worse than impacts predicted in many other similar studies worldwide (e.g. Williams et al. 2003, Thomas et al. 2004, Urban 2015). By 2070, under a business-as-usual emission scenario (RCP8.5) and ongoing severe land cover change, approximately 85% of species are projected to experience an average population decline of more than 85%, with almost 200 species predicted to decline to zero population size. The potential for extensive extinction is real and frightening.

Future impacts of change in land cover only are severe with most species losing between 30-90% of their population size by 2070 (Figure 5.6c), however, these impacts are much less severe than those predicted due to climatic change. In general, impacts are dominated by the climate change component. A number of previous studies have highlighted the need to conduct research on the combined impacts of climate and land cover (Trisurat et al., 2014, Ordonez et al., 2014, Fraixedas et al., 2015, Elmhagen et al., 2015, García-Valdés et al., 2015, Osipova and Sangermano, 2016, Frishkoff et al., 2016, Radinger et al., 2016). My results contrast with several previous studies suggesting that land-use change will be more severe than climatic change on tropical birds (Jetz et al., 2007) and mammals in northern Thailand (Trisurat et al., 2014). I would argue that although land cover change has undoubtedly been the most significant impact thus far, climate change will far surpass it in the future. I will discuss this more in Chapter 6.

The analyses suggest that the combined impacts of climate and land cover are partially additive, that is, they are worse than climate or land cover change alone but the combination is less than the sum of the two indicating that there is some overlap in their impacts, an unsurprising result and similar to some previous work (e.g. Mantyka-pringle et al. (2012). The impacts predicted based on changes in range size or population size are qualitatively similar in pattern, however impacts are more extreme in all analyses considering population size (as previously discussed in chapter 4). As could be expected in any projection of global environmental change there will be some species that are winners, some that are not affected and some that are losers, this is the case here with both climate and land cover change impacts. Projected impacts increase with the severity of the emission scenario and time into the future, clearly demonstrating the urgent need for emission reduction to save species and to buy time for adaptation (Warren et al., 2013).

Projected impacts are not uniformly distributed across all ecological subsets of the bird community (figure 5.7). There are relatively uniform impacts in different habitat preference groups which is unexpected as a more severe impact on forest specialists and less impact on generalists was expected. Further work would be needed to test this further however it must be kept in mind that these analyses assume unlimited dispersal. It is likely that the habitat specialists would be much less likely to achieve unlimited dispersal in a matrix of highly modified land cover as is present over much of Thailand. Lowland species fare better than upland endemics, a common pattern globally (Shoo et al., 2005a, Williams et al., 2007, Li et al., 2009, Forero-Medina et al., 2011b, Laurance et al., 2011, Anderson et al., 2013, Freeman and Class Freeman, 2014, Dulle et al., 2016). Southern species from the Sundaic bioregion dominate the group of species expected to increase in the future ("winners"). Many Sundaic species are expected to increase their range and population size as they can increasingly take advantage of more habitat becoming available as the climate warms further to the north in Thailand where there is much larger land areas with forest than in the peninsula. There was no strong differences across the feeding guilds examined with similar levels of sensitivity to the modelled changes across guilds (Figure 5.5 and Figure 5.7). As discussed in Chapter4, there is a suggestion that migrant species will not be as impacted as resident species, however, this would warrant a more detailed analysis of each species and their individual migratory pattern.

Overall, projected changes in the spatial pattern of species richness seem to be numerically driven by climatic change, however, it is mediated in subtle ways by land cover. The loss of species richness is most severe in lowland areas with an increased concentration of species in uplands as species shift distributions into cooler areas. This pattern is most noticeable where there is also existing land cover of upland forest, particularly within the protected forest complexes. This pattern highlights the importance of upland refugia in protected areas with relatively intact forest cover.

The future for Thailand's forest birds is grim given the current trends in global emissions and habitat loss in Thailand. The combined impacts of climate and land cover change could be catastrophic based on the projections in this study, with over 85% of species becoming threatened by 2070 and most of these being critically endangered or potentially extinct by the latter parts of the 21st century. Initially the increase in threatened species is a combination of species becoming vulnerable, endangered, however over time, increasingly severe emission scenarios and with the inclusion of future land cover change, the threat status is dominated by most species becoming critically endangered. In fact, by 2070 the combined models predict that many species have a complete 100% loss of suitable environmental space, potentially resulting in extinction.

Predicting total species extinction is difficult due to lag effects in population decline (Fordham et al. 2016), buffering effects of small refugia protecting small populations at spatial scales below the resolution of the models and the potential for some species to be more resilient than expected due to unknown factors (Williams et al. 2008). However, these models are also relatively conservative for several reasons: they assume completely unlimited dispersal as the suitable environment shifts; they do not account for more severe declines instigated by the loss of a necessary biotic or abiotic interaction; make no allowance for accelerated impacts due to deleterious genetic changes induced by small population size; do not account for increasingly fragmented population structure across a matrix of highly modified land cover and subsequent isolation of suitable habitat patches across Thailand; and, the often large distances between protected forest complexes with highly urbanized and agricultural systems in between. Although predictions of impacts based on species distribution models are recognized to be too extreme in some cases (Maggini et al., 2014, Valladares et al., 2014, Hoffmann et al., 2015), the combination of climatic change and land cover change presented here are likely to actually be conservative.

In conclusions, the huge challenge facing the future of this globally significant biodiversity is both a global issue (emission reduction) and a local issue (existing and ongoing habitat loss) and both will need to be addressed to minimize future impacts (Beaumont et al., 2008, Beaumont and Duursma, 2012). There are limited options for addressing this issue, particularly given the far greater impact of climate; the most important action is the urgent and significant reduction in carbon emissions globally. Some benefits may be realised by protecting upland forest refugia and increasing the protected estate in upland regions across Thailand. Some further benefits could be potentially obtained by systematic, strategic prioritisation in protecting and restoring forest connectivity across the landscape.

Chapter 6:
General discussion

It is now firmly established that anthropogenic climate change and habitat loss are the most significant threats to global biodiversity, the continued functioning of natural ecosystems and the ecosystem services that support human society, economies and general well-being (Pecl et al., 2017). Nowhere is this challenge more important and urgent than in the Tropics where the majority of the world's biodiversity resides in combination with the highest levels of human impacts and land cover change with no signs of this impact decreasing as populations and economies in the tropics continue to rapidly expand. Thailand is such a place with high levels of historical land cover change, globally significant biodiversity and an accelerating economy that inevitably leads to ongoing and accelerating threats to natural ecosystems. Assessment of the spatial and temporal vulnerability of this biodiversity is critically important if there is to be any chance of positive adaptation aimed at minimising the future degradation of Thailand's biodiversity. However, there has been little research on this topic in Thailand and this thesis represents an important step forward by making available for the first time the following knowledge:

1. A systematic, standardised survey of forest bird abundance and community structure right across Thailand covering a large proportion of both geographic and environmental space (Chapter 2);
2. High resolution current distribution maps of forest birds species based on the systematic surveys and a collation of all available bird records from other sources such as museums and bird clubs that are quantitatively linked to climate and habitat (Chapter 3);
3. A quantitative evaluation of the relative contribution of important climate and land cover variables in explaining bird distributions and patterns of species richness across Thailand (Chapter 3);
4. An assessment of the vulnerability of these species to future climate change that includes an examination of the uncertainty of the projects based on different global climate models and different global emission scenarios (Chapter 4); and

5. A quantitative assessment of the relative contribution of climate change and land cover change to the conservation status and level of threat to Thailand's forest birds (Chapter 5).

So what did I find?

Chapter 2 describes the results obtained from the field surveys that were conducted across the latitudinal and elevational gradients covering forests in Thailand. This approach followed and extends previous work done within the Williams research group at James Cook University in the Australian Wet Tropics. Systematically sampling across these important environment gradients provides the highest efficiency in delineating broad patterns of biodiversity and since these two gradients provide a space-for-time substitution to examine temperature, they are particularly useful for predicting climate change impacts (Rahbek, 1995, McCain, 2009a). My data demonstrates that species distributions and assemblage structure was tightly associated with these temperature gradients. Most individual bird species showed an abundance pattern that systematically changed across elevation in all parts of the country and there was significant biogeographic turnover of species associated with the latitudinal gradient. Species richness within forest was surprisingly uniform across many areas although there a tendency for lower richness in the lowlands, a relatively flat pattern across mid-elevations from 500 to 1500 m asl and a slight decline at the uplands (Figures 2.3 and 3.9). Empirical field data in chapter 2 showed species richness declining at higher elevation (Figure 2.3); however, richness based on species distribution models in chapter 3 did not decrease as noticeably (Figure 3.9). The strength of the relationship between assemblage structure and temperature gradients demonstrated in Chapter 2 implies a high likelihood that species distributions and abundance patterns will move higher as global temperatures increase (Figure 2.9a).

Chapter 3 utilises the standarised survey data discussed in chapter 2 and an extensive collation of available bird occurrence data from across Thailand collected in previous research studies, museums, bird clubs, government and individual ornithologists. The dataset represents the most comprehensive source of information on forest birds in Thailand. Using this combined data, I produced high resolution species distribution maps for over 300 species of birds across the entirety of Thailand, in itself a valuable management and policy resource. The analyses presented in Chapter 3 seek to identify which specific environmental variables are the most consistently important across all the species. My analyses clearly suggest that climate is far better at delineating the overall distribution extent of most species than land-cover. However, for each individual species, land-cover is usually the variable that contributes the most to the species distribution model (Figure 3.7). My interpretation of these results is that climate, particularly maximum temperature, annual mean temperature and rainfall seasonality, drives the overall regional species distribution of most species, but within this range, land-cover strongly influences their presence within a specific landscape. This makes intuitive ecological sense and is supported by previous studies examining this question (Thuiller et al., 2004a, Howard et al., 2015). Thus, Chapter 3 results in a strong recommendation that to be able to predict future species distributions and biodiversity pattern well in a world where habitat has already been and continues to be modified, it is crucial to include both climate and land-cover.

Chapter 4 suggests that climate change will be a devastating impact on the forest birds of Thailand with dramatic declines in distribution area and population size with many species likely to become critically endangered or extinct over the remainder of this century. This chapter explores climate change impacts on birds via the widely used approach of correlative species distribution models and projecting future climate change impacts on each species. A quantitative assessment of the uncertainty of these projects was based on using the IPCC emission scenarios and a range of global climate models. My analyses take one important additional step here beyond what is done in most studies of this nature, that is, to assess changes in total population size rather than only distribution area.

Population size has been previously demonstrated to be a much more sensitive and informative parameter in this context (Shoo et al., 2005b, VanDerWal et al., 2009a). Chapter 4 demonstrates that population size declines under future climates are much more severe across many more species than those predicted by distribution changes alone and predict a great many more species becoming critically endangered (Figure 4.10, 4.11, 5.9 and 5.10). Utilising estimates of population size in this manner is biologically more meaningful as it takes into consideration the high resolution spatial distribution of habitat quality as well as the absolute changes in area.

However, as I previously emphasized, more robust projections of future conservation threats to species should be based on a combination of both climate and land-cover. Thus in chapter

5, I combined the scenarios of future climatic change used in chapter 4 with spatially-explicit scenarios of future land-cover change across Thailand to predict the combined impacts on the forest bird biodiversity. The combined effects of climate and land-cover change could be additive, synergistic (greater than the sum), or antagonistic (less than the sum) (Oliver and Morecroft, 2014). The analytical methods I used cannot entirely resolve between these effects, however my results clearly demonstrate that the combination is likely to produce negative impacts on biodiversity vastly greater than either impact separately (Figure 5.10). There is undoubtedly some overlap in impacts however many species are being impacted by both similarly so the combined impact is not purely additive. As shown in previous chapters, climate is the most important factor defining range boundaries but the local presence of a species in any given landscape locality will be strongly influenced by suitable habitat presence (land-cover). It is critical for environmental policy and management decisions to be informed by a consideration of both of these important impacts in order to implement effective conservation adaptation to minimize future losses.

Although the future impacts of climate change are shown to be far greater than future land-cover change, it is important to keep in mind that the impacts of severe habitat loss have already largely happened in this region and this study is starting with a baseline that is already highly impacted. To describe this more carefully, I have constructed a conceptual model of the likely impacts of climate and land-cover on the biodiversity of Thailand's birds (Figure 6.1).

This conceptual model suggest that there have already been significant impacts on biodiversity from the extensive forest loss across Thailand and that in the future approximately a further 30 species of birds will become threated due to land-cover change. However, with current rates of climatic change and weak global emission control, the threat posed by anthropogenic climate change will quickly overtake and swamp the future impacts of further habitat loss. I have not been able to measure the impacts that a changing climate may have already had due to lack of historical data but it is likely, based on global evidence, that there has already been distribution shifts and population decline similar to those observed in the montane rainforests of the Australia Wet Tropics (Williams et al., 2017). This is indicated in Figure 6.1 by the small unmeasured impacts in the climate line. The combined impacts suggested by my analyses are sobering to say the least with well over 80% of all species predicted to be threatened in the future. Conserving Thailand’s incredible biodiversity requires a combination of reducing the ongoing pressure on forests by minimizing further clearing and restoring function in remnants and remaining forests but most critical is the urgent need to control and reduce the global emission of greenhouse gas into the atmosphere. Ultimately, this is the only action that will reduce the potential for catastrophic impacts on biodiversity, ecosystem function and human well-being.

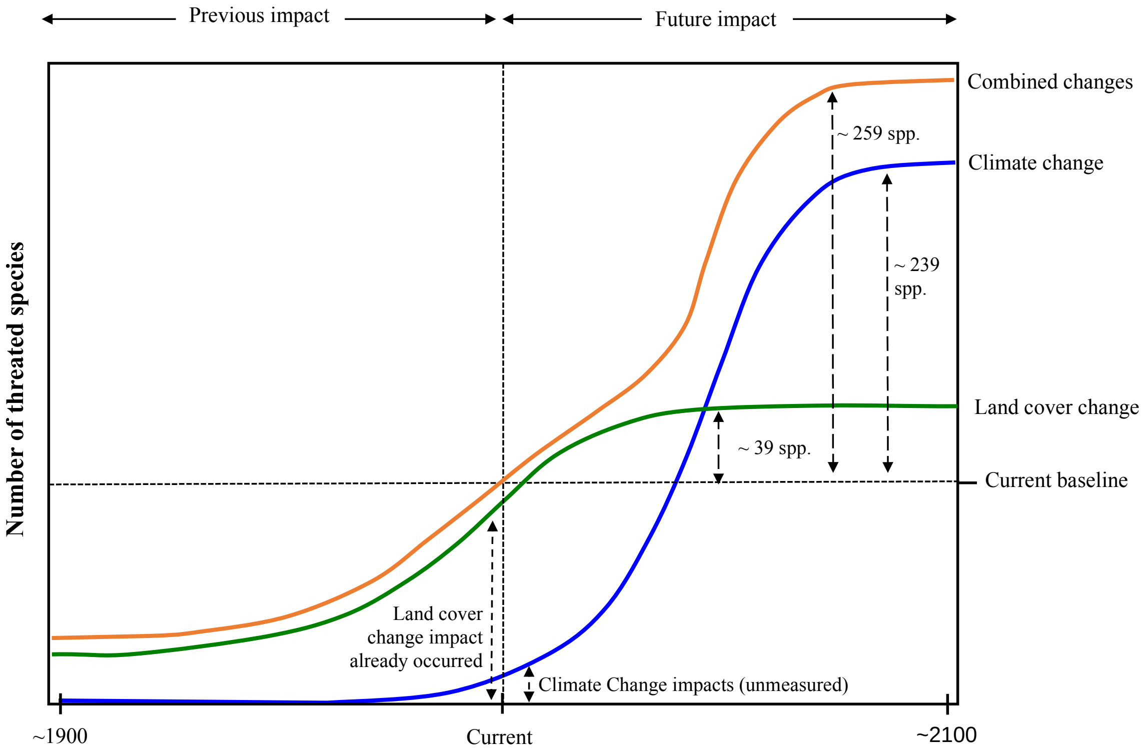


Figure 6.1 Conceptual diagram of the past and future impacts of climate, land-cover change and combined climate and land-cover change on the number of threatened species of tropical forest birds in Thailand.

References

ACHARYA, B. K., SANDERS, N. J., VIJAYAN, L. & CHETTRI, B. 2011. Elevational Gradients in Bird Diversity in the Eastern Himalaya: An Evaluation of Distribution Patterns and Their Underlying Mechanisms. *PLoS ONE,* 6**,** e29097.

AIELLO-LAMMENS, M. E., CHU-AGOR, M. L., CONVERTINO, M., FISCHER, R. A., LINKOV, I. & RESIT AKÇAKAYA, H. 2011. The impact of sea-level rise on Snowy Plovers in Florida: integrating geomorphological, habitat, and metapopulation models. *Global Change Biology,* 17**,** 3644-3654.

AKAIKE, H. 1987. Factor analysis and AIC. *Psychometrika,* 52**,** 317-332.

AKÇAKAYA, H. R., BUTCHART, S. H. M., MACE, G. M., STUART, S. N. & HILTON-TAYLOR, C. 2006. Use and misuse of the IUCN Red List Criteria in projecting climate change impacts on biodiversity. *Glob Chang Biol,* 12**,** 2037-2043.

ALLOUCHE, O., TSOAR, A. & KADMON, R. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *Journal of applied ecology,* 43**,** 1223-1232.

ANDERSON, A. S., STORLIE, C. J., SHOO, L. P., PEARSON, R. G. & WILLIAMS, S. E. 2013. Current Analogues of Future Climate Indicate the Likely Response of a Sensitive Montane Tropical Avifauna to a Warming World. *PLoS ONE,* 8**,** e69393.

ANDREN, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos***,** 355-366.

ANGELO, C. & RIPLEY, B. 2016. *boot: Bootstrap R (S-Plus) Functions*, R package version 1.3-18.

ARAÚJO, B. & RAHBEK, C. 2006. How Does Climate Change Affect Biodiversity? *Science,* 313**,** 1396.

ARAÚJO, M. B., CABEZA, M., THUILLER, W., HANNAH, L. & WILLIAMS, P. H. 2004. Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. *Glob Chang Biol,* 10**,** 1618-1626.

ARAÚJO, M. B. & GUISAN, A. 2006. Five (or so) challenges for species distribution modelling. *Journal of Biogeography,* 33**,** 1677-1688.

ARAÚJO, M. B., PEARSON, R. G., THUILLER, W. & ERHARD, M. 2005. Validation of species–climate impact models under climate change. *Glob Chang Biol,* 11**,** 1504-1513.

ASNER, G. P., LOARIE, S. R. & HEYDER, U. 2010. Combined effects of climate and land-use change on the future of humid tropical forests. *Conservation Letters,* 3**,** 395-403.

BARBET-MASSIN, M., THUILLER, W. & JIGUET, F. 2012. The fate of European breeding birds under climate, land-use and dispersal scenarios. *Global Change Biology,* 18**,** 881-890.

BARBRAUD, C., RIVALAN, P., INCHAUSTI, P., NEVOUX, M., ROLLAND, V. & WEIMERSKIRCH, H. 2011. Contrasted demographic responses facing future climate change in Southern Ocean seabirds. *J Anim Ecol,* 80**,** 89-100.

BARROS, C., GUÉGUEN, M., DOUZET, R., CARBONI, M., BOULANGEAT, I., ZIMMERMANN, N. E., MÜNKEMÜLLER, T., THUILLER, W. & MORI, A. 2017. Extreme climate events counteract the effects of climate and land-use changes in Alpine tree lines. *Journal of Applied Ecology,* 54**,** 39-50.

BCST 2016. Check List Bird of Thailand on August 2016.

BEALE, C. M., BAKER, N. E., BREWER, M. J. & LENNON, J. J. 2013. Protected area networks and savannah bird biodiversity in the face of climate change and land degradation. *Ecology Letters,* 16**,** 1061-1068.

BEAUMONT, L. J., HUGHES, L. & POULSEN, M. 2005. Predicting species distributions: use of climatic parameters in BIOCLIM and its impact on predictions of species' current and future distributions. *Ecological Modelling,* 186**,** 251-270.

BEAUMONT, L. J., MCALLAN, I. A. W. & HUGHES, L. 2006. A matter of timing: changes in the first date of arrival and last date of departure of Australian migratory birds. *Global Change Biology,* 12**,** 1339-1354.

BEAUMONT, L. J., PITMAN, A. J., POULSEN, M. & HUGHES, L. 2007. Where will species go? Incorporating new advances in climate modelling into projections of species distributions. *Glob Chang Biol,* 13**,** 1368-1385.

BEAUMONT, L. J., HUGHES, L. & PITMAN, A. J. 2008. Why is the choice of future climate scenarios for species distribution modelling important? *Ecology Letters,* 11**,** 1135-1146.

BEAUMONT, L. J., PITMAN, A., PERKINS, S., ZIMMERMANN, N. E., YOCCOZ, N. G. & THUILLER, W. 2011. Impacts of climate change on the world's most exceptional ecoregions. *Proceedings of the National Academy of Sciences,* 108**,** 2306-2311.

BEAUMONT, L. J. & DUURSMA, D. 2012. Global Projections of 21st Century Land-Use Changes in Regions Adjacent to Protected Areas. *PLOS ONE,* 7**,** e43714.

BELLARD, C., BERTELSMEIER, C., LEADLEY, P., THUILLER, W. & COURCHAMP, F. 2012. Impacts of climate change on the future of biodiversity. *Ecology Letters,* 15**,** 365-377.

BENISTON, M. 2003. Climatic change in mountain regions: a review of possible impacts. *Climate Variability and Change in High Elevation Regions: Past, Present & Future.* Springer.

BENNETT, J. M., CUNNINGHAM, S. C., CONNELLY, C. A., CLARKE, R. H., THOMSON, J. R. & MAC NALLY, R. 2013. The interaction between a drying climate and land use affects forest structure and above-ground carbon storage. *Global Ecology and Biogeography,* 22**,** 1238-1247.

BERRY, P. M., ROUNSEVELL, M. D. A., HARRISON, P. A. & AUDSLEY, E. 2006. Assessing the vulnerability of agricultural land use and species to climate change and the role of policy in facilitating adaptation. *Environmental Science & Policy,* 9**,** 189-204.

BESTION, E., TEYSSIER, A., RICHARD, M., CLOBERT, J. & COTE, J. 2015. Live Fast, Die Young: Experimental Evidence of Population Extinction Risk due to Climate Change. *PLoS Biol,* 13**,** e1002281.

BETHKE, R. W. & NUDDS, T. D. 1995. Effects of Climate Change and Land Use on Duck Abundance in Canadian Prairie-Parklands. *Ecological Applications,* 5**,** 588-600.

BIVAND, R., TIM KEITT, BARRY ROWLINGSON, EDZER PEBESMA, MICHAEL SUMNER, ROBERT HIJMANS & ROUAULT, E. 2016. *rgdal: Bindings for the Geospatial Data Abstraction Library*, R package version 1.1-10.

BLAKE, J. G. & LOISELLE, B. A. 2000. Diversity of birds along an elevational gradient in the Cordillera central, Costa Rica. *The Auk,* 117**,** 663-686.

BOMHARD, B., RICHARDSON, D. M., DONALDSON, J. S., HUGHES, G. O., MIDGLEY, G. F., RAIMONDO, D. C., REBELO, A. G., ROUGET, M. & THUILLER, W. 2005. Potential impacts of future land use and climate change on the Red List status of the Proteaceae in the Cape Floristic Region, South Africa. *Glob Chang Biol,* 11**,** 1452-1468.

BONEBRAKE, T. C. & MASTRANDREA, M. D. 2010. Tolerance adaptation and precipitation changes complicate latitudinal patterns of climate change impacts. *Proceedings of the National Academy of Sciences,* 107**,** 12581-12586.

BOTH, C., BOUWHUIS, S., LESSELLS, C. M. & VISSER, M. E. 2006. Climate change and population declines in a long-distance migratory bird. *Nature,* 441**,** 81-83.

BOTH, C. & TE MARVELDE, L. 2007. Climate change and timing of avian breeding and migration throughout Europe. *Climate Research,* 35**,** 93-105.

BOTH, C., VAN TURNHOUT, C. A. M., BIJLSMA, R. G., SIEPEL, H., VAN STRIEN, A. J. & FOPPEN, R. P. B. 2010. Avian population consequences of climate change are most severe for long-distance migrants in seasonal habitats. *Proceedings of the Royal Society B-Biological Sciences,* 277**,** 1259-1266.

BOUCHER-LALONDE, V., THÉRIAULT, F. L. & CURRIE, D. J. 2014. Can climate explain interannual local extinctions among bird species? *Journal of Biogeography,* 41**,** 443-451.

BRAWN, J. D., BENSON, T. J., STAGER, M., SLY, N. D. & TARWATER, C. E. 2016. Impacts of changing rainfall regime on the demography of tropical birds. *Nature Climate Change*.

BRODIE, J., POST, E. & LAURANCE, W. F. 2012. Climate change and tropical biodiversity: a new focus. *Trends in Ecology & Evolution,* 27**,** 145-150.

BROOK, B. W., AKÇAKAYA, H. R., KEITH, D. A., MACE, G. M., PEARSON, R. G. & ARAÚJO, M. B. 2009. Integrating bioclimate with population models to improve forecasts of species extinctions under climate change. *Biol Lett,* 5**,** 723-725.

BROOK, B. W., SODHI, N. S. & BRADSHAW, C. J. A. 2008. Synergies among extinction drivers under global change. *Trends in Ecology & Evolution,* 23**,** 453-460.

BUCKLIN, D. N., BASILLE, M., BENSCOTER, A. M., BRANDT, L. A., MAZZOTTI, F. J., ROMAÑACH, S. S., SPEROTERRA, C. & WATLING, J. I. 2015. Comparing species distribution models constructed with different subsets of environmental predictors. *Diversity and distributions,* 21**,** 23-35.

CAMPBELL, J. B. & WYNNE, R. H. 2011. *Introduction to remote sensing*, Guilford Press.

CARR, J. A., HUGHES, A.F., FODEN, W.B. 2014. A Climate Change Vulnerability Assessment of West African Species.

CHADWICK, R., GOOD, P., MARTIN, G. & ROWELL, D. P. 2015. Large rainfall changes consistently projected over substantial areas of tropical land. *Nature Climate Change*.

CHAMBERS, L. E., BEAUMONT, L. J. & HUDSON, I. L. 2014. Continental scale analysis of bird migration timing: influences of climate and life history traits—a generalized mixture model clustering and discriminant approach. *International Journal of Biometeorology,* 58**,** 1147-1162.

CHAO, A., CHAZDON, R. L., COLWELL, R. K. & SHEN, T.-J. 2005. A new statistical approach for assessing similarity of species composition with incidence and abundance data. *Ecology Letters,* 8**,** 148-159.

CHAO, A. & CHIU, C. H. 2016. Species richness: estimation and comparison. *Wiley StatsRef: Statistics Reference Online***,** 1-26.

CHEN, I.-C., HILL, J. K., OHLEMÜLLER, R., ROY, D. B. & THOMAS, C. D. 2011. Rapid Range Shifts of Species Associated with High Levels of Climate Warming. *Science,* 333**,** 1024-1026.

CHEN, I.-C., SHIU, H.-J., BENEDICK, S., HOLLOWAY, J. D., CHEY, V. K., BARLOW, H. S., HILL, J. K. & THOMAS, C. D. 2009. Elevation increases in moth assemblages over 42 years on a tropical mountain. *Proceedings of the National Academy of Sciences,* 106**,** 1479-1483.

CHETTRI, B., BHUPATHY, S. & ACHARYA, B. K. 2010. Distribution pattern of reptiles along an eastern Himalayan elevation gradient, India. *Acta Oecologica,* 36**,** 16-22.

CLAVERO, M., VILLERO, D. & BROTONS, L. 2011. Climate change or land use dynamics: do we know what climate change indicators indicate? *PLoS One,* 6**,** e18581.

COLWELL, R. K., BREHM, G., CARDELÚS, C. L., GILMAN, A. C. & LONGINO, J. T. 2008. Global Warming, Elevational Range Shifts, and Lowland Biotic Attrition in the Wet Tropics. *Science,* 322**,** 258-261.

COLWELL, ROBERT K., CARSTEN RAHBEK & NICHOLAS J. GOTELLI 2004. The Mid‐Domain Effect and Species Richness Patterns: What Have We Learned So Far? *The American Naturalist,* 163**,** E1-E23.

CRAIG, R. 2004. A Field Guide to the Birds of Thailand. New Holland, London, United Kingdom.

CRAIG, R. 2009. A Field Guide to the Birds of South-East Asia. Bloomsbury Publishing PLC, London, United Kingdom.

CRICK, H. Q. P. 2004. The impact of climate change on birds. *Ibis,* 146**,** 48-56.

DALE, V. H. 1997. The relationship between land-use cange and climate change. *Ecological Applications,* 7**,** 753-769.

DARLING, E. S., MCCLANAHAN, T. R. & CÔTÉ, I. M. 2010. Combined effects of two stressors on Kenyan coral reefs are additive or antagonistic, not synergistic. *Conservation Letters,* 3**,** 122-130.

DAVID, M., ACHIM ZEILEIS, KURT HORNIK, FLORIAN GERBER & FRIENDLY, M. 2015. *vcd: Visualizing Categorical Data*, R package version 1.4-1.

DAWSON, T. P., JACKSON, S. T., HOUSE, J. I., PRENTICE, I. C. & MACE, G. M. 2011. Beyond Predictions: Biodiversity Conservation in a Changing Climate. *Science,* 332**,** 53-58.

DE CHAZAL, J. & ROUNSEVELL, M. D. A. 2009. Land-use and climate change within assessments of biodiversity change: A review. *Global Environmental Change,* 19**,** 306-315.

DEUTSCH, C. A., TEWKSBURY, J. J., HUEY, R. B., SHELDON, K. S., GHALAMBOR, C. K., HAAK, D. C. & MARTIN, P. R. 2008. Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences,* 105**,** 6668-6672.

DISTLER, T., SCHUETZ, J. G., VELÁSQUEZ-TIBATÁ, J. & LANGHAM, G. M. 2015. Stacked species distribution models and macroecological models provide congruent projections of avian species richness under climate change. *Journal of Biogeography,* 42**,** 976-988.

DORMANN, C. F., SCHYMANSKI, S. J., CABRAL, J., CHUINE, I., GRAHAM, C., HARTIG, F., KEARNEY, M., MORIN, X., RÖMERMANN, C. & SCHRÖDER, B. 2012. Correlation and process in species distribution models: bridging a dichotomy. *Journal of Biogeography,* 39**,** 2119-2131.

DOUGLAS, B., M. MAECHLER, B. BOLKER & WALKER, S. 2015. Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software,* 67**,** 1-48.

DULLE, H. I., FERGER, S. W., CORDEIRO, N. J., HOWELL, K. M., SCHLEUNING, M., BÖHNING-GAESE, K. & HOF, C. 2016. Changes in abundances of forest understorey birds on Africa's highest mountain suggest subtle effects of climate change. *Diversity and Distributions,* 22**,** 288-299.

DULLINGER, S., GATTRINGER, A., THUILLER, W., MOSER, D., ZIMMERMANN, N. E., GUISAN, A., WILLNER, W., PLUTZAR, C., LEITNER, M. & MANG, T. 2012. Extinction debt of high-mountain plants under twenty-first-century climate change. *Nature Climate Change,* 2**,** 619-622.

EDZER, P., ROGER BIVAND, BARRY ROWLINGSON, VIRGILIO GOMEZ-RUBIO, ROBERT HIJMANS, MICHAEL SUMNER, DON MACQUEEN, JIM LEMON & O'BRIEN, J. 2016. *sp: Classes and Methods for Spatial Data*, R package version 1.2-3.

EGLINGTON, S. M. & PEARCE-HIGGINS, J. W. 2012. Disentangling the relative importance of changes in climate and land-use intensity in driving recent bird population trends. *PLoS One,* 7**,** e30407.

ELITH, J. & GRAHAM, C. H. 2009. Do they? How do they? WHY do they differ? On finding reasons for differing performances of species distribution models. *Ecography,* 32**,** 66-77.

ELITH, J., H. GRAHAM*, C., P. ANDERSON, R., DUDÍK, M., FERRIER, S., GUISAN, A., J. HIJMANS, R., HUETTMANN, F., R. LEATHWICK, J., LEHMANN, A., LI, J., G. LOHMANN, L., A. LOISELLE, B., MANION, G., MORITZ, C., NAKAMURA, M., NAKAZAWA, Y., MCC. M. OVERTON, J., TOWNSEND PETERSON, A., J. PHILLIPS, S., RICHARDSON, K., SCACHETTI-PEREIRA, R., E. SCHAPIRE, R., SOBERÓN, J., WILLIAMS, S., S. WISZ, M. & E. ZIMMERMANN, N. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography,* 29**,** 129-151.

ELITH, J., KEARNEY, M. & PHILLIPS, S. 2010. The art of modelling range-shifting species. *Methods in Ecology and Evolution,* 1**,** 330-342.

ELITH, J. & LEATHWICK, J. R. 2009. Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. *Annual Review of Ecology, Evolution, and Systematics,* 40**,** 677-697.

ELMHAGEN, B., DESTOUNI, G., ANGERBJÖRN, A., BORGSTRÖM, S., BOYD, E., COUSINS, S. A. O., DALÉN, L., EHRLÉN, J., ERMOLD, M., HAMBÄCK, P. A., HEDLUND, J., HYLANDER, K., JARAMILLO, F., LAGERHOLM, V. K., LYON, S. W., MOOR, H., NYKVIST, B., PASANEN-MORTENSEN, M., PLUE, J., PRIETO, C., VAN DER VELDE, Y. & LINDBORG, R. 2015. Interacting effects of change in climate, human population, land use, and water use on biodiversity and ecosystem services. *Ecology and Society,* 20.

ESRI. 2014. *ArcGIS for Destop* [Online]. Available: http://www.esri.com/ [Accessed].

EVANGELISTA, P. H., KUMAR, S., STOHLGREN, T. J. & YOUNG, N. E. 2011. Assessing forest vulnerability and the potential distribution of pine beetles under current and future climate scenarios in the Interior West of the US. *Forest Ecology and Management,* 262**,** 307-316.

FENG, X., PORPORATO, A. & RODRIGUEZ-ITURBE, I. 2013. Changes in rainfall seasonality in the tropics. *Nature Climate Change,* 3**,** 811-815.

FERRARINI, A., ALATALO, J. M. & GUSTIN, M. 2017. Climate change will seriously impact bird species dwelling above the treeline: A prospective study for the Italian Alps. *Science of The Total Environment,* 590–591**,** 686-694.

FIELDING, A. H. & BELL, J. F. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental conservation,* 24**,** 38-49.

FLOUSEK, J., TELENSKY, T., HANZELKA, J. & REIF, J. 2015. Population Trends of Central European Montane Birds Provide Evidence for Adverse Impacts of Climate Change on High-Altitude Species. *PLoS One,* 10**,** e0139465.

FODEN, W. B., BUTCHART, S. H. M., STUART, S. N., VIÉ, J.-C., AKÇAKAYA, H. R., ANGULO, A., DEVANTIER, L. M., GUTSCHE, A., TURAK, E., CAO, L., DONNER, S. D., KATARIYA, V., BERNARD, R., HOLLAND, R. A., HUGHES, A. F., O'HANLON, S. E., GARNETT, S. T., ŞEKERCIOĞLU, Ç. H. & MACE, G. M. 2013. Identifying the World's Most Climate Change Vulnerable Species: A Systematic Trait-Based Assessment of all Birds, Amphibians and Corals. *PLoS One,* 8**,** e65427.

FORERO-MEDINA, G., JOPPA, L. & PIMM, S. L. 2011a. Constraints to Species' Elevational Range Shifts as Climate Changes. *Conservation Biology,* 25**,** 163-171.

FORERO-MEDINA, G., TERBORGH, J., SOCOLAR, S. J. & PIMM, S. L. 2011b. Elevational Ranges of Birds on a Tropical Montane Gradient Lag behind Warming Temperatures. *PLoS ONE,* 6**,** e28535.

FACULTY OF FORESTRY. 2012. Ecological corridor study for important forest complexes in Thailand.

FOURCADE, Y., ENGLER, J. O., RÖDDER, D. & SECONDI, J. 2014. Mapping Species Distributions with MAXENT Using a Geographically Biased Sample of Presence Data: A Performance Assessment of Methods for Correcting Sampling Bias. *PLoS ONE,* 9**,** e97122.

FOX, R., OLIVER, T. H., HARROWER, C., PARSONS, M. S., THOMAS, C. D. & ROY, D. B. 2014. Long-term changes to the frequency of occurrence of British moths are consistent with opposing and synergistic effects of climate and land-use changes. *J Appl Ecol,* 51**,** 949-957.

FRAIXEDAS, S., LEHIKOINEN, A. & LINDÉN, A. 2015. Impacts of climate and land-use change on wintering bird populations in Finland. *Journal of Avian Biology,* 46**,** 63-72.

FRANCO, A. M. A., HILL, J. K., KITSCHKE, C., COLLINGHAM, Y. C., ROY, D. B., FOX, R., HUNTLEY, B. & THOMAS, C. D. 2006. Impacts of climate warming and habitat loss on extinctions at species' low-latitude range boundaries. *Glob Chang Biol,* 12**,** 1545-1553.

FREEMAN, B. G. & CLASS FREEMAN, A. M. 2014. Rapid upslope shifts in New Guinean birds illustrate strong distributional responses of tropical montane species to global warming. *Proceedings of the National Academy of Sciences,* 111**,** 4490-4494.

FRISHKOFF, L. O., HADLY, E. A. & DAILY, G. C. 2015. Thermal niche predicts tolerance to habitat conversion in tropical amphibians and reptiles. *Glob Chang Biol,* 21**,** 3901-16.

FRISHKOFF, L. O., KARP, D. S., FLANDERS, J. R., ZOOK, J., HADLY, E. A., DAILY, G. C. & M'GONIGLE, L. K. 2016. Climate change and habitat conversion favour the same species. *Ecol Lett,* 19**,** 1081-90.

FU, C., HUA, X., LI, J., CHANG, Z., PU, Z. & CHEN, J. 2006. Elevational patterns of frog species richness and endemic richness in the Hengduan Mountains, China: geometric constraints, area and climate effects. *Ecography,* 29**,** 919-927.

GALE, G. A., ROUND, P. D., PIERCE, A. J., NIMNUAN, S., PATTANAVIBOOL, A. & BROCKELMAN, W. Y. 2009. A Field Test of Distance Sampling Methods for a Tropical Forest Bird Community *The Auk,* 126**,** 439-448.

GARCÍA-VALDÉS, R., SVENNING, J.-C., ZAVALA, M. A., PURVES, D. W. & ARAÚJO, M. B. 2015. Evaluating the combined effects of climate and land-use change on tree species distributions. *Journal of Applied Ecology,* 52**,** 902-912.

GARDALI, T., SEAVY, N. E., DIGAUDIO, R. T. & COMRACK, L. A. 2012. A Climate Change Vulnerability Assessment of California's At-Risk Birds. *PLoS ONE,* 7**,** e29507.

GASNER, M. R., JANKOWSKI, J. E., CIECKA, A. L., KYLE, K. O. & RABENOLD, K. N. 2010. Projecting the local impacts of climate change on a Central American montane avian community. *Biological Conservation,* 143**,** 1250-1258.

GAÜZÈRE, P., JIGUET, F., DEVICTOR, V. & LOYOLA, R. 2016. Can protected areas mitigate the impacts of climate change on bird's species and communities? *Diversity and Distributions,* 22**,** 625-637.

GIBSON-REINEMER, D. K., SHELDON, K. S. & RAHEL, F. J. 2015. Climate change creates rapid species turnover in montane communities. *Ecol Evol,* 5**,** 2340-7.

GILLINGHAM, P. K., PALMER, S. C. F., HUNTLEY, B., KUNIN, W. E., CHIPPERFIELD, J. D. & THOMAS, C. D. 2012. The relative importance of climate and habitat in determining the distributions of species at different spatial scales: a case study with ground beetles in Great Britain. *Ecography,* 35**,** 831-838.

GOTELLI, N. J. & COLWELL, R. K. 2011. Estimating species richness. *in A. E. Magurran and B. J. McGill, editors. Frontiers in measuring biodiversity. Oxford University Press, New York***,** 39-54.

GRAHAM, C. H., MORITZ, C. & WILLIAMS, S. E. 2006. Habitat history improves prediction of biodiversity in forest fauna. *Proceedings of the National Academy of Sciences of the United States of America,* 103**,** 632-636.

GREGORY, R. D., WILLIS, S. G., JIGUET, F., VOŘÍŠEK, P., KLVAŇOVÁ, A., VAN STRIEN, A., HUNTLEY, B., COLLINGHAM, Y. C., COUVET, D. & GREEN, R. E. 2009. An Indicator of the Impact of Climatic Change on European Bird Populations. *PLoS ONE,* 4**,** e4678.

GREGORY, R. W., BEN BOLKER, LODEWIJK BONEBAKKER, ROBERT GENTLEMAN, WOLFGANG HUBER ANDY LIAW, THOMAS LUMLEY, MARTIN MAECHLER, ARNI MAGNUSSON, STEFFEN MOELLER, MARC SCHWARTZ & VENABLES, B. 2016. gplots: Various R Programming Tools for Plotting Data. R package version 3.0.1.

GUO, Q., KELT, D. A., SUN, Z., LIU, H., HU, L., REN, H. & WEN, J. 2013. Global variation in elevational diversity patterns. *Scientific Reports,* 3**,** 3007.

HANNAH, L., MIDGLEY, G. F. & MILLAR, D. 2002. Climate change-integrated conservation strategies. *Global Ecology and Biogeography,* 11**,** 485-495.

HARRIS, J. B. C., DWI PUTRA, D., GREGORY, S. D., BROOK, B. W., PRAWIRADILAGA, D. M., SODHI, N. S., WEI, D. & FORDHAM, D. A. 2014. Rapid deforestation threatens mid-elevational endemic birds but climate change is most important at higher elevations. *Diversity and Distributions,* 20**,** 773-785.

HARRIS, J. B. C., SEKERCIOGLU, C. H., SODHI, N. S., FORDHAM, D. A., PATON, D. C. & BROOK, B. W. 2011. The tropical frontier in avian climate impact research. *Ibis,* 153**,** 877-882.

HEIKKINEN, R., LUOTO, M., LEIKOLA, N., PÖYRY, J., SETTELE, J., KUDRNA, O., MARMION, M., FRONZEK, S. & THUILLER, W. 2010. Assessing the vulnerability of European butterflies to climate change using multiple criteria. *Biodiversity and Conservation,* 19**,** 695-723.

HERZOG, S. K., KESSLER, M. & BACH, K. 2005. The elevational gradient in Andean bird species richness at the local scale: a foothill peak and a high-elevation plateau. *Ecography,* 28**,** 209-222.

HIJMANS, R. J., CAMERON, S. E., PARRA, J. L., JONES, P. G. & JARVIS, A. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology,* 25**,** 1965-1978.

HIJMANS, R. J. & ELITH, J. 2014. Species distribution modeling with R.

HIJMANS, R. J., JACOB VAN ETTEN, JOE CHENG, MATTEO MATTIUZZI, MICHAEL SUMNER, JONATHAN A. GREENBERG, OSCAR PERPINAN LAMIGUEIRO, ANDREW BEVAN, ETIENNE B. RACINE & SHORTRIDGE, A. 2015. raster: Geographic Data Analysis and Modeling.

HIJMANS, R. J., JACOB VAN ETTEN, JOE CHENG, MATTEO MATTIUZZI, MICHAEL SUMNER, JONATHAN A. GREENBERG, OSCAR PERPINAN LAMIGUEIRO, ANDREW BEVAN, ETIENNE B. RACINE & SHORTRIDGE, A. 2016. *raster: Geographic Data Analysis and Modeling*, R package version 2.5-8.

HOF, A. R., JANSSON, R. & NILSSON, C. 2012. The usefulness of elevation as a predictor variable in species distribution modelling. *Ecological Modelling,* 246**,** 86-90.

HOF, C., ARAUJO, M. B., JETZ, W. & RAHBEK, C. 2011. Additive threats from pathogens, climate and land-use change for global amphibian diversity. *Nature,* 480**,** 516-9.

HOFFMANN, D., VASCONCELOS, M. F. D. & MARTINS, R. R. P. 2015. How climate change can affect the distribution range and conservation status of an endemic bird from the highlands of eastern Brazil: the case of the Gray-backed Tachuri, Polystictus superciliaris (Aves, Tyrannidae). *Biota Neotropica.,* 15**,** e20130075.

HOWARD, C., STEPHENS, P. A., PEARCE-HIGGINS, J. W., GREGORY, R. D. & WILLIS, S. G. 2015. The drivers of avian abundance: patterns in the relative importance of climate and land use. *Global Ecology and Biogeography,* 24**,** 1249-1260.

HU, W., WU, F., GAO, J., YAN, D., LIU, L. & YANG, X. 2016. Influences of interpolation of species ranges on elevational species richness gradients. *Ecography***,** n/a-n/a.

HUEY, R. B., KEARNEY, M. R., KROCKENBERGER, A., HOLTUM, J. A. M., JESS, M. & WILLIAMS, S. E. 2012. Predicting organismal vulnerability to climate warming: roles of behaviour, physiology and adaptation. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 367**,** 1665-1679.

HUGHES, A. C. 2017. Understanding the drivers of Southeast Asian biodiversity loss. *Ecosphere* 8, 1-33.

HUGHES, A. C., SATASOOK, C., BATES, P. J. J., BUMRUNGSRI, S. & JONES, G. 2012. The projected effects of climatic and vegetation changes on the distribution and diversity of Southeast Asian bats. *Glob Chang Biol,* 18, 1854-1865.

HUGHES J. B. , P. D. R. & WOODRUFF, D. S. 2003. The location of the Indochinese-Sundaic biogeographic transition in plants and birds. *NAT. HlsT. BULL. SIAM SOC.,* 51, 97-108.

HUGHES, J. B., ROUND, P. D. & WOODRUFF, D. S. 2003. The Indochinese–Sundaic faunal transition at the Isthmus of Kra: an analysis of resident forest bird species distributions. *Journal of Biogeography,* 30, 569-580.

IPCC. 2012. *Managing the risks of extreme events and disasters to advance climate change adaptation. ,* Cambridge, UK, and New York, NY, USA., Cambridge University Press.

IPCC. 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,.

IPCC. 2014. *Climate Change 2014: Impacts, Adaptation and Vulnerability. Working Group II contribution to the IPCC 5th Assessment Report*

IUCN. 2001. *IUCN Red List Categories and Criteria*, IUCN.

IUCN. 2017. Guidelines for application of IUCN Red List Criteria. Version 13. *Prepared by the Standards and Petitions Subcommittee. Downloadable from* http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

JENKINS, C. N., PIMM, S. L. & JOPPA, L. N. 2013. Global patterns of terrestrial vertebrate diversity and conservation. *Proceedings of the National Academy of Sciences,* 110, E2602-E2610.

JENOUVRIER, S. 2013. Impacts of climate change on avian populations. *Glob Chang Biol,* 19, 2036-2057.

JENOUVRIER, S., CASWELL, H., BARBRAUD, C., HOLLAND, M., STRŒVE, J., WEIMERSKIRCH, H. 2009. Correction for Jenouvrier et al., Demographic models and IPCC climate projections predict the decline of an emperor penguin population. *Proceedings of the National Academy of Sciences,* 106, 11425-11425.

JETZ, W., WILCOVE, D. S. & DOBSON, A. P. 2007. Projected Impacts of Climate and Land-Use Change on the Global Diversity of Birds. *PLoS Biol,* 5**,** e157.

JIGUET, F., DEVICTOR, V., OTTVALL, R., VAN TURNHOUT, C., VAN DER JEUGD, H. & LINDSTRÖM, Å. 2010. Bird population trends are linearly affected by climate change along species thermal ranges. *Proceedings of the Royal Society B: Biological Sciences,* 277**,** 3601-3608.

JIMÉNEZ-VALVERDE, A., BARVE, N., LIRA-NORIEGA, A., MAHER, S. P., NAKAZAWA, Y., PAPEŞ, M., SOBERÓN, J., SUKUMARAN, J. & PETERSON, A. T. 2011. Dominant climate influences on North American bird distributions. *Global Ecology and Biogeography,* 20**,** 114-118.

JONES, C. C. 2012. Challenges in predicting the future distributions of invasive plant species. *Forest Ecology and Management,* 284**,** 69-77.

JUMP, A. S., MÁTYÁS, C. & PEÑUELAS, J. 2009. The altitude-for-latitude disparity in the range retractions of woody species. *Trends in Ecology & Evolution,* 24**,** 694-701.

KATTAN, G. H. & FRANCO, P. 2004. Bird diversity along elevational gradients in the Andes of Colombia: area and mass effects. *Global Ecology and Biogeography,* 13**,** 451-458.

KEITH, D. A., AKÇAKAYA, H. R., THUILLER, W., MIDGLEY, G. F., PEARSON, R. G., PHILLIPS, S. J., REGAN, H. M., ARAÚJO, M. B. & REBELO, T. G. 2008. Predicting extinction risks under climate change: coupling stochastic population models with dynamic bioclimatic habitat models. *Biol Lett,* 4**,** 560-563.

KEITH, D. A., MAHONY, M., HINES, H., ELITH, J., REGAN, T. J., BAUMGARTNER, J. B., HUNTER, D., HEARD, G. W., MITCHELL, N. J., PARRIS, K. M., PENMAN, T., SCHEELE, B., SIMPSON, C. C., TINGLEY, R., TRACY, C. R., WEST, M. & AKCAKAYA, H. R. 2014. Detecting extinction risk from climate change by IUCN Red List criteria. *Conserv Biol,* 28**,** 810-9.

KEITH, D. A., RODRÍGUEZ, J. P., BROOKS, T. M., BURGMAN, M. A., BARROW, E. G., BLAND, L., COMER, P. J., FRANKLIN, J., LINK, J., MCCARTHY, M. A., MILLER, R. M., MURRAY, N. J., NEL, J., NICHOLSON, E., OLIVEIRA-MIRANDA, M. A., REGAN, T. J., RODRÍGUEZ-CLARK, K. M., ROUGET, M. & SPALDING, M. D. 2015. The IUCN Red List of Ecosystems: Motivations, Challenges, and Applications. *Conservation Letters,* 8**,** 214-226.

KENT, C., CHADWICK, R. & ROWELL, D. P. 2015. Understanding Uncertainties in Future Projections of Seasonal Tropical Precipitation. *Journal of Climate,* 28**,** 4390-4413.

KLORVUTTIMONTARA, S., MCCLEAN, C. J. & HILL, J. K. 2011. Evaluating the effectiveness of Protected Areas for conserving tropical forest butterflies of Thailand. *Biological Conservation,* 144**,** 2534-2540.

KOH, L. P., KETTLE, C. J., SHEIL, D., LEE, T. M., GIAM, X., GIBSON, L. & CLEMENTS, G. R. 2013. Biodiversity State and Trends in Southeast Asia. *In:* EDITOR-IN-CHIEF: SIMON, A. L. (ed.) *Encyclopedia of Biodiversity (Second Edition).* Waltham: Academic Press.

KÖRNER, C. 2000. Why are there global gradients in species richness? mountains might hold the answer. *Trends in Ecology & Evolution,* 15**,** 513-514.

KRAMER-SCHADT, S., NIEDBALLA, J., PILGRIM, J. D., SCHRÖDER, B., LINDENBORN, J., REINFELDER, V., STILLFRIED, M., HECKMANN, I., SCHARF, A. K., AUGERI, D. M., CHEYNE, S. M., HEARN, A. J., ROSS, J., MACDONALD, D. W., MATHAI, J., EATON, J., MARSHALL, A. J., SEMIADI, G., RUSTAM, R., BERNARD, H., ALFRED, R., SAMEJIMA, H., DUCKWORTH, J. W., BREITENMOSER-WUERSTEN, C., BELANT, J. L., HOFER, H. & WILTING, A. 2013. The importance of correcting for sampling bias in MaxEnt species distribution models. *Diversity and Distributions,* 19**,** 1366-1379.

LA SORTE, F. A. & JETZ, W. 2010a. Avian distributions under climate change: towards improved projections. *J Exp Biol,* 213**,** 862-869.

LA SORTE, F. A. & JETZ, W. 2010b. Projected range contractions of montane biodiversity under global warming. *Proceedings of the Royal Society B: Biological Sciences,* 277**,** 3401-3410.

LAURANCE, W. F., CAROLINA USECHE, D., SHOO, L. P., HERZOG, S. K., KESSLER, M., ESCOBAR, F., BREHM, G., AXMACHER, J. C., CHEN, I. C., GÁMEZ, L. A., HIETZ, P., FIEDLER, K., PYRCZ, T., WOLF, J., MERKORD, C. L., CARDELUS, C., MARSHALL, A. R., AH-PENG, C., APLET, G. H., DEL CORO ARIZMENDI, M., BAKER, W. J., BARONE, J., BRÜHL, C. A., BUSSMANN, R. W., CICUZZA, D., EILU, G., FAVILA, M. E., HEMP, A., HEMP, C., HOMEIER, J., HURTADO, J., JANKOWSKI, J., KATTÁN, G., KLUGE, J., KRÖMER, T., LEES, D. C., LEHNERT, M., LONGINO, J. T., LOVETT, J., MARTIN, P. H., PATTERSON, B. D., PEARSON, R. G., PEH, K. S. H., RICHARDSON, B., RICHARDSON, M., SAMWAYS, M. J., SENBETA, F., SMITH, T. B., UTTERIDGE, T. M. A., WATKINS, J. E., WILSON, R., WILLIAMS, S. E. & THOMAS, C. D. 2011. Global warming, elevational ranges and the vulnerability of tropical biota. *Biological Conservation,* 144**,** 548-557.

LDD. 2014. Land use 2012 classification Bangkok, Thailnd: Land and Development Department.

LEE, P.-F., DING, T.-S., HSU, F.-H. & GENG, S. 2004. Breeding bird species richness in Taiwan: distribution on gradients of elevation, primary productivity and urbanization. *Journal of Biogeography,* 31**,** 307-314.

LEE, T. & JETZ, W. 2011. Unravelling the structure of species extinction risk for predictive conservation science. *Proceedings of the Royal Society B: Biological Sciences,* 278**,** 1329-1338.

LEKAGUL, B. and P. D. ROUND. 1991. A guide to the birds of Thailand. Saha Karn Bhaet Co, Thailand.

LEMOINE, N., BAUER, H.-G., PEINTINGER, M. & BÖHNING-GAESE, K. 2007. Effects of Climate and Land-Use Change on Species Abundance in a Central European Bird Community. *Conservation Biology,* 21**,** 495-503.

LI, J. I. N., HILBERT, D. W., PARKER, T. & WILLIAMS, S. 2009. How do species respond to climate change along an elevation gradient? A case study of the grey-headed robin (Heteromyias albispecularis). *Glob Chang Biol,* 15**,** 255-267.

LIMSAKUL, A. 2011. *Thailand's First Assessment Report on Climate Change 2011; working group I: Scientific Basis of Climate Change,* Bangkok, Thailand, Wiki Ltd.

LIU, C., WHITE, M., NEWELL, G. & GRIFFIOEN, P. 2013. Species distribution modelling for conservation planning in Victoria, Australia. *Ecological Modelling,* 249**,** 68-74.

LUOTO, M., VIRKKALA, R. & HEIKKINEN, R. K. 2007. The role of land cover in bioclimatic models depends on spatial resolution. *Global Ecology and Biogeography,* 16**,** 34-42.

MACLEAN, I. M. D. & WILSON, R. J. 2011. Recent ecological responses to climate change support predictions of high extinction risk. *Proceedings of the National Academy of Sciences,* 108**,** 12337-12342.

MAGGINI, R., LEHMANN, A., ZBINDEN, N., ZIMMERMANN, N. E., BOLLIGER, J., SCHRÖDER, B., FOPPEN, R., SCHMID, H., BENISTON, M. & JENNI, L. 2014. Assessing species vulnerability to climate and land use change: the case of the Swiss breeding birds. *Diversity and distributions,* 20**,** 708-719.

MAINA, J., DE MOEL, H., VERMAAT, J. E., HENRICH BRUGGEMANN, J., GUILLAUME, M. M. M., GROVE, C. A., MADIN, J. S., MERTZ-KRAUS, R. & ZINKE, J. 2012. Linking coral river runoff proxies with climate variability, hydrology and land-use in Madagascar catchments. *Marine Pollution Bulletin,* 64**,** 2047-2059.

MANTYKA-PRINGLE, C. S., MARTIN, T. G. & RHODES, J. R. 2012. Interactions between climate and habitat loss effects on biodiversity: a systematic review and meta-analysis. *Glob Chang Biol,* 18**,** 1239-1252.

MANTYKA-PRINGLE, C. S., VISCONTI, P., DI MARCO, M., MARTIN, T. G., RONDININI, C. & RHODES, J. R. 2015. Climate change modifies risk of global biodiversity loss due to land-cover change. *Biological Conservation,* 187**,** 103-111.

MARINI, M. Â., BARBET-MASSIN, M., LOPES, L. E. & JIGUET, F. 2009. Predicted Climate-Driven Bird Distribution Changes and Forecasted Conservation Conflicts in a Neotropical Savanna. *Conservation Biology,* 23**,** 1558-1567.

MARTIN, Y., VAN DYCK, H., DENDONCKER, N. & TITEUX, N. 2013. Testing instead of assuming the importance of land use change scenarios to model species distributions under climate change. *Global Ecology and Biogeography,* 22**,** 1204-1216.

MCCAIN, C. M. 2004. The mid-domain effect applied to elevational gradients: species richness of small mammals in Costa Rica. *Journal of Biogeography,* 31**,** 19-31.

MCCAIN, C. M. 2005. Elevational gradients in diversity of small mammals. *Ecology,* 86**,** 366-372.

MCCAIN, C. M. 2006. Could temperature and water availability drive elevational species richness patterns? A global case study for bats. *Global Ecology and Biogeography,* 0**,** 061120101210015-???

MCCAIN, C. M. 2009a. Global analysis of bird elevational diversity. *Global Ecology and Biogeography,* 18**,** 346-360.

MCCAIN, C. M. 2009b. Vertebrate range sizes indicate that mountains may be 'higher' in the tropics. *Ecology Letters,* 12**,** 550-560.

MCCAIN, C. M. & JOHN-ARVID, G. 2010. Elevational Gradients in Species Richness. *Encyclopedia of Life Science (ELS).* John Wiley & Sons, Ltd: Chichester.

MCKINNEY, M. L. 1997. Extinction vulnerability and selectivity: combining ecological and paleontological views. *Annual Review of Ecology and Systematics,* 28**,** 495-516.

MENG, H., CARR, J., BERADUCCI, J., BOWLES, P., BRANCH, W. R., CAPITANI, C., CHENGA, J., COX, N., HOWELL, K., MALONZA, P., MARCHANT, R.,

MBILINYI, B., MUKAMA, K., MSUYA, C., PLATTS, P. J., SAFARI, I., SPAWLS, S., SHENNAN-FARPON, Y., WAGNER, P. & BURGESS, N. D. 2016. Tanzania's reptile biodiversity: Distribution, threats and climate change vulnerability. *Biological Conservation*.

MERRILL, R. M., GUTIÉRREZ, D., LEWIS, O. T., GUTIÉRREZ, J., DÍEZ, S. B. & WILSON, R. J. 2008. Combined effects of climate and biotic interactions on the elevational range of a phytophagous insect. *Journal of Animal Ecology,* 77**,** 145-155.

MØLLER, A. P., RUBOLINI, D. & LEHIKOINEN, E. 2008. Populations of migratory bird species that did not show a phenological response to climate change are declining. *Proceedings of the National Academy of Sciences,* 105**,** 16195-16200.

MORA, C., METZGER, R., ROLLO, A. & MYERS, R. A. 2007. Experimental simulations about the effects of overexploitation and habitat fragmentation on populations facing environmental warming. *Proceedings of the Royal Society B: Biological Sciences,* 274**,** 1023-1028.

MURRELL, P. 2005. *R Graphics*, Chapman & Hall/CRC Press.

MYERS, N., MITTERMEIER, R. A., MITTERMEIER, C. G., DA FONSECA, G. A. & KENT, J. 2000. Biodiversity hotspots for conservation priorities. *Nature,* 403**,** 853-858.

NAKAO, K., HIGA, M., TSUYAMA, I., MATSUI, T., HORIKAWA, M. & TANAKA, N. 2013. Spatial conservation planning under climate change: Using species distribution modeling to assess priority for adaptive management of Fagus crenata in Japan. *Journal for Nature Conservation,* 21**,** 406-413.

NAPHEETHAPAT, J., LEKAKUL, B. & SANGUANSOMBAT, W. 2012. Bird of Thailand: Birds-watching handbook. Bangkok, Thailand: Boonsong Lakakul Press.

NESDB 2017. The Twelfth National Economic and Social Development Plan (2017 - 2021). Bangkok, Thailand: Office of the National Economic and Social Development Board Office of the Prime Minister.

NEWBOLD, T., HUDSON, L. N., HILL, S. L., CONTU, S., LYSENKO, I., SENIOR, R. A., BORGER, L., BENNETT, D. J., CHOIMES, A., COLLEN, B., DAY, J., DE PALMA, A., DIAZ, S., ECHEVERRIA-LONDONO, S., EDGAR, M. J., FELDMAN, A., GARON, M., HARRISON, M. L., ALHUSSEINI, T., INGRAM, D. J., ITESCU, Y., KATTGE, J., KEMP, V., KIRKPATRICK, L., KLEYER, M., CORREIA, D. L., MARTIN, C. D., MEIRI, S., NOVOSOLOV, M., PAN, Y., PHILLIPS, H. R., PURVES, D. W., ROBINSON, A., SIMPSON, J., TUCK, S. L., WEIHER, E.,

WHITE, H. J., EWERS, R. M., MACE, G. M., SCHARLEMANN, J. P. & PURVIS, A. 2015. Global effects of land use on local terrestrial biodiversity. *Nature,* 520**,** 45-50.

NEWBOLD, T., SCHARLEMANN, J. P., BUTCHART, S. H., SEKERCIOGLU, C. H., ALKEMADE, R., BOOTH, H. & PURVES, D. W. 2013. Ecological traits affect the response of tropical forest bird species to land-use intensity. *Proc Biol Sci,* 280**,** 20122131.

OKSANEN, J., F. GUILLAUME BLANCHET, ROELAND KINDT, PIERRE LEGENDRE, PETER R. MINCHIN, R. B. O'HARA, GAVIN L. SIMPSON, PETER SOLYMOS, M. HENRY H. STEVENS & WAGNER, H. 2015. vegan: Community Ecology Package.

OLIVER, T. H. & MORECROFT, M. D. 2014. Interactions between climate change and land use change on biodiversity: attribution problems, risks, and opportunities. *Wiley Interdisciplinary Reviews: Climate Change,* 5**,** 317-335.

ONEP 2007. *Thailand Red Data: Vertebrates,* Bangkok, Thailand, Office of Natural Resources and Environmental Policy and Planning, Ministry of Natural Resources and Environment.

ORDONEZ, A., MARTINUZZI, S., RADELOFF, V. C. & WILLIAMS, J. W. 2014. Combined speeds of climate and land-use change of the conterminous US until 2050. *Nature Climate Change,* 4**,** 811-816.

OSIPOVA, L. & SANGERMANO, F. 2016. Surrogate species protection in Bolivia under climate and land cover change scenarios. *Journal for Nature Conservation,* 34**,** 107-117.

PACIFICI, M., FODEN, W. B., VISCONTI, P., WATSON, J. E. M., BUTCHART, S. H. M., KOVACS, K. M., SCHEFFERS, B. R., HOLE, D. G., MARTIN, T. G., AKCAKAYA, H. R., CORLETT, R. T., HUNTLEY, B., BICKFORD, D., CARR, J. A., HOFFMANN, A. A., MIDGLEY, G. F., PEARCE-KELLY, P., PEARSON, R. G., WILLIAMS, S. E., WILLIS, S. G., YOUNG, B. & RONDININI, C. 2015. Assessing species vulnerability to climate change. *Nature Clim. Change,* 5**,** 215-224.

PAN, X., DING, Z., HU, Y., LIANG, J., WU, Y., SI, X., GUO, M., HU, H. & JIN, K. 2016. Elevational pattern of bird species richness and its causes along a central Himalaya gradient, China. *PeerJ,* 4**,** e2636.

PARMESAN, C. 2006. Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution, and Systematics,* 37**,** 637-669.

PARMESAN, C., BURROWS, M. T., DUARTE, C. M., POLOCZANSKA, E. S., RICHARDSON, A. J., SCHOEMAN, D. S. & SINGER, M. C. 2013. Beyond climate change attribution in conservation and ecological research. *Ecology Letters,* 16**,** 58-71.

PARMESAN, C. & YOHE, G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature,* 421**,** 37-42.

PEARCE-HIGGINS, J. W., EGLINGTON, S. M., MARTAY, B. & CHAMBERLAIN, D. E. 2015. Drivers of climate change impacts on bird communities. *J Anim Ecol,* 84**,** 943-54.

PEARSON, R. G. & DAWSON, T. P. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Global Ecology and Biogeography,* 12**,** 361-371.

PEARSON, R. G., DAWSON, T. P. & LIU, C. 2004. Modelling species distributions in Britain: a hierarchical integration of climate and land-cover data. *Ecography,* 27**,** 285-298.

PECL, G. T., ARAÚJO, M. B., BELL, J. D., BLANCHARD, J., BONEBRAKE, T. C., CHEN, I.-C., CLARK, T. D., COLWELL, R. K., DANIELSEN, F., EVENGÅRD, B., FALCONI, L., FERRIER, S., FRUSHER, S., GARCIA, R. A., GRIFFIS, R. B., HOBDAY, A. J., JANION-SCHEEPERS, C., JARZYNA, M. A., JENNINGS, S., LENOIR, J., LINNETVED, H. I., MARTIN, V. Y., MCCORMACK, P. C., MCDONALD, J., MITCHELL, N. J., MUSTONEN, T., PANDOLFI, J. M., PETTORELLI, N., POPOVA, E., ROBINSON, S. A., SCHEFFERS, B. R., SHAW, J. D., SORTE, C. J. B., STRUGNELL, J. M., SUNDAY, J. M., TUANMU, M.-N., VERGÉS, A., VILLANUEVA, C., WERNBERG, T., WAPSTRA, E. & WILLIAMS, S. E. 2017. Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science,* 355.

PEERY, M. Z., GUTIÉRREZ, R. J., KIRBY, R., LEDEE, O. E. & LAHAYE, W. 2012. Climate change and spotted owls: potentially contrasting responses in the Southwestern United States. *Global Change Biology,* 18**,** 865-880.

PEH, K. S. H. 2007. Potential effects of climate change on elevational distributions of tropical birds in Southeast Asia. *The Condor,* 109(2), 437-441. doi:10.1650/0010-5422(2007)109[437:peocco]2.0.co;2

PETERSON, A. T., SOBERÓN, J., PEARSON, R. G., ANDERSON, R. P., MARTÍNEZ-MEYER, E., NAKAMURA, M. & ARAÚJO, M. B. 2011. *Ecological Niches and Geographic Distributions (MPB-49)*, Princeton University Press.

PHILLIPS, S. J. 2008. Transferability, sample selection bias and background data in presence-only modelling: a response to Peterson et al. (2007). *Ecography,* 31**,** 272-278.

PHILLIPS, S. J., ANDERSON, R. P. & SCHAPIRE, R. E. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling,* 190**,** 231-259.

PHILLIPS, S. J., DUD, M. & SCHAPIRE, R. E. 2004. A maximum entropy approach to species distribution modeling. *Proceedings of the twenty-first international conference on Machine learning.* Banff, Alberta, Canada: ACM.

PHILLIPS, S. J. & DUDÍK, M. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography,* 31**,** 161-175.

PIMM, S. L., JENKINS, C. N., ABELL, R., BROOKS, T. M., GITTLEMAN, J. L., JOPPA, L. N., RAVEN, P. H., ROBERTS, C. M. & SEXTON, J. O. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. *Science,* 344.

POMPE, S., HANSPACH, J., BADECK, F., KLOTZ, S., THUILLER, W. & KÜHN, I. 2008. Climate and land use change impacts on plant distributions in Germany. *Biol Lett,* 4**,** 564-567.

POST, E., FORCHHAMMER, M. C., BRET-HARTE, M. S., CALLAGHAN, T. V., CHRISTENSEN, T. R., ELBERLING, B., FOX, A. D., GILG, O., HIK, D. S., HØYE, T. T., IMS, R. A., JEPPESEN, E., KLEIN, D. R., MADSEN, J., MCGUIRE, A. D., RYSGAARD, S., SCHINDLER, D. E., STIRLING, I., TAMSTORF, M. P., TYLER, N. J. C., VAN DER WAL, R., WELKER, J., WOOKEY, P. A., SCHMIDT, N. M. & AASTRUP, P. 2009. Ecological Dynamics Across the Arctic Associated with Recent Climate Change. *Science,* 325**,** 1355-1358.

PRATUMTHONG, D. & PATTANAVIBOOL, A. 2006. Bird community structure along altitudinal gradients in a Montane evergreen forest of Umphang Wildlife Sanctuary. *Journal of Wildlife in Thailand,* 13**,** 138-148.

PRESSEY, R. L., CABEZA, M., WATTS, M. E., COWLING, R. M. & WILSON, K. A. 2007. Conservation planning in a changing world. *Trends in Ecology & Evolution,* 22**,** 583-592.

PYRCZ, T. W. & WOJTUSIAK, J. 2002. The vertical distribution of pronophiline butterflies (Nymphalidae, Satyrinae) along an elevational transect in Monte Zerpa (Cordillera de Mérida, Venezuela) with remarks on their diversity and parapatric distribution. *Global Ecology and Biogeography,* 11**,** 211-221.

RADINGER, J., HOLKER, F., HORKY, P., SLAVIK, O., DENDONCKER, N. & WOLTER, C. 2016. Synergistic and antagonistic interactions of future land use and climate change on river fish assemblages. *Glob Chang Biol,* 22**,** 1505-22.

RAHBEK, C. 1995. The elevational gradient of species richness: a uniform pattern? *Ecography,* 18**,** 200-205.

RAHBEK, C. 2005. The role of spatial scale and the perception of large-scale species-richness patterns. *Ecology Letters,* 8**,** 224-239.

RAHBEK, C., GOTELLI, N. J., COLWELL, R. K., ENTSMINGER, G. L., RANGEL, T. F. L. V. B. & GRAVES, G. R. 2007. Predicting continental-scale patterns of bird species richness with spatially explicit models. *Proceedings of the Royal Society B: Biological Sciences,* 274**,** 165-174.

RAXWORTHY, C. J., PEARSON, R. G., RABIBISOA, N., RAKOTONDRAZAFY, A. M., RAMANAMANJATO, J.-B., RASELIMANANA, A. P., WU, S., NUSSBAUM, R. A. & STONE, D. A. 2008. Extinction vulnerability of tropical montane endemism from warming and upslope displacement: a preliminary appraisal for the highest massif in Madagascar. *Global Change Biology,* 14**,** 1703-1720.

REGOS, A., D'AMEN, M., TITEUX, N., HERRANDO, S., GUISAN, A., BROTONS, L. & DI MININ, E. 2016. Predicting the future effectiveness of protected areas for bird conservation in Mediterranean ecosystems under climate change and novel fire regime scenarios. *Diversity and Distributions,* 22**,** 83-96.

REIF, J., VOŘÍŠEK, P., ŠT'ASTNÝ, K., KOSCHOVÁ, M. & BEJČEK, V. 2008. The impact of climate change on long-term population trends of birds in a central European country. *Animal Conservation,* 11**,** 412-421.

RESIDE, A. E., VANDERWAL, J., GARNETT, S. T. & KUTT, A. S. 2016. Vulnerability of Australian tropical savanna birds to climate change. *Austral Ecology,* 41**,** 106-116.

RESIDE, A. E., VANDERWAL, J., KUTT, A., WATSON, I. & WILLIAMS, S. 2012a. Fire regime shifts affect bird species distributions. *Diversity and Distributions,* 18**,** 213-225.

RESIDE, A. E., VANDERWAL, J. & KUTT, A. S. 2012b. Projected changes in distributions of Australian tropical savanna birds under climate change using three dispersal scenarios. *Ecology and evolution,* 2**,** 705-718.

RESIDE, A. E., VANDERWAL, J. J., KUTT, A. S. & PERKINS, G. C. 2010. Weather, Not Climate, Defines Distributions of Vagile Bird Species. *PLoS ONE,* 5**,** e13569.

RFD 2001. Final report of 2000 Forest type classification. Bangkok, Thailand: Royal Forest Department.

RFD 2014. Final report for 2012 Forest classification Bangkok, Thailand: Division of Forest management.

RFD 2015. Foresty Statistic Data 2015. Bangkok, Thailand: The Royal Forest Department.

ROBSON, C. & ALLEN, R. 2008. *A Field Guide to the Birds of South-East Asia*, New Holland.

RODRIGUEZ, J. P., KEITH, D. A., RODRIGUEZ-CLARK, K. M., MURRAY, N. J., NICHOLSON, E., REGAN, T. J., MILLER, R. M., BARROW, E. G., BLAND, L. M., BOE, K., BROOKS, T. M., OLIVEIRA-MIRANDA, M. A., SPALDING, M. & WIT, P. 2015. A practical guide to the application of the IUCN Red List of Ecosystems criteria. *Philos Trans R Soc Lond B Biol Sci,* 370**,** 20140003.

ROOT, T. L., PRICE, J. T., HALL, K. R., SCHNEIDER, S. H., ROSENZWEIG, C. & POUNDS, J. A. 2003. Fingerprints of global warming on wild animals and plants. *Nature,* 421**,** 57-60.

ROSENZWEIG, C., KAROLY, D., VICARELLI, M., NEOFOTIS, P., WU, Q., CASASSA, G., MENZEL, A., ROOT, T. L., ESTRELLA, N., SEGUIN, B., TRYJANOWSKI, P., LIU, C., RAWLINS, S. & IMESON, A. 2008. Attributing physical and biological impacts to anthropogenic climate change. *Nature,* 453**,** 353-357.

ROUND, P. D. & GALE, G. A. 2008. Changes in the Status of Lophura Pheasants in Khao Yai National Park, Thailand: A Response to Warming Climate? *Biotropica,* 40**,** 225-230.

ROUND, P. D., HUGHES, J. B. & WOODRUFF, D. S. 2003. Latitudinal range limits of resident forest birds in Thailand and the Indochinese–Sundaic zoogeographic transition. *Natural History Bulletin of the Siam Society,* 51**,** 69-96.

SAINO, N., AMBROSINI, R., RUBOLINI, D., VON HARDENBERG, J., PROVENZALE, A., HÜPPOP, K., HÜPPOP, O., LEHIKOINEN, A., LEHIKOINEN, E., RAINIO, K., ROMANO, M. & SOKOLOV, L. 2011. Climate warming, ecological mismatch at arrival and population decline in migratory birds. *Proceedings of the Royal Society B: Biological Sciences,* 278**,** 835-842.

SALA, O. E., STUART CHAPIN , F., III, ARMESTO, J. J., BERLOW, E., BLOOMFIELD, J., DIRZO, R., HUBER-SANWALD, E., HUENNEKE, L. F., JACKSON, R. B., KINZIG, A., LEEMANS, R., LODGE, D. M., MOONEY, H. A., OESTERHELD, M.

N., POFF, N. L., SYKES, M. T., WALKER, B. H., WALKER, M. & WALL, D. H. 2000. Global Biodiversity Scenarios for the Year 2100. *Science,* 287**,** 1770-1774.

SANDERS, N. J. & RAHBEK, C. 2012. The patterns and causes of elevational diversity gradients. *Ecography,* 35**,** 1-3.

SANGUANSOMBAT, W. 2005. Thailand Red Data: Birds. Bangkok, Thailand: Office of Natural Resources and Environmental Policy and Planning.

SCHNEIDER, S. H. & ROOT, T. L. 2013. Climate Change and Ecology, Synergism of. *In:* LEVIN, S. A. (ed.) *Encyclopedia of Biodiversity (Second Edition).* Waltham: Academic Press.

SCHWARTZ, M. W., IVERSON, L. R., PRASAD, A. M., MATTHEWS, S. N. & O'CONNOR, R. J. 2006. Predicting extinctions as a result of climate change. *Ecology,* 87**,** 1611-1615.

SEACLID, C.-S. A. 2016. General Circulation Models and RCPs. Southeast Asia Climate Downscaling Experiment (SEACLID). http://www.ukm.my/seaclid-cordex/.

ŞEKERCIOĞLU, Ç. H., PRIMACK, R. B. & WORMWORTH, J. 2012. The effects of climate change on tropical birds. *Biological Conservation,* 148**,** 1-18.

ŞEKERCIOĞLU, Ç. H., SCHNEIDER, S. H., FAY, J. P. & LOARIE, S. R. 2008. Climate Change, Elevational Range Shifts, and Bird Extinctions. *Conservation Biology,* 22**,** 140-150.

SELWOOD, K. E., MCGEOCH, M. A. & MAC NALLY, R. 2014. The effects of climate change and land-use change on demographic rates and population viability. *Biol Rev Camb Philos Soc*.

SHANNON, C. E. & WEAVER, W. 1949. *The Mathematical Theory of Communication.* , University of Illinois Press, Urbana.

SHOO, L. P., WILLIAMS, S. E. & HERO, J.-M. 2005a. Climate warming and the forest birds of the Australian Wet Tropics: Using abundance data as a sensitive predictor of change in total population size. *Biological Conservation,* 125**,** 335-343.

SHOO, L. P., WILLIAMS, S. E. & HERO, J.-M. 2005b. Potential decoupling of trends in distribution area and population size of species with climate change. *Glob Chang Biol,* 11**,** 1469-1476.

SIRAMI, C., CAPLAT, P., POPY, S., CLAMENS, A., ARLETTAZ, R., JIGUET, F., BROTONS, L. & MARTIN, J.-L. 2017. Impacts of global change on species distributions: obstacles and solutions to integrate climate and land use. *Global Ecology and Biogeography,* 26**,** 385-394.

SODHI, N. S., KOH, L. P., BROOK, B. W. & NG, P. K. L. 2004. Southeast Asian biodiversity: an impending disaster. *Trends in Ecology & Evolution,* 19**,** 654-660.

SODHI, N. S., KOH, L. P., CLEMENTS, R., WANGER, T. C., HILL, J. K., HAMER, K. C., CLOUGH, Y., TSCHARNTKE, T., POSA, M. R. C. & LEE, T. M. 2010a. Conserving Southeast Asian forest biodiversity in human-modified landscapes. *Biological Conservation,* 143**,** 2375-2384.

SODHI, N. S. & LIOW, L. H. 2000. Improving Conservation Biology Research in Southeast Asia. *Conservation Biology,* 14**,** 1211-1212.

SODHI, N. S., POSA, M. C., LEE, T., BICKFORD, D., KOH, L. & BROOK, B. W. 2010b. The state and conservation of Southeast Asian biodiversity. *Biodiversity and Conservation,* 19**,** 317-328.

SODHI, N. S., SEKERCIOGLU, C. H., BARLOW, J. & ROBINSON, S. K. 2011. *Conservation of tropical birds*, John Wiley & Sons.

SODHI, N. S. & SMITH, K. G. 2007. Conservation of tropical birds: mission possible? *Journal of Ornithology,* 148**,** 305-309.

SOHL, T. L. 2014. The relative impacts of climate and land-use change on conterminous United States bird species from 2001 to 2075.

SPELLERBERG, I. F. & FEDOR, P. J. 2003. A tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the 'Shannon–Wiener' Index. *Global Ecology and Biogeography,* 12**,** 177-179.

STANTON, J. C., SHOEMAKER, K. T., PEARSON, R. G. & AKCAKAYA, H. R. 2015. Warning times for species extinctions due to climate change. *Glob Chang Biol,* 21**,** 1066-77.

SULTAIRE, S. M., PAULI, J. N., MARTIN, K. J., MEYER, M. W., NOTARO, M. & ZUCKERBERG, B. 2016. Climate change surpasses land-use change in the contracting range boundary of a winter-adapted mammal. *Proc Biol Sci,* 283**,** 20153104.

SUN, Y., WANG, T., SKIDMORE, A. K., PALMER, S. C. F., YE, X., DING, C., WANG, Q. & WINTLE, B. 2016. Predicting and understanding spatio-temporal dynamics of species recovery: implications for Asian crested ibisNipponia nipponconservation in China. *Diversity and Distributions,* 22**,** 893-904.

SUNTHISUK, T. 2006. *Forest of Thailand*, Office of the Forest Herbarium, Department of National Parks, Wildlife and Plant Conservation.

TAYLOR, S. L. & POLLARD, K. S. 2008. Evaluation of Two Methods to Estimate and Monitor Bird Populations. *PLOS ONE,* 3**,** e3047.

TERBORGH, J. 1977. Bird Species Diversity on an Andean Elevational Gradient. *Ecology,* 58**,** 1007-1019.

TEWKSBURY, J. J., HUEY, R. B. & DEUTSCH, C. A. 2008. Putting the heat on tropical animals. *Science,* 320**,** 1296.

THOMAS, C. D., CAMERON, A., GREEN, R. E., BAKKENES, M., BEAUMONT, L. J., COLLINGHAM, Y. C., ERASMUS, B. F. N., DE SIQUEIRA, M. F., GRAINGER, A., HANNAH, L., HUGHES, L., HUNTLEY, B., VAN JAARSVELD, A. S., MIDGLEY, G. F., MILES, L., ORTEGA-HUERTA, M. A., TOWNSEND PETERSON, A., PHILLIPS, O. L. & WILLIAMS, S. E. 2004. Extinction risk from climate change. *Nature,* 427**,** 145-148.

THOMAS, C. D., FRANCO, A. M. A. & HILL, J. K. 2006. Range retractions and extinction in the face of climate warming. *Trends in Ecology & Evolution,* 21**,** 415-416.

THOMAS, C. D. & GILLINGHAM, P. K. 2015. The performance of protected areas for biodiversity under climate change. *The Linnean Society of London, Biological Journal of the Linnean Society,* 115**,** 718-730.

THOMAS, C. D. & WILLIAMSON, M. 2012. Extinction and climate change. *Nature,* 482**,** E4-E5.

THUILLER, W., ARAÚJO, M. B. & LAVOREL, S. 2004a. Do we need land-cover data to model species distributions in Europe? *Journal of Biogeography,* 31**,** 353-361.

THUILLER, W., ARAUJO, M. B., PEARSON, R. G., WHITTAKER, R. J., BROTONS, L. & LAVOREL, S. 2004b. Biodiversity conservation: Uncertainty in predictions of extinction risk. *Nature,* 430.

THUILLER, W., GUÉGUEN, M., GEORGES, D., BONET, R., CHALMANDRIER, L., GARRAUD, L., RENAUD, J., ROQUET, C., VAN ES, J. & ZIMMERMANN, N. E. 2014. Are different facets of plant diversity well protected against climate and land cover changes? A test study in the French Alps. *Ecography,* 37**,** 1254-1266.

TINGLEY, M. W., KOO, M. S., MORITZ, C., RUSH, A. C. & BEISSINGER, S. R. 2012. The push and pull of climate change causes heterogeneous shifts in avian elevational ranges. *Glob Chang Biol,* 18**,** 3279-3290.

TINGLEY, M. W., MONAHAN, W. B., BEISSINGER, S. R. & MORITZ, C. 2009. Birds track their Grinnellian niche through a century of climate change. *Proceedings of the National Academy of Sciences,* 106**,** 19637-19643.

TOBIAS, S., OLIVER SANDER, NIKO BEERENWINKEL & LENGAUER, T. 2015. *ROCR: Visualizing the Performance of Scoring Classifiers*, R package version 1.0-7.

TORSTEN, H., FRANK BRETZ & WESTFALL, P. 2008. Simultaneous Inference in General Parametric Models. *Models. Biometrical Journal,* 50**,** 346--363.

TRISURAT, Y. 2011. *Thailand's First Assessment Report on Climate Change 2011; working group II: Impacts, Vulnerability and Adaptation (Forest and Terrestial Ecosystem),* Bangkok, Thailand, Wiki Ltd.

TRISURAT, Y., ALKEMADE, R. & VERBURG, P. H. 2010. Projecting land-use change and its consequences for biodiversity in northern Thailand. *Environ Manage,* 45**,** 626-39.

TRISURAT, Y., CHIMCHOME, V., PATTANAVIBOOL, A., JINAMOY, S., THONGAREE, S., KANCHANASAKHA, B., SIMCHAROEN, S., SRIBUAROD, K., MAHANNOP, N. & POONSWAD, P. 2013. An assessment of the distribution and conservation status of hornbill species in Thailand. *Oryx,* 47**,** 441-450.

TRISURAT, Y., KANCHANASAKA, B. & KREFT, H. 2014. Assessing potential effects of land use and climate change on mammal distributions in northern Thailand. *Wildlife Research,* 41**,** 522.

URBAN, M. C. 2015. Accelerating extinction risk from climate change. *Science,* 348**,** 571-573.

VALLADARES, F., MATESANZ, S., GUILHAUMON, F., ARAUJO, M. B., BALAGUER, L., BENITO-GARZON, M., CORNWELL, W., GIANOLI, E., VAN KLEUNEN, M., NAYA, D. E., NICOTRA, A. B., POORTER, H. & ZAVALA, M. A. 2014. The effects of phenotypic plasticity and local adaptation on forecasts of species range shifts under climate change. *Ecol Lett,* 17**,** 1351-64.

VAN VUUREN, D. P., EDMONDS, J., KAINUMA, M., RIAHI, K., THOMSON, A., HIBBARD, K., HURTT, G. C., KRAM, T., KREY, V., LAMARQUE, J.-F., MASUI, T., MEINSHAUSEN, M., NAKICENOVIC, N., SMITH, S. J. & ROSE, S. K. 2011. The representative concentration pathways: an overview. *Climatic Change,* 109**,** 5-31.

VANDERWAL, J., FALCONI, L., JANUCHOWSKI, S., SHOO, L. & STORLIE, C. 2011. SDMTools: Species distribution modelling tools: Tools for processing data associated with species distribution modelling exercises. *R package version,* 1.

VANDERWAL, J., LUKE P. SHOO, CHRISTOPHER N. JOHNSON & STEPHEN E. WILLIAMS 2009a. Abundance and the Environmental Niche: Environmental Suitability Estimated from Niche Models Predicts the Upper Limit of Local Abundance. *The American Naturalist,* 174**,** 282-291.

VANDERWAL, J., MURPHY, H. T., KUTT, A. S., PERKINS, G. C., BATEMAN, B. L., PERRY, J. J. & RESIDE, A. E. 2013. Focus on poleward shifts in species' distribution underestimates the fingerprint of climate change. *Nature Clim. Change,* 3**,** 239-243.

VANDERWAL, J., SHOO, L. P., GRAHAM, C. & WILLIAMS, S. E. 2009b. Selecting pseudo-absence data for presence-only distribution modeling: How far should you stray from what you know? *Ecological Modelling,* 220**,** 589-594.

VEDDER, O., BOUWHUIS, S. & SHELDON, B. C. 2013. Quantitative assessment of the importance of phenotypic plasticity in adaptation to climate change in wild bird populations. *PLoS Biol,* 11**,** e1001605.

VELÁSQUEZ-TIBATÁ, J., SALAMAN, P. & GRAHAM, C. 2013. Effects of climate change on species distribution, community structure, and conservation of birds in protected areas in Colombia. *Regional Environmental Change,* 13**,** 235-248.

VENABLES, W. N. & RIPLEY, B. D. 2002. *Modern Applied Statistics with S.,* New York, Springer.

VERBURG & OVERMARS 2009a. The CLUE model. *Landscape Ecology* 24**,** 1167-1181.

VERBURG, P. H. & OVERMARS, K. P. 2009b. Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. *Landscape Ecology,* 24**,** 1167.

VERMAAT, J. E., HELLMANN, F. A., VAN TEEFFELEN, A. J. A., VAN MINNEN, J., ALKEMADE, R., BILLETER, R., BEIERKUHNLEIN, C., BOITANI, L., CABEZA, M., FELD, C. K., HUNTLEY, B., PATERSON, J. & WALLISDEVRIES, M. F. 2017. Differentiating the effects of climate and land use change on European biodiversity: A scenario analysis. *Ambio,* 46**,** 277-290.

VIEILLEDENT, G., CORNU, C., CUNÍ SANCHEZ, A., LEONG POCK-TSY, J.-M. & DANTHU, P. 2013. Vulnerability of baobab species to climate change and effectiveness of the protected area network in Madagascar: Towards new conservation priorities. *Biological Conservation,* 166**,** 11-22.

VIRKKALA, R. 2016. Long-term decline of southern boreal forest birds: consequence of habitat alteration or climate change? *Biodiversity and Conservation,* 25**,** 151-167.

WARREN, R., VANDERWAL, J., PRICE, J., WELBERGEN, J. A., ATKINSON, I., RAMIREZ-VILLEGAS, J., OSBORN, T. J., JARVIS, A., SHOO, L. P., WILLIAMS, S. E. & LOWE, J. 2013. Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss. *Nature Climate Change,* 3**,** 678-682.

WATLING, J. I., ROMAÑACH, S. S., BUCKLIN, D. N., SPEROTERRA, C., BRANDT, L. A., PEARLSTINE, L. G. & MAZZOTTI, F. J. 2012. Do bioclimate variables improve performance of climate envelope models? *Ecological Modelling,* 246**,** 79-85.

WHITE, R. L. & BENNETT, P. M. 2015. Elevational distribution and extinction risk in birds. *PLoS One***,** 1-17.

WILLIAMS, J. W., JACKSON, S. T. & KUTZBACH, J. E. 2007. Projected distributions of novel and disappearing climates by 2100 AD. *Proceedings of the National Academy of Sciences,* 104**,** 5738-5742.

WILLIAMS, S., LARINA, F. & CRAIG, M. 2016. State of Wet Tropics Report 2015-2016. Ancient, Endemic, Rare and Threatened Vetebrate of the Wet Tropics.

WILLIAMS, S. E., BOLITHO, E. E. & FOX, S. 2003. Climate change in Australian tropical forests: an impending environmental catastrophe. *Proceedings of the Royal Society of London. Series B: Biological Sciences,* 270**,** 1887-1892.

WILLIAMS, S. E., FALCONI, L. E., LOWE, A., BOWMAN, D., GARNETT, S., KITCHING, R., MORITZ, C., CHRISTMAS, M., BOULTER, S. & ISAAC, J. 2017. National Climate Change Adaptation Research Plan: Terrestrial Biodiversity: Update 2017. Gold Coast: National Climate Change Adaptation research Facility.

WILLIAMS, S. E. & MIDDLETON, J. 2008. Climatic seasonality, resource bottlenecks, and abundance of forest birds: implications for global climate change. *Diversity and Distributions,* 14**,** 69-77.

WILLIAMS, S. E., SHOO, L. P., HENRIOD, R. & PEARSON, R. G. 2010. Elevational gradients in species abundance, assemblage structure and energy use of forest birds in the Australian Wet Tropics bioregion. *Austral Ecology,* 35**,** 650-664.

WILLIAMS, S. E., SHOO, L. P., ISAAC, J. L., HOFFMANN, A. A. & LANGHAM, G. 2008. Towards an Integrated Framework for Assessing the Vulnerability of Species to Climate Change. *PLoS Biol,* 6**,** e325.

WILSON, R. J., GUTIÉRREZ, D., GUTIÉRREZ, J., MARTÍNEZ, D., AGUDO, R. & MONSERRAT, V. J. 2005. Changes to the elevational limits and extent of species ranges associated with climate change. *Ecology Letters,* 8**,** 1138-1146.

WOODRUFF, D. S. & TURNER, L. M. 2009. The Indochinese–Sundaic zoogeographic transition: a description and analysis of terrestrial mammal species distributions. *Journal of Biogeography,* 36**,** 803-821.

WORMWORTH, J. M., KARL 2006. Bird species and climate change: The Global Status Report: A synthesis of current scientific understanding of anthropogenic climate change impacts on global bird species now, and projected future effects. *echnical Report. Climate Risk Pty Limited (Australia), Fairlight, New South Wales*.

WU, Y., COLWELL, R. K., RAHBEK, C., ZHANG, C., QUAN, Q., WANG, C. & LEI, F. 2013a. Explaining the species richness of birds along a subtropical elevational gradient in the Hengduan Mountains. *Journal of Biogeography,* 40**,** 2310-2323.

WU, Y., YANG, Q., WEN, Z., XIA, L., ZHANG, Q. & ZHOU, H. 2013b. What drives the species richness patterns of non-volant small mammals along a subtropical elevational gradient? *Ecography,* 36**,** 185-196.

YACKULIC, C. B., CHANDLER, R., ZIPKIN, E. F., ROYLE, J. A., NICHOLS, J. D., CAMPBELL GRANT, E. H., & VERAN, S. (2013). Presence-only modelling using MAXENT: when can we trust the inferences? *Methods in Ecology and Evolution, 4*(3), 236-243. doi:10.1111/2041-210x.12004

YAMAURA, Y., AMANO, T., KOIZUMI, T., MITSUDA, Y., TAKI, H. & OKABE, K. 2009. Does land-use change affect biodiversity dynamics at a macroecological scale? A case study of birds over the past 20 years in Japan. *Animal Conservation,* 12**,** 110-119.

YU X-D, LU¨L, LUO T-H & H-Z, Z. 2013. Elevational Gradient in Species Richness Pattern of Epigaeic Beetles and Underlying Mechanisms at East Slope of Balang Mountain in Southwestern China. *PLoS ONE,* 8**,** e69177.

ZHANG, J., NIELSEN, S. E., CHEN, Y., GEORGES, D., QIN, Y., WANG, S.-S., SVENNING, J.-C. & THUILLER, W. 2016. Extinction risk of North American seed plants elevated by climate and land-use change. *Journal of Applied Ecology,* 54**,** 303-312.

Appendices

Appendices in the text

Appendix Table 1

Species list of Thailand's forest birds with species code used in species distribution Models, also list of ecological subgroups, current conservation with global status (IUCN) and Thailand status, number of individual recorded by survey within each subregion, and remark as Mc is a list of species used in the species distribution model only; Mobs is list of species used in species distribution model and data analysi in Chapter 2; and Obs is list of species used in observed analysis in Chapter 2 only.

List of ecological subgroup:

1. Habitat groups: EFS = evergreen forest specialist; EDS = evergreen forest specialist but occur in deciduous forest; EBS = evergreen forest specialist but occur in bamboo forest; EOS = evergreen forest specialist but occur in edge forest, open area, and other (not include forest); GEN - occur in evergreen forest but common in other forest, occur in evergreen forest but common in edge forest, open area and other (not include forest area); and NOF = never occur in evergreen forest). Habitat preferences follow the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012).

2. Feeding guilds:F = frugivorous; G = granivorous; I = insectivorous; N = nectarivorous; O = omnivorous; R = raptor, and S = scavenger). Feeding guilds defined by Lekagul and Round (1991), Round et al., (2003), and Napheethapat et al. (2012).

3. Elevational range limits: L = lowland ; M = montane ;W = widespread. Elevational range limits defined on published elevational range limits (Round et al., 2003, Napheethapat et al., 2012).

4. Biogeographic subregions: IN = Indochinese; INS = Indochinese-southern cross; S = Sundaic; SN = Sundaic-northern cross; and W = widespread. Thailand's birds occur in an overlap zone between two major zoogeographic clades of birds - the Indochinese and Sundaic subregions of the Oriental zoogeographic region, defined groups based on the definitions provided by Hughes et al. (2003), Round et al. (2003) and the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012).

5. Seasonal migratory classes: B = breeding visitor; N = non-breeding visitor; NR = mainly non-breeding visitor but maybe resident; R= resident or presumed resident; RN = mainly resident but maybe non-breeding visitor; P = mainly spring and autumn passage migrant, and U = uncertainty according to the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012, BCST, 2016).

Current conservation status: Thai means the current conservation status within Thailand; IUCN means the globally current conservation status. IN = increase; NT = near threatened; VU = vulnerable; EN = endangered; and CR = critically endangered.

Subregions: DI = Doi Inthanon; HK = Huai Kha Khaeng; KY = Khao Yai; KK = Kaeng Krachan; HL = Hala Bala.

Remarks: Mc = species used in the species distribution model only; Mobs = species used in species distribution model and data analysi in Chapter 2; and Obs = species used in observed analysis in Chapter 2 only.

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	**Feed**	**Ele**	**Geo**	**Mig**	**Thai**	**IUCN**	**DI**	**HK**	**KY**	**KK**	**HL**	
ABAB	Pellorneidae	Abbott's Babbler	*Malacocincla abbotti*	EDS	O	W	W	R				x	x	x		Mobs
ABFC	Muscicapidae	Asian Brown Flycatcher	*Muscicapa dauurica*	NOF	I	W	IN	NR			x	x	x	x	x	Mobs
ABHB	Bucerotidae	Austen's Brown Hornbill	*Anorrhinus austeni*	EBS	O	L	IN	R		NT			x	x		Mobs
ABOL	Strigidae	Asian Barred Owlet	*Glaucidium cuculoides*	EBS	O	W	INS	R			x	x	x	x		Mobs
ADCK	Cuculidae	Asian Drongo Cuckoo	*Surniculus lugubris*	EBS	I	W	W	RN			x	x	x	x	x	Mobs
ADG	Dicruridae	Ashy Drongo	*Dicrurus leucophaeus*	NOF	I	W	W	RN			x	x	x	x		Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
AECK	Cuculidae	Asian Emerald Cuckoo	*Chrysococcyx maculatus*	EOS	I	W	IN	R			x	x	x	x		Mc
AFBL	Irenidae	Asian Fairy-bluebird	*Irena puella*	EDS	F	W	W	R			x	x	x	x	x	Mobs
AFC	Falconidae	Amur Falcon	*Falco amurensis*	EDS	I	L	SN	P			x					Obs
AKE	Cuculidae	Asian Koel	*Eudynamys scolopaceus*	EDS	I	L	INS	R					x			Obs
ALWB	Phylloscopidae	Alström's Warbler	*Seicercus soror*	EDS	I	W	W	N			x	x	x	x		Mobs
AMIN	Campephagidae	Ashy Minivet	*Pericrocotus divaricatus*	EDS	I	W	W	N				x	x			Mobs
APFC	Monarchidae	Asian Paradise-flycatcher	*Terpsiphone paradisi*	EDS	I	W	W	RN			x	x		x	x	Mobs
APSW	Apodidae	Asian Palm Swift	*Cypsiurus balasiensis*	GEN	I	W	W	R					x	x		Mobs
ARBUL	Pycnonotidae	Asian Red-eyed Bulbul	*Pycnonotus brunneus*	NOF	O	L	SN	R							x	Mobs
ARWB	Phylloscopidae	Arctic Warbler	*Phylloscopus borealis*	EOS	I	W	W	N			x	x	x	x	x	Mobs
ASBUL	Pycnonotidae	Ashy Bulbul	*Hemixos flavala*	EDS	O	W	W	R					x	x		Mobs
ASLWB	Phylloscopidae	Ashy-throated Leaf Warbler	*Phylloscopus maculipennis*	EDS	I	M	IN	R	VU		x					Mobs
ASMAR	Hirundinidae	Asian House Martin	*Delichon dasypus*	GEN	I	W	W	NR			x		x	x	x	Mc
ASST	Cettiidae	Asian Stubtail	*Urosphena squameiceps*	EBS	O	W	IN	N			x	x				Mobs
ATB	Cisticolidae	Ashy Tailorbird	*Orthotomus ruficeps*	EOS	I	W	W	R							x	Obs
AWPG	Columbidae	Ashy Wood Pigeon	*Columba pulchricollis*	EDS	F	W	IN	R			x					Obs
AWSW	Artamidae	Ashy Woodswallow	*Artamus fuscus*	GEN	I	W	W	R					x			Obs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
BABB	Eurylaimidae	Banded Broadbill	*Eurylaimus javanicus*	EFS	I	W	W	R				x	x	x	x	Mobs
BBBE	Meropidae	Blue-bearded Bee-eater	*Nyctyornis athertoni*	EFS	I	W	INS	R			x	x	x	x		Mobs
BBBO	Strigidae	Brown Boobook	*Ninox scutulata*	EFS	I	L	S	R					x			Obs
BBCK	Cuculidae	Banded Bay Cuckoo	*Cacomantis sonneratii*	EOS	I	W	W	R			x	x	x	x	x	Mobs
BBKF	Alcedinidae	Blue-banded Kingfisher	*Alcedo euryzona*	EFS	O	L	SN	R	VU	VU		x			x	Mobs
BBMK	Cuculidae	Black-bellied Malkoha	*Phaenicophaeus diardi*	EFS	I	L	SN	R		NT					x	Mobs
BBNT	Apodidae	Brown-backed Needletail	*Hirundapus giganteus*	EDS	O	W	W	R						x		Obs
BBP	Phasianidae	Bar-backed Partridge	*Arborophila brunneopectus*	EFS	O	L	IN	R	NT			x				Mobs
BBUL	Pycnonotidae	Black Bulbul	*Hypsipetes leucocephalus*	EDS	O	M	IN	RN			x					Mobs
BBWB	Locustellidae	Baikal Bush Warbler	*Locustella davidi*	GEN	I	L	SN	N			x					Obs
BBWP	Picidae	Bamboo Woodpecker	*Gecinulus viridis*	EDS	I	W	W	R				x		x		Obs
BBZ	Accipitridae	Black Baza	*Aviceda leuphotes*	GEN	I	W	W	RN			x			x		Obs
BCBAB	Pellorneidae	Black-capped Babbler	*Pellorneum capistratum*	EDS	I	W	W	R							x	Obs
BCBUL	Pycnonotidae	Black-crested Bulbul	*Pycnonotus flaviventris*	EDS	O	W	W	R			x	x	x	x	x	Mobs
BCDV	Columbidae	Barred Cuckoo Dove	*Macropygia unchall*	EDS	F	W	W	R			x		x			Mobs
BCFV	Pellorneidae	Brown-cheeked Fulvetta	*Alcippe poioicephala*	EFS	I	W	W	R			x	x	x	x		Mobs
BCHB	Bucerotidae	Bushy-crested Hornbill	*Anorrhinus galeritus*	EFS	O	L	SN	R	NT						x	Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
BDG	Dicruridae	Black Drongo	*Dicrurus macrocercus*	NOF	I	W	W	RN			x	x	x	x		Mobs
BEBB	Megalaimidae	Blue-eared Barbet	*Megalaima australis*	EBS	O	W	W	R				x	x	x	x	Mobs
BEKF	Alcedinidae	Blue-eared Kingfisher	*Alcedo meninting*	EDS	I	W	IN	R					x			Obs
BFM	Podargidae	Blyth's Frogmouth	*Batrachostomus affinis*	EDS	I	W	W	R				x	x			Obs
BFO	Strigidae	Brown Fish Owl	*Ketupa zeylonensis*	GEN	I	W	W	R						x		Obs
BFSK	Tephrodornithidae	Bar-winged Flycatcher-shrike	*Hemipus picatus*	EDS	I	W	W	R			x	x	x		x	Mobs
BFV	Pellorneidae	Brown Fulvetta	*Alcippe brunneicauda*	EFS	I	L	S	R		NT					x	Mobs
BFWP	Picidae	Black-and-buff Woodpecker	*Meiglyptes jugularis*	EOS	I	W	W	R				x				Obs
BHBUL	Pycnonotidae	Black-headed Bulbul	*Pycnonotus atriceps*	EDS	O	W	W	R			x	x	x	x	x	Mobs
BHE	Accipitridae	Blyth's Hawk Eagle	*Nisaetus alboniger*	EFS	R	L	S	R							x	Mobs
BHO	Oriolidae	Black-hooded Oriole	*Oriolus xanthornus*	NOF	I	W	W	R				x				Mobs
BHPR	Psittacidae	Blue-crowned Hanging Parrot	*Loriculus galgulus*	EDS	F	L	S	R							x	Mobs
BHWP	Picidae	Black-headed Woodpecker	*Picus erythropygius*	EFS	I	L	S	R				x				Obs
BIWB	Phylloscopidae	Bianchi's Warbler	*Seicercus valentini*	EDS	I	L	IN	R			x			x		Mc
BK	Accipitridae	Black Kite	*Milvus migrans*	EDS	O	W	W	R				x				Obs
BKF	Alcedinidae	Banded Kingfisher	*Lacedo pulchella*	EBS	O	W	W	R				x	x	x	x	Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	**Feed**	**Ele**	**Geo**	**Mig**	**Thai**	**IUCN**	**DI**	**HK**	**KY**	**KK**	**HL**	
BLBKF	Alcedinidae	Black-backed Kingfisher	*Ceyx erithacus*	EFS	O	L	S	R							x	Obs
BLE	Accipitridae	Black Eagle	*Lophaetus malayensis*	EFS	O	L	SN	R						x		Obs
BLFSK	Tephrodornithidae	Black-winged Flycatcher-shrike	*Hemipus hirundinaceus*	EDS	I	W	W	R							x	Obs
BLNO	Oriolidae	Black-naped Oriole	*Oriolus chinensis*	NOF	I	W	W	RN			x	x	x	x		Mobs
BLSUN	Nectariniidae	Black-throated Sunbird	*Aethopyga saturata*	EDS	N	W	W	R			x	x	x	x		Mobs
BLT	Leiothrichidae	Black Laughingthrush	*Melanocichla lugubris*	EFS	I	L	S	R					x			Obs
BLWB	Phylloscopidae	Blyth's Leaf Warbler	*Phylloscopus reguloides*	EDS	I	M	IN	R			x	x	x			Mobs
BNMO	Monarchidae	Black-naped Monarch	*Hypothymis azurea*	EDS	I	W	W	RN			x	x	x	x	x	Mobs
BNWP	Picidae	Buff-necked Woodpecker	*Meiglyptes tukki*	EDS	I	W	W	R		NT					x	Obs
BPTT	Pittidae	Blue Pitta	*Pitta cyanea*	EBS	O	W	W	R				x	x	x		Mobs
BRBB	Megalaimidae	Brown Barbet	*Caloramphus fuliginosus*	EDS	F	W	INS	R							x	Obs
BRDG	Dicruridae	Bronzed Drongo	*Dicrurus aeneus*	EDS	I	W	W	R			x	x	x	x		Mobs
BRMIN	Campephagidae	Brown-rumped Minivet	*Pericrocotus cantonensis*	EDS	I	W	W	N					x	x		Mobs
BROCK	Muscicapidae	Blue Rockthrush	*Monticola solitarius*	NOF	O	L	S	NR					x			Mobs
BRPR	Psittacidae	Blue-rumped Parrot	*Psittinus cyanurus*	EDS	G	L	INS	R		NT				x		Obs
BRWP	Picidae	Buff-rumped Woodpecker	*Meiglyptes tristis*	EFS	I	W	W	R						x	x	Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
BSFC	Muscicapidae	Brown-streaked Flycatcher	*Muscicapa williamsoni*	EDS	I	W	W	R							x	Obs
BSK	Laniidae	Brown Shrike	*Lanius cristatus*	NOF	O	W	W	RN			x		x	x	x	Mc
BSKB	Vireonidae	Blyth's Shrike-babbler	*Pteruthius aeralatus*	EBS	O	M	INS	R			x	x		x		Mobs
BSW	Hirundinidae	Barn Swallow	*Hirundo rustica*	NOF	I	W	W	RN			x					Mobs
BTBAB	Timaliidae	Black-throated Babbler	*Stachyris nigricollis*	EDS	I	L	S	R	VU	NT					x	Mobs
BTBB	Megalaimidae	Blue-throated Barbet	*Megalaima asiatica*	EBS	O	W	W	R			x	x	x	x		Mobs
BTFC	Muscicapidae	Blue-throated Flycatcher	*Cyornis rubeculoides*	GEN	I	W	W	RN			x	x				Mobs
BTHFC	Falconidae	Black-thighed Falconet	*Microhierax fringillarius*	EBS	R	W	SN	R							x	Obs
BTLT	Leiothrichidae	Black-throated Laughingthrus h	*Dryonastes chinensis*	EFS	I	W	INS	R			x	x	x	x		Mobs
BTSUN	Nectariniidae	Brown-throated Sunbird	*Anthreptes malacensis*	EOS	N	W	W	R							x	Obs
BUBAB	Pellorneidae	Buff-breasted Babbler	*Pellorneum tickelli*	EDS	O	W	W	R			x	x		x	x	Mobs
BVBUL	Pycnonotidae	Buff-vented Bulbul	*Iole olivacea*	EDS	O	W	W	R		NT	x	x		x	x	Mobs
BWCKS	Campephagidae	Black-winged Cuckooshrike	*Coracina melaschistos*	EBS	I	M	IN	RN			x	x	x	x		Mobs
BWLB	Chloropseidae	Blue-winged Leafbird	*Chloropsis cochinchinensis*	EDS	O	W	W	R			x	x	x	x	x	Mobs
BWM	Leiothrichidae	Blue-winged Minla	*Siva cyanouroptera*	EDS	F	W	W	R			x	x				Mobs
BWO	Strigidae	Brown Wood Owl	*Strix leptogrammica*	GEN	I	W	W	R						x		Obs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
BWP	Picidae	Banded Woodpecker	*Chrysophlegma miniaceum*	EFS	I	W	W	R							x	Mobs
BWP	Picidae	Bay Woodpecker	*Blythipicus pyrrhotis*	EDS	I	W	W	R			x	x		x		Obs
BWPTT	Pittidae	Blue-winged Pitta	*Pitta moluccensis*	EDS	O	W	W	R				x	x			Obs
BWT	Muscicapidae	Blue Whistlingthrush	*Myophonus caeruleus*	EFS	O	W	W	RN			x	x	x			Mobs
BWTC	Muscicapidae	Blue Whistlingthrush	*Myophonus caeruleus caeruleus*	EDS	O	W	W	R			x					Obs
BYBB	Eurylaimidae	Black-and-yellow Broadbill	*Eurylaimus ochromalus*	EDS	I	L	SN	R		NT				x	x	Mobs
BYU	Zosteropidae	Burmese Yuhina	*Yuhina humilis*	EDS	I	M	IN	R			x					Obs
CBAB	Pellorneidae	Collared Babbler	*Gampsorhynchus torquatus*	EBS	O	W	W	R						x		Mobs
CBB	Megalaimidae	Coppersmith Barbet	*Megalaima haemacephala*	NOF	O	W	W	R			x	x	x	x		Mobs
CBBAB	Timaliidae	Coral-billed Scimitar Babbler	*Pomatorhinus ferruginosus*	EBS	I	M	INS	R				x		x		Mobs
CBDG	Dicruridae	Crow-billed Drongo	*Dicrurus annectans*	GEN	I	W	IN	RN			x		x			Obs
CBFC	Muscicapidae	Chinese Blue Flycatcher	*Cyornis glaucicomans*	EDS	I	W	W	N						x		Obs
CBFP	Dicaeidae	Crimson-breasted Flowerpecker	*Prionochilus percussus*	EDS	N	W	W	R							x	Obs
CBGCK	Cuculidae	Coral-billed Ground Cuckoo	*Carpococcyx renauldi*	EDS	O	L	INS	R					x			Obs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
CBMK	Cuculidae	Chestnut-breasted Malkoha	*Phaenicophaeus curvirostris*	EDS	I	W	W	R						x	x	Mobs
CBUL	Pycnonotidae	Cinereous Bulbul	*Hemixos cinerea*	EDS	O	L	S	R			x	x	x	x	x	Mobs
CFB	Pycnonotidae	Crested Finchbill	*Spizixos canifrons*	EDS	I	W	W	R			x					Obs
CGH	Accipitridae	Crested Goshawk	*Accipiter trivirgatus*	EOS	R	W	W	R			x	x	x	x		Mobs
CHBE	Meropidae	Chestnut-headed Bee-eater	*Merops leschenaulti*	EBS	I	W	W	RN			x		x	x		Mobs
CHE	Accipitridae	Changeable Hawk Eagle	*Nisaetus limnaeetus*	EFS	O	W	SN	R							x	Obs
CLLWB	Phylloscopidae	Claudia's Leaf Warbler	*Phylloscopus claudiae*	EDS	I	M	W	N			x					Obs
CNCWB	Phylloscopidae	Chestnut-crowned Warbler	*Seicercus castaniceps*	EFS	I	W	W	N			x			x		Mobs
CNFOR	Muscicapidae	Chestnut-naped Forktail	*Enicurus ruficapillus*	GEN	O	W	W	R		NT	x				x	Mobs
COEDV	Columbidae	Common Emerald Dove	*Chalcophaps indica*	EDS	F	W	W	R			x	x	x	x	x	Mobs
COFB	Picidae	Common Flameback	*Dinopium javanense*	EBS	I	W	W	R			x	x	x	x		Mobs
COGMP	Corvidae	Common Green Magpie	*Cissa chinensis*	EFS	O	W	INS	R			x	x	x	x		Mobs
COHMY	Sturnidae	Common Hill Myna	*Gracula religiosa*	EDS	O	W	W	R	NT			x	x	x		Mobs
COKF	Alcedinidae	Common Kingfisher	*Alcedo atthis*	GEN	O	W	W	N					x		x	Mobs
COL	Strigidae	Collared Owlet	*Glaucidium brodiei*	EFS	O	W	W	R			x	x	x	x		Mobs
COMIO	Aegithinidae	Common Iora	*Aegithina tiphia*	NOF	I	W	W	R			x	x	x	x	x	Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
CORF	Fringillidae	Common Rosefinch	*Carpodacus erythrinus*	GEN	G	W	W	N			x					Obs
COTB	Cisticolidae	Common Tailorbird	*Orthotomus sutorius*	NOF	I	W	W	R			x	x	x	x	x	Mobs
COWSK	Tephrodornithidae	Common Woodshrike	*Tephrodornis pondicerianus*	EDS	I	W	IN	R				x				Obs
CPH	Ardeidae	Chinese Pond Heron	*Ardeola bacchus*	EFS	O	L	S	N						x		Obs
CRBAB	Timaliidae	Chestnut-rumped Babbler	*Stachyris maculata*	EDS	I	L	S	R		NT					x	Mobs
CRJ	Corvidae	Crested Jay	*Platylophus galericulatus*	EFS	O	L	SN	R		NT				x	x	Mobs
CROCK	Muscicapidae	Chestnut-bellied Rockthrush	*Monticola rufiventris*	EFS	I	L	SN	R			x					Obs
CRSUN	Nectariniidae	Crimson Sunbird	*Aethopyga siparaja*	EDS	N	W	W	R					x	x	x	Mobs
CRTG	Trogonidae	Cinnamon-rumped Trogon	*Harpactes orrhophaeus*	EDS	I	M	IN	R		NT					x	Obs
CSBAB	Timaliidae	Chestnut-backed Scimitar Babbler	*Pomatorhinus montanus*	EDS	I	W	IN	R							x	Obs
CSE	Accipitridae	Crested Serpent Eagle	*Spilornis cheela*	EDS	R	W	W	RN			x	x	x		x	Mobs
CSKB	Vireonidae	Clicking Shrike-babbler	*Pteruthius intermedius*	EFS	O	W	W	R			x					Mobs
CSO	Strigidae	Collared Scops Owl	*Otus lettia*	EDS	I	W	INS	R					x			Obs
CSPH	Accipitridae	Chinese Sparrowhawk	*Accipiter soloensis*	GEN	I	W	IN	P						x		Obs
CTM	Leiothrichidae	Chestnut-tailed Minla	*Chrysominla strigula*	EDS	F	M	IN	R			x					Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
CTWP	Picidae	Checker-throated Woodpecker	*Chrysophlegma mentale*	EFS	I	L	S	R							x	Obs
CVBUL	Pycnonotidae	Cream-vented Bulbul	*Pycnonotus simplex*	EDS	O	L	S	R					x		x	Mobs
CVNUT	Sittidae	Chestnut-vented Nuthatch	*Sitta nagaensis*	EDS		W	IN	R			x					Obs
CWBAB	Timaliidae	Chestnut-winged Babbler	*Stachyris erythroptera*	EDS	I	L	S	R							x	Mobs
CWCK	Cuculidae	Chestnut-winged Cuckoo	*Clamator coromandus*	GEN	O	W	W	P				x				Obs
CWE	Zosteropidae	Chestnut-flanked White-eye	*Zosterops erythropleurus*	NOF	I	M	INS	N			x	x				Mobs
CWWP	Picidae	Crimson-winged Woodpecker	*Picus puniceus*	EFS	I	W	W	R						x	x	Mobs
DBB	Eurylaimidae	Dusky Broadbill	*Corydon sumatranus*	EFS	I	W	W	R				x	x	x	x	Mobs
DBSI	Leiothrichidae	Dark-backed Sibia	*Malacias melanoleucus*	EDS	N	M	IN	R			x	x				Mobs
DCMAR	Hirundinidae	Dusky Crag Martin	*Ptyonoprogne concolor*	EDS	I	W	INS	R			x					Obs
DITG	Trogonidae	Diard's Trogon	*Harpactes diardii*	EDS	I	L	INS	R		NT					x	Obs
DNTB	Cisticolidae	Dark-necked Tailorbird	*Orthotomus atrogularis*	EBS	I	W	W	R			x	x	x	x	x	Mobs
DSFC	Muscicapidae	Dark-sided Flycatcher	*Muscicapa sibirica*	EBS	I	W	W	N			x		x	x	x	Mobs
DSTH	Turdidae	Dark-sided Thrush	*Zoothera marginata*	EFS	O	L	S	R			x			x		Obs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
DTO	Oriolidae	Dark-throated Oriole	*Oriolus xanthonotus*	EFS	I	L	S	R	NT	NT					x	Mobs
DUSWB	Phylloscopidae	Dusky Warbler	*Phylloscopus fuscatus*	NOF	I	W	W	N			x	x		x		Mobs
DVLWB	Phylloscopidae	Davison's Leaf Warbler	*Phylloscopus davisoni*	EFS	I	M	IN	R			x	x	x			Mobs
EBTH	Turdidae	Eyebrowed Thrush	*Turdus obscurus*	EDS	O	W	W	N			x	x	x			Mobs
ECLWB	Phylloscopidae	Eastern Crowned Leaf Warbler	*Phylloscopus coronatus*	EDS	I	W	W	N			x		x	x	x	Mobs
EJCR	Corvidae	Eastern Jungle Crow	*Corvus levaillantii*	EFS	O	L	S	R			x	x	x			Obs
EPTT	Pittidae	Eared Pitta	*Pitta phayrei*	EBS	O	L	INS	R				x		x		Mobs
EUHP	Upupidae	Eurasian Hoopoe	*Upupa epops*	GEN	O	W	W	RN				x	x			Obs
EUJ	Corvidae	Eurasian Jay	*Garrulus glandarius*	NOF	O	L	IN	R			x					Mobs
EUWC	Scolopacidae	Eurasian Woodcock	*Scolopax rusticola*	EFS	O	M	W	N			x					Obs
EWBAB	Pellorneidae	Eyebrowed Wren Babbler	*Napothera epilepidota*	EDS	I	W	W	R			x	x				Obs
EWE	Zosteropidae	Everett's White-eye	*Zosterops everetti*	EDS	I	W	SN	R			x		x	x	x	Mobs
EYWAG	Motacillidae	Eastern Yellow Wagtail	*Motacilla flava*	NOF	O	W	W	RN					x			Mc
FBAB	Pellorneidae	Ferruginous Babbler	*Trichastoma bicolor*	EDS	I	L	INS	R				x				Obs
FBFP	Dicaeidae	Fire-breasted Flowerpecker	*Dicaeum ignipectum*	EDS	F	W	W	R			x	x	x	x	x	Mobs
FBUL	Pycnonotidae	Flavescent Bulbul	*Pycnonotus flavescens*	NOF	O	M	INS	R			x	x	x	x	x	Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
FERFC	Muscicapidae	Ferruginous Flycatcher	*Muscicapa ferruginea*	EBS	I	W	W	N				x			x	Mobs
FIBUL	Pycnonotidae	Finsch's Bulbul	*Alophoixus finschii*	EDS	I	W	W	R		NT					x	Obs
FJFC	Muscicapidae	Fulvous-chested Jungle Flycatcher	*Cyornis olivaceus*	EDS	I	W	W	R				x		x	x	Obs
FP	Phasianidae	Ferruginous Partridge	*Caloperdix oculeus*	EOS	O	W	W	R		NT		x		x		Obs
FTBAB	Timaliidae	Fluffy-backed Tit Babbler	*Macronus ptilosus*	EDS	I	M	IN	R							x	Obs
FWAG	Motacillidae	Forest Wagtail	*Dendronanthus indicus*	EDS	I	W	W	N					x	x		Obs
GAR	Phasianidae	Great Argus	*Argusianus argus*	EFS	I	L	SN	R	VU	NT					x	Mobs
GBAB	Timaliidae	Golden Babbler	*Stachyridopsis chrysaea*	EFS	O	W	W	R			x	x		x		Mobs
GBB	Megalaimidae	Great Barbet	*Megalaima virens*	EBS	O	M	INS	R			x	x	x	x		Mobs
GBBUL	Pycnonotidae	Grey-bellied Bulbul	*Pycnonotus cyaniventris*	EDS	O	L	S	R		NT					x	Mobs
GBMK	Cuculidae	Green-billed Malkoha	*Phaenicophaeus tristis*	EOS	I	W	W	R			x	x	x	x		Mobs
GBPB	Sylviidae	Grey-breasted Parrotbill	*Suthora poliotis*	EBS	F	M	INS	R			x					Mc
GBPR	Cisticolidae	Grey-breasted Prinia	*Prinia hodgsonii*	NOF	I	L	INS	R			x		x	x		Mc
GBSK	Laniidae	Grey-backed Shrike	*Lanius tephronotus*	NOF	O	W	INS	RN			x		x			Mc
GBSPH	Nectariniidae	Grey-breasted Spiderhunter	*Arachnothera modesta*	EDS	N	W	W	R						x	x	Mobs
GBTES	Cettiidae	Grey-bellied Tesia	*Tesia cyaniventer*	EFS	I	L	S	N			x	x				Obs
GCBUL	Pycnonotidae	Grey-cheeked Bulbul	*Alophoixus bres*	EFS	O	L	S	R	NT						x	Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
GCC	Cuculidae	Greater Coucal	*Centropus sinensis*	NOF	O	W	W	R				x	x	x		Mobs
GCFC	Stenostiridae	Grey-headed Canary-flycatcher	*Culicicapa ceylonensis*	EDS	I	W	W	RN			x	x	x	x	x	Mobs
GCFV	Pellorneidae	Grey-cheeked Fulvetta	*Alcippe fratercula*	EFS	I	W	IN	R			x	x		x		Mobs
GCMIN	Campephagidae	Grey-chinned Minivet	*Pericrocotus solaris*	EDS	I	W	INS	R			x	x				Mobs
GCMY	Sturnidae	Golden-crested Myna	*Ampeliceps coronatus*	EDS	O	W	W	R					x			Obs
GCO	Turdidae	Green Cochoa	*Cochoa viridis*	EFS	O	M	IN	R	NT		x	x				Mobs
GCWB	Phylloscopidae	Grey-crowned Warbler	*Seicercus tephrocephalus*	EFS	I	L	S	N			x	x	x			Obs
GEBB	Megalaimidae	Green-eared Barbet	*Megalaima faiostricta*	EFS	O	L	INS	R				x	x	x		Mobs
GEBUL	Pycnonotidae	Grey-eyed Bulbul	*Iole propinqua*	EDS	O	W	W	R			x	x	x	x	x	Mobs
GFB	Picidae	Greater Flameback	*Chrysocolaptes guttacristatus*	EBS	I	W	W	R				x	x	x		Mobs
GFLB	Chloropseidae	Golden-fronted Leafbird	*Chloropsis aurifrons*	EBS	O	L	INS	R			x	x	x			Mobs
GGLB	Chloropseidae	Greater Green Leafbird	*Chloropsis sonnerati*	EFS	O	L	SN	R						x	x	Mobs
GHB	Bucerotidae	Great Hornbill	*Buceros bicornis*	EBS	O	W	W	R	NT	NT		x	x	x	x	Mobs
GHBAB	Timaliidae	Grey-headed Babbler	*Stachyris poliocephala*	EDS	I	L	S	R							x	Mobs
GHWP	Picidae	Grey-headed Woodpecker	*Picus canus*	EOS	I	W	W	R				x				Obs
GIPG	Columbidae	Green Imperial Pigeon	*Ducula aenea*	EDS	G	W	W	R				x	x			Obs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
GJFC	Muscicapidae	Grey-chested Jungle Flycatcher	*Cyornis umbratilis*	EDS	I	W	W	R		NT					x	Obs
GNJ	Caprimulgidae	Grey Nightjar	*Caprimulgus jotaka*	EFS	I	L	INS	RN			x					Obs
GNLT	Leiothrichidae	Greater Necklaced Laughingthrush h	*Garrulax pectoralis*	EOS	I	W	W	R				x		x		Obs
GPF	Phasianidae	Green Peafowl	*Pavo muticus*	EDS	O	W	W	R		EN		x				Obs
GPP	Phasianidae	Grey Peacock Pheasant	*Polyplectron bicalcaratum*	EFS	O	W	INS	R				x		x		Mobs
GPTT	Pittidae	Giant Pitta	*Pitta caerulea*	EFS	O	L	S	R		NT					x	Obs
GPWP	Picidae	Grey-capped Pygmy Woodpecker	*Dendrocopos canicapillus*	GEN	I	W	W	R			x	x		x		Mobs
GRBB	Eurylaimidae	Green Broadbill	*Calyptomena viridis*	EFS	F	L	INS	R		NT			x	x	x	Obs
GRBB	Eurylaimidae	Black-and-red Broadbill	*Cymbirhynchus macrorhynchos*	EFS	I	W	W	R							x	Mobs
GRDG	Dicruridae	Greater Racket-tailed Drongo	*Dicrurus paradiseus*	EBS	I	W	W	R			x	x	x	x	x	Mobs
GREIO	Aegithinidae	Green Iora	*Aegithina viridissima*	EFS	I	L	SN	R		NT					x	Mobs
GRIO	Aegithinidae	Great Iora	*Aegithina lafresnayei*	EFS	I	W	W	R				x	x	x	x	Mobs
GRTW	Hemiprocnidae	Grey-rumped Treeswift	*Hemiprocne longipennis*	EDS	I	M	IN	R						x		Obs
GSTH	Turdidae	Grey-sided Thrush	*Turdus feae*	EDS	O	M	IN	N		VU	x					Obs
GSUN	Nectariniidae	Mrs. Gould's Sunbird	*Aethopyga gouldiae*	EDS	N	M	IN	U			x	x				Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	**Feed**	**Ele**	**Geo**	**Mig**	**Thai**	**IUCN**	**DI**	**HK**	**KY**	**KK**	**HL**	
GSWP	Picidae	Great Slaty Woodpecker	*Mulleripicus pulverulentus*	EOS	I	W	W	R		VU		x		x		Obs
GTBAB	Timaliidae	Grey-throated Babbler	*Stachyris nigriceps*	EDS	I	W	W	R			x	x		x	x	Mobs
GTBB	Megalaimidae	Golden-throated Barbet	*Megalaima franklinii*	EFS	O	W	W	R			x	x		x		Mobs
GTIT	Aegithalidae	Great Tit	*Parus major*	EOS	I	M	SN	NR			x					Obs
GTP	Corvidae	Grey Treepie	*Dendrocitta formosae*	EDS	O	M	INS	R			x	x		x		Mobs
GTSUN	Nectariniidae	Green-tailed Sunbird	*Aethopyga nipalensis*	EDS	N	W	W	R	NT		x					Mobs
GWAG	Motacillidae	Grey Wagtail	*Motacilla cinerea*	GEN	O	W	W	N						x		Mobs
GWB	Phylloscopidae	Greenish Warbler	*Phylloscopus trochiloides*	EDS	I	W	IN	N			x		x	x		Mobs
GWBB	Megalaimidae	Gold-whiskered Barbet	*Megalaima chrysopogon*	EFS	O	L	S	R						x	x	Mobs
GYN	Picidae	Greater Yellownape	*Chrysophlegma flavinucha*	EBS	I	W	W	R			x	x	x	x		Mobs
HBBUL	Pycnonotidae	Hairy-backed Bulbul	*Tricholestes criniger*	EDS	O	L	SN	R							x	Mobs
HBFC	Muscicapidae	Hainan Blue Flycatcher	*Cyornis hainanus*	EBS	I	L	INS	RN				x	x	x		Mobs
HCDG	Dicruridae	Hair-crested Drongo	*Dicrurus hottentottus*	EDS	I	W	INS	RN			x	x	x	x		Mobs
HFM	Podargidae	Hodgson's Frogmouth	*Batrachostomus hodgsoni*	EFS	I	L	INS	R			x					Obs
HIBFC	Muscicapidae	Hill Blue Flycatcher	*Cyornis banyumas*	EDS	I	W	W	RN			x	x	x	x		Mobs
HMHB	Bucerotidae	Helmeted Hornbill	*Rhinoplax vigil*	EFS	O	L	S	R		NT					x	Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
HPR	Cisticolidae	Hill Prinia	*Prinia superciliaris*	EBS	I	M	IN	R			x					Mobs
HPTT	Pittidae	Hooded Pitta	*Pitta sordida*	EFS	O	L	S	R						x	x	Obs
HSL	Apodidae	Himalayan Swiftlet	*Aerodramus brevirostris*	EDS	I	W	IN	NR						x		Mobs
HSW	Apodidae	House Swift	*Apus nipalensis*	GEN	I	W	W	R			x		x			Mobs
HSWP	Picidae	Heart-spotted Woodpecker	*Hemicircus canente*	EBS	I	W	W	R				x	x	x		Mobs
HULWB	Phylloscopidae	Hume's Leaf Warbler	*Phylloscopus humei*	EDS	I	M	IN	N			x	x				Mobs
HUTC	Certhiidae	Hume's Treecreeper	*Certhia manipurensis*	EFS	I	M	IN	R			x					Mobs
ICKSK	Campephagidae	Indochinese Cuckooshrike	*Coracina polioptera*	NOF	I	L	INS	R			x	x				Mobs
INCK	Cuculidae	Indian Cuckoo	*Cuculus micropterus*	EBS	I	W	W	RN			x		x	x	x	Mobs
INROL	Coraciidae	Indian Roller	*Coracias benghalensis*	NOF	I	W	W	R			x	x	x	x		Mc
JSPH	Accipitridae	Japanese Sparrowhawk	*Accipiter gularis*	GEN	R	W	W	RN			x		x	x		Mc
JWE	Zosteropidae	Japanese White-eye	*Zosterops japonicus*	EBS	I	W	IN	N			x	x	x	x		Mobs
LBB	Megalaimidae	Lineated Barbet	*Megalaima lineata*	GEN	O	W	W	R			x	x	x	x		Mobs
LBCR	Corvidae	Large-billed Crow	*Corvus macrorhynchos*	NOF	S	W	W	R			x		x	x		Mc
LBFC	Muscicapidae	Large Blue Flycatcher	*Cyornis magnirostris*	EDS	I	W	INS	N					x			Obs
LBSPH	Nectariniidae	Long-billed Spiderhunter	*Arachnothera robusta*	EOS	N	W	W	R							x	Obs
LCDV	Columbidae	Little Cuckoo Dove	*Macropygia ruficeps*	GEN	G	W	W	R				x		x		Obs
LCSK	Campephagidae	Large Cuckooshrike	*Coracina macei*	EFS	I	M	SN	R				x	x	x		Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
LECKSK	Campephagidae	Lesser Cuckooshrike	*Coracina fimbriata*	EDS	I	L	SN	R					x		x	Obs
LGLB	Chloropseidae	Lesser Green Leafbird	*Chloropsis cyanopogon*	EDS	O	L	SN	R		NT					x	Mobs
LHCK	Cuculidae	Large Hawk Cuckoo	*Hierococcyx sparverioides*	EBS	I	W	W	R			x	x				Mobs
LNIL	Muscicapidae	Large Niltava	*Niltava grandis*	EFS	O	W	W	R			x	x				Mobs
LNLT	Leiothrichidae	Lesser Necklaced Laughingthrush	*Garrulax monileger*	EDS	I	W	INS	R				x	x	x		Mobs
LPFC	Muscicapidae	Little Pied Flycatcher	*Ficedula westermanni*	EDS	I	W	W	R			x		x	x		Mobs
LRDG	Dicruridae	Lesser Racket-tailed Drongo	*Dicrurus remifer*	EFS	I	W	W	R			x	x	x	x		Mobs
LSBAB	Timaliidae	Large Scimitar Babbler	*Pomatorhinus hypoleucos*	EBS	I	W	W	R					x	x		Mobs
LSHOT	Muscicapidae	Lesser Shortwing	*Brachypteryx leucophrys*	EFS	O	W	W	R			x					Mobs
LSPH	Nectariniidae	Little Spiderhunter	*Arachnothera longirostra*	EDS	N	W	W	R			x	x	x	x	x	Mobs
LTBB	Eurylaimidae	Long-tailed Broadbill	*Psarisomus dalhousiae*	EFS	I	M	INS	R			x	x	x			Mobs
LTMIN	Campephagidae	Long-tailed Minivet	*Pericrocotus ethologus*	EDS	I	W	IN	RN			x					Mobs
LTSI	Leiothrichidae	Long-tailed Sibia	*Heterophasia picaoides*	EDS	I	W	IN	R				x				Obs
LWBAB	Pellorneidae	Large Wren Babbler	*Turdinus macrodactylus*	EFS	I	L	S	R		NT					x	Obs
LWP	Picidae	Laced Woodpecker	*Picus vittatus*	GEN	I	W	W	R				x	x	x		Mobs
LWSK	Tephrodornithidae	Large Woodshrike	*Tephrodornis virgatus*	EDS	I	W	W	R			x	x			x	Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
LYN	Picidae	Lesser Yellownape	*Picus chlorolophus*	EOS	O	W	W	R				x				Obs
MARO	Oriolidae	Maroon Oriole	*Oriolus traillii*	GEN	O	W	W	RN			x					Obs
MBAB	Pellorneidae	Moustached Babbler	*Malacopteron magnirostre*	EFS	I	L	SN	R							x	Mobs
MBB	Megalaimidae	Moustached Barbet	*Megalaima incognita*	EFS	O	M	IN	R				x	x	x		Mobs
MBP	Phasianidae	Mountain Bamboo Partridge	*Bambusicola fytchii*	EFS	O	L	S	R						x		Obs
MBPTT	Pittidae	Malayan Banded Pitta	*Pitta irena*	EFS	O	W	W	R		NT					x	Obs
MBUL	Pycnonotidae	Mountain Bulbul	*Ixos mcclellandii*	EDS	O	W	W	R			x	x	x	x		Mobs
MBWB	Cettiidae	Manchurian Bush Warbler	*Cettia canturians*	EDS	I	W	INS	N			x					Obs
MHCK	Cuculidae	Malaysian Hawk Cuckoo	*Hierococcyx fugax*	EFS	I	L	SN	R							x	Obs
MHCK	Cuculidae	Moustached Hawk Cuckoo	*Hierococcyx vagans*	EFS	I	W	SN	R		NT				x		Obs
MHE	Accipitridae	Mountain Hawk Eagle	*Nisaetus nipalensis*	GEN	O	W	W	R			x			x		Obs
MIPG	Columbidae	Mountain Imperial Pigeon	*Ducula badia*	EFS	F	W	W	R			x	x	x	x		Mobs
MMFC	Muscicapidae	Mugimaki Flycatcher	*Ficedula mugimaki*	EDS	I	M	IN	N				x	x		x	Obs
MOLWB	Phylloscopidae	Mountain Leaf Warbler	*Phylloscopus trivirgatus*	EFS	I	L	S	N			x		x	x		Obs
MOTB	Cettiidae	Mountain Tailorbird	*Phyllergates cuculatus*	EDS	I	W	W	R			x			x		Mobs
MPP	Phasianidae	Mountain Peacock Pheasant	*Polyplectron inopinatum*	EDS	O	W	W	R		VU		x				Obs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
MWB	Phylloscopidae	Martens's Warbler	*Seicercus omeiensis*	EBS	I	M	IN	N			x			x		Mobs
MWP	Picidae	Maroon Woodpecker	*Blythipicus rubiginosus*	EFS	I	W	W	R							x	Mobs
OBFP	Dicaeidae	Orange-bellied Flowerpecker	*Dicaeum trigonostigma*	EDS	F	L	SN	R						x	x	Mobs
OBLB	Chloropseidae	Orange-bellied Leafbird	*Chloropsis hardwickii*	EDS	O	M	INS	R			x	x		x		Mobs
OBPIP	Motacillidae	Olive-backed Pipit	*Anthus hodgsoni*	NOF	O	W	W	N			x					Mobs
OBSUN	Nectariniidae	Olive-backed Sunbird	*Cinnyris jugularis*	NOF	N	W	W	R			x	x	x	x		Mobs
OBTG	Trogonidae	Orange-breasted Trogon	*Harpactes oreskios*	EBS	I	W	W	R				x	x	x	x	Mobs
OBWP	Picidae	Olive-backed Woodpecker	*Dinopium rafflesii*	EDS	I	L	IN	R		NT				x		Obs
OCBUL	Pycnonotidae	Ochraceous Bulbul	*Alophoixus ochraceus*	EFS	O	L	SN	R					x	x	x	Mobs
ODKF	Alcedinidae	Oriental Dwarf Kingfisher	*Ceyx erithaca*	EDS	I	L	SN	RN							x	Obs
ODL	Coraciidae	Oriental Dollarbird	*Eurystomus orientalis*	EFS	I	L	S	RN					x	x		Obs
OHB	Accipitridae	Oriental Honey-buzzard	*Pernis ptilorhynchus*	EDS	R	W	W	R			x		x	x		Mc
OHTH	Turdidae	Orange-headed Thrush	*Geokichla citrina*	EDS	O	W	INS	RN				x		x		Mobs
OLBUL	Pycnonotidae	Olive Bulbul	*Iole virescens*	EFS	O	L	IN	R				x				Mobs
OLWB	Phylloscopidae	Orange-barred Leaf Warbler	*Phylloscopus pulcher*	EDS	I	W	W	N			x					Obs
OMAR	Muscicapidae	Oriental Magpie Robin	*Copsychus saularis*	NOF	I	W	W	RN			x	x	x	x	x	Mc

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
OPHB	Bucerotidae	Oriental Pied Hornbill	*Anthracoceros albirostris*	EBS	O	W	W	R				x	x	x		Mobs
OWE	Zosteropidae	Oriental White-eye	*Zosterops palpebrosus*	EDS	F	W	W	R			x	x	x	x		Mobs
OWP	Picidae	Orange-backed Woodpecker	*Reinwardtipicus validus*	EFS	I	L	S	R							x	Obs
PASW	Hirundinidae	Pacific Swallow	*Hirundo tahitica*	GEN	I	W	W	R						x		Obs
PBFC	Muscicapidae	Pale Blue Flycatcher	*Cyornis unicolor*	EDS	I	W	W	R			x				x	Mobs
PCK	Cuculidae	Plaintive Cuckoo	*Cacomantis merulinus*	GEN	I	W	W	R				x			x	Mobs
PFT	Rhipiduridae	Pied Fantail	*Rhipidura javanica*	EOS	I	W	W	R					x			Obs
PLFP	Dicaeidae	Plain Flowerpecker	*Dicaeum minullum*	EDS	I	W	INS	R			x		x	x	x	Mobs
PLLWB	Phylloscopidae	Pale-legged Leaf Warbler	*Phylloscopus tenellipes*	EBS	F	L	IN	N			x	x	x	x		Mobs
PLWB	Phylloscopidae	Pallas's Leaf Warbler	*Phylloscopus proregulus*	EDS	I	M	IN	N			x					Obs
PNSUN	Nectariniidae	Purple-naped Sunbird	*Hypogramma hypogrammicu m*	EDS	I	W	W	R			x				x	Mobs
PSUN	Nectariniidae	Plain Sunbird	*Anthreptes simplex*	EDS	N	L	SN	R						x	x	Mobs
PSW	Apodidae	Pacific Swift	*Apus pacificus*	GEN	I	W	SN	N							x	Obs
PTBAB	Timaliidae	Pin-striped Tit Babbler	*Macronus gularis*	GEN	N	W	W	R			x	x	x	x	x	Mobs
PTBUL	Pycnonotidae	Puff-throated Bulbul	*Alophoixus pallidus*	EFS	I	L	IN	R			x	x	x	x		Mobs
PTGPG	Columbidae	Pin-tailed Green Pigeon	*Treron apicauda*	EBS	F	W	W	R						x		Obs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
PTPAR	Estrildidae	Pin-tailed Parrotfinch	*Erythrura prasina*	EDS	G	L	INS	R						x		Obs
PUBAB	Pellorneidae	Puff-throated Babbler	*Pellorneum ruficeps*	GEN	O	W	W	R			x	x	x	x	x	Mobs
PUCO	Turdidae	Purple Cochoa	*Cochoa purpurea*	EDS	I	M	W	R			x					Obs
PURSUN	Nectariniidae	Purple Sunbird	*Cinnyris asiaticus*	EFS	N	M	SN	R			x			x		Obs
PWBAB	Pnoepygidae	Pygmy Wren-Babbler	*Pnoepyga pusilla*	EFS	O	W	W	R			x			x		Mobs
RBAB	Eupetidae	Rail-babbler	*Eupetes macrocerus*	EFS	I	L	S	R							x	Obs
RBBAB	Timaliidae	Red-billed Scimitar Babbler	*Pomatorhinus ochraceiceps*	EFS	I	L	S	R				x		x		Obs
RBBE	Meropidae	Red-bearded Bee-eater	*Nyctyornis amictus*	EFS	O	W	W	R						x	x	Mobs
RBFC	Muscicapidae	Rufous-browed Flycatcher	*Anthipes solitaris*	EBS	I	W	W	R			x	x		x		Mobs
RBKF	Alcedinidae	Rufous-backed Kingfisher	*Ceyx rufidorsus*	GEN	I	L	SN	NR							x	Mobs
RBMK	Cuculidae	Red-billed Malkoha	*Zanclostomus javanicus*	EDS	O	L	SN	R							x	Mobs
RBMP	Corvidae	Red-billed Blue Magpie	*Urocissa erythroryncha*	NOF	I	L	INS	R				x				Mobs
RBNIL	Muscicapidae	Rufous-bellied Niltava	*Niltava sundara*	EFS	O	L	IN	N			x					Mobs
RBSI	Leiothrichidae	Rufous-backed Sibia	*Leioptila annectans*	ESO	I	W	W	R			x	x				Obs
RCBAB	Pellorneidae	Rufous-crowned Babbler	*Malacopteron magnum*	EFS	O	L	S	R	NT	NT					x	Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
RCFC	Muscicapidae	Rufous-chested Flycatcher	*Ficedula dumetoria*	EFS	I	L	S	R	VU	NT	x	x			x	Mobs
RCKF	Alcedinidae	Rufous-collared Kingfisher	*Actenoides concretus*	EFS	I	L	S	R	VU	NT					x	Mobs
RFBAB	Timaliidae	Rufous-fronted Babbler	*Stachyridopsis rufifrons*	EBS	O	W	W	R			x	x		x		Mobs
RHB	Bucerotidae	Rhinoceros Hornbill	*Buceros rhinoceros*	EFS	O	L	S	R	EN	NT					x	Mobs
RHTG	Trogonidae	Red-headed Trogon	*Harpactes erythrocephalus*	EFS	I	W	W	R			x	x	x			Mobs
RJF	Phasianidae	Red Junglefowl	*Gallus gallus*	GEN	O	W	W	R			x	x	x	x		Mobs
RMIN	Campephagidae	Rosy Minivet	*Pericrocotus roseus*	EDS	I	W	W	N			x	x				Mobs
RMK	Cuculidae	Raffles's Malkoha	*Rhinortha chlorophaea*	EDS	I	W	W	R			x	x	x	x	x	Mobs
RNHB	Bucerotidae	Rufous-necked Hornbill	*Aceros nipalensis*	EDS	O	W	W	R		VU		x				Mobs
RNPTT	Pittidae	Rusty-naped Pitta	*Pitta oatesi*	EFS	O	W	INS	R			x	x				Mobs
RNTG	Trogonidae	Red-naped Trogon	*Harpactes kasumba*	EFS	I	L	S	R		NT					x	Mobs
RPC	Picidae	Rufous Piculet	*Sasia abnormis*	EBS	I	L	S	R							x	Mobs
RPR	Cisticolidae	Rufescent Prinia	*Prinia rufescens*	EDS	I	W	W	R			x					Obs
RSO	Strigidae	Reddish Scops Owl	*Otus rufescens*	EDS	I	W	W	R		NT					x	Obs
RSUN	Nectariniidae	Ruby-cheeked Sunbird	*Chalcoparia singalensis*	NOF	N	W	W	R			x	x	x		x	Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
RTBB	Megalaimidae	Red-throated Barbet	*Megalaima mystacophanos*	EFS	O	L	SN	R		NT		x		x	x	Mobs
RTP	Phasianidae	Rufous-throated Partridge	*Arborophila rufogularis*	EDS	O	W	W	R			x	x		x		Obs
RTPT	Phasianidae	Rufous-throated Partridge	*Larvivora sibilans*	EDS	O	M	INS	R			x					Mc
RTSHA	Muscicapidae	Rufous-tailed Shama	*Copsychus pyrropygus*	EDS	O	W	INS	R		NT					x	Obs
RTSUN	Nectariniidae	Red-throated Sunbird	*Anthreptes rhodolaema*	EDS	N	M	INS	R		NT					x	Obs
RTTB	Cisticolidae	Rufous-tailed Tailorbird	*Orthotomus sericeus*	EDS	I	W	W	R							x	Obs
RTTP	Corvidae	Racket-tailed Treepie	*Crypsirina temia*	NOF	O	W	W	R			x		x			Mobs
RUFT	Corvidae	Rufous Treepie	*Dendrocitta vagabunda*	EOS	I	W	W	R				x	x	x		Obs
RWB	Phylloscopidae	Radde's Warbler	*Phylloscopus schwarzi*	NOF	I	W	W	N			x		x			Mobs
RWBUL	Pycnonotidae	Red-whiskered Bulbul	*Pycnonotus jocosus*	NOF	O	W	W	R	NT				x			Mobs
RWFV	Pellorneidae	Rufous-winged Fulvetta	*Pseudominla castaneceps*	EDS	I	M	W	R			x		x			Mobs
RWLW	Charadriidae	Red-wattled Lapwing	*Vanellus indicus*	EDS	I	L	IN	R					x			Obs
RWP	Picidae	Rufous Woodpecker	*Micropternus brachyurus*	EBS	I	W	W	R							x	Mobs
RWPH	Tephrodornithidae	Rufous-winged Philentoma	*Philentoma pyrhoptera*	EFS	O	W	SN	R							x	Obs
SBAB	Pellorneidae	Short-tailed Babbler	*Malacocincla malaccensis*	EDS	I	W	W	R		NT					x	Obs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
SBAFC	Muscicapidae	Slaty-backed Flycatcher	*Ficedula sordida*	EDS	I	M	INS	N			x		x			Mobs
SBAR	Leiothrichidae	Spectacled Barwing	*Actinodura ramsayi*	EDS	O	W	W	R			x					Mobs
SBBB	Eurylaimidae	Silver-breasted Broadbill	*Serilophus lunatus*	EDS	I	W	W	R			x	x	x	x	x	Mobs
SBBUL	Pycnonotidae	Scaly-breasted Bulbul	*Pycnonotus squamatus*	EDS	O	L	S	R		NT					x	Mobs
SBFC	Muscicapidae	Slaty-blue Flycatcher	*Ficedula tricolor*	NOF	I	M	IN	R			x					Mc
SBFOR	Muscicapidae	Slaty-backed Forktail	*Enicurus schistaceus*	GEN	O	W	W	R			x	x	x			Mobs
SBFP	Dicaeidae	Scarlet-backed Flowerpecker	*Dicaeum cruentatum*	NOF	F	W	W	R			x		x	x	x	Mobs
SBLWB	Phylloscopidae	Sulphur-breasted Leaf Warbler	*Phylloscopus ricketti*	EDS	I	L	INS	N			x	x	x	x		Mobs
SBMIN	Campephagidae	Short-billed Minivet	*Pericrocotus brevirostris*	EDS	I	L	IN	R			x					Mobs
SBO	Oriolidae	Slender-billed Oriole	*Oriolus tenuirostris*	EFS	O	L	S	RN				x				Obs
SBP	Phasianidae	Scaly-breasted Partridge	*Arborophila chloropus*	EBS	O	L	INS	R				x	x	x		Mobs
SBRO	Muscicapidae	Siberian Blue Robin	*Larvivora cyane*	EDS	O	W	W	N					x	x	x	Mobs
SBTES	Cettiidae	Slaty-bellied Tesia	*Tesia olivea*	EFS	O	M	IN	R			x					Mobs
SBUL	Pycnonotidae	Striated Bulbul	*Pycnonotus striatus*	EDS	O	M	IN	R			x	x				Mobs
SBWP	Picidae	Stripe-breasted Woodpecker	*Dendrocopos atratus*	EDS	I	L	INS	R			x					Obs
SCBAB	Pellorneidae	Scaly-crowned Babbler	*Malacopteron cinereum*	EFS	I	W	W	R					x		x	Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
SCMIN	Campephagidae	Scarlet Minivet	*Pericrocotus speciosus*	EDS	I	W	W	R			x	x	x	x	x	Mobs
SEBUL	Pycnonotidae	Streak-eared Bulbul	*Pycnonotus blanfordi*	NOF	O	W	W	R			x	x	x	x		Mobs
SELT	Leiothrichidae	Silver-eared Laughingthrush	*Trochalopteron melanostigma*	EDS	I	M	INS	R			x	x				Mobs
SHBUL	Pycnonotidae	Sooty-headed Bulbul	*Pycnonotus aurigaster*	NOF	O	W	INS	R			x		x			Mobs
SK	Accipitridae	Shikra	*Accipiter badius*	GEN	R	L	INS	RN			x	x	x			Mobs
SKBUL	Pycnonotidae	Streaked Bulbul	*Ixos malaccensis*	EFS	O	L	S	R		NT				x	x	Mobs
SMES	Leiothrichidae	Silver-eared Mesia	*Leiothrix argentauris*	EDS	O	W	W	R			x					Mobs
SNBAB	Timaliidae	Spot-necked Babbler	*Stachyris strialata*	EFS	I	W	W	R				x		x		Mobs
SNFC	Muscicapidae	Snowy-browed Flycatcher	*Ficedula hyperythra*	EFS	I	M	IN	R			x				x	Mobs
SNIL	Muscicapidae	Small Niltava	*Niltava macgrigoriae*	EFS	O	M	IN	R			x					Mobs
SOBAB	Pellorneidae	Sooty-capped Babbler	*Malacopteron affine*	EDS	I	M	IN	R		NT					x	Obs
SPBUL	Pycnonotidae	Spectacled Bulbul	*Pycnonotus erythrophthalmos*	EDS	O	L	S	R							x	Mobs
SPC	Picidae	Speckled Piculet	*Picumnus innominatus*	EDS	I	W	IN	R			x					Mobs
SPDV	Columbidae	Spotted Dove	*Spilopelia chinensis*	EFS	G	L	S	R					x			Mobs
SPFT	Rhipiduridae	Spotted Fantail	*Rhipidura perlata*	EFS	I	L	S	R	VU						x	Mobs
SPS	Phasianidae	Silver Pheasant	*Lophura nycthemera*	EBS	G	M	IN	R	NT		x		x			Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
SPWBAB	Timaliidae	Spotted Wren Babbler	*Spelaeornis formosus*	NOF	F	W	W	R			x					Obs
SRTG	Trogonidae	Scarlet-rumped Trogon	*Harpactes duvaucelii*	EBS	I	L	S	R	NT	NT					x	Mobs
SSPH	Nectariniidae	Spectacled Spiderhunter	*Arachnothera flavigaster*	EFS	N	L	S	R						x	x	Obs
STBAB	Pellorneidae	Spot-throated Babbler	*Pellorneum albiventre*	EFS	I	L	SN	R			x					Obs
STBUL	Pycnonotidae	Stripe-throated Bulbul	*Pycnonotus finlaysoni*	NOF	O	W	W	R			x	x	x	x		Mobs
STBWP	Picidae	Streak-breasted Woodpecker	*Picus viridanus*	EDS	I	W	W	R						x		Obs
STCC	Cuculidae	Short-toed Coucal	*Centropus rectunguis*	GEN	I	W	W	R		VU					x	Obs
STH	Turdidae	Siberian Thrush	*Geokichla sibirica*	EDS	I	W	W	P			x	x				Obs
STIT	Paridae	Sultan Tit	*Melanochlora sultanea*	EDS	I	W	W	R			x	x	x	x	x	Mobs
STSPH	Nectariniidae	Streaked Spiderhunter	*Arachnothera magna*	EDS	N	W	INS	R			x	x		x	x	Mobs
STWBAB	Pellorneidae	Streaked Wren Babbler	*Napothera brevicaudata*	EDS	O	W	W	R				x				Mobs
SWFOR	Muscicapidae	Southern White-crowned Forktail	*Enicurus leschenaulti*	GEN	O	L	SN	R							x	Obs
SWPG	Columbidae	Speckled Wood Pigeon	*Columba hodgsonii*	EOS	F	W	IN	N			x					Obs
SYU	Zosteropidae	Striated Yuhina	*Staphida castaniceps*	EDS	F	M	INS	R			x	x				Mobs
TAFC	Muscicapidae	Taiga Flycatcher	*Ficedula albicilla*	EBS	I	W	W	N			x	x	x	x		Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
TBFC	Muscicapidae	Tickell's Blue Flycatcher	*Cyornis tickelliae*	EBS	I	W	W	R			x	x	x	x		Mobs
TBFP	Dicaeidae	Thick-billed Flowerpecker	*Dicaeum agile*	EDS	F	W	W	R			x					Mobs
TBHB	Bucerotidae	Tickell's Brown Hornbill	*Anorrhinus tickelli*	EBS	O	L	INS	R	VU	NT		x		x		Mobs
TBWB	Phylloscopidae	Two-barred Warbler	*Phylloscopus plumbeitarsus*	EDS	I	L	IN	N			x		x	x		Mobs
TEMSUM	Nectariniidae	Temminck's Sunbird	*Aethopyga temminckii*	EOS	N	W	W	R							x	Obs
TGPG	Columbidae	Thick-billed Green Pigeon	*Treron curvirostra*	EDS	F	W	W	R			x	x	x	x	x	Mobs
TSK	Laniidae	Tiger Shrike	*Lanius tigrinus*	NOF	O	W	W	P							x	Mobs
VERFC	Muscicapidae	Verditer Flycatcher	*Eumyias thalassinus*	EDS	O	W	W	RN			x	x	x	x	x	Mobs
VHPR	Psittacidae	Vernal Hanging Parrot	*Loriculus vernalis*	EBS	F	W	W	R				x	x	x		Mobs
VICK	Cuculidae	Violet Cuckoo	*Chrysococcyx xanthorhynchus*	EDS	I	W	W	R							x	Obs
VNIL	Muscicapidae	Vivid Niltava	*Niltava vivida*	EDS	O	M	IN	N			x					Mobs
VNUT	Sittidae	Velvet-fronted Nuthatch	*Sitta frontalis*	EDS	I	W	W	R			x		x	x	x	Mobs
WBBAB	Timaliidae	White-browed Scimitar Babbler	*Pomatorhinus schisticeps*	EBS	I	W	W	R			x	x	x	x		Mobs
WBEP	Vireonidae	White-bellied Erpornis	*Erpornis zantholeuca*	EDS	O	W	W	R			x	x	x	x	x	Mobs
WBEWP	Picidae	White-bellied Woodpecker	*Dryocopus javensis*	GEN	I	W	W	R	NT			x				Obs
WBFT	Rhipiduridae	White-browed Fantail	*Rhipidura aureola*	EFS	I	L	SN	R			x					Obs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
WBGPG	Columbidae	White-bellied Green Pigeon	*Treron sieboldii*	EDS	F	L	IN	R			x					Obs
WBPC	Picidae	White-browed Piculet	*Sasia ochracea*	EBS	I	M	W	R			x			x		Mobs
WCBAB	Pellorneidae	White-chested Babbler	*Trichastoma rostratum*	EDS	I	W	W	R		NT					x	Mobs
WCHB	Bucerotidae	White-crowned Hornbill	*Berenicornis comatus*	EFS	O	L	SN	R		NT					x	Mobs
WCLT	Leiothrichidae	White-crested Laughingthrush	*Garrulax leucolophus*	EBS	I	W	INS	R				x	x	x		Mobs
WFOR	Muscicapidae	Northern White-crowned Forktail	*Enicurus sinensis*	EDS	I	W	W	R			x		x			Mobs
WGFC	Muscicapidae	White-gorgeted Flycatcher	*Anthipes monileger*	EBS	I	L	IN	R			x					Mobs
WGPG	Columbidae	Wedge-tailed Green Pigeon	*Treron sphenurus*	EFS	F	M	IN	R			x					Mobs
WHB	Bucerotidae	Wrinkled Hornbill	*Aceros corrugatus*	EFS	O	M	IN	R	EN	NT					x	Obs
WNLT	Leiothrichidae	White-necked Laughingthrush	*Garrulax strepitans*	EFS	I	L	IN	R			x	x				Mobs
WRHB	Bucerotidae	Wreathed Hornbill	*Rhyticeros undulatus*	EBS	O	W	W	R					x	x	x	Mobs
WRMU	Estrildidae	White-rumped Munia	*Lonchura striata*	NOF	G	W	W	R			x			x		Mobs
WRSHA	Muscicapidae	White-rumped Shama	*Copsychus malabaricus*	EBS	I	W	W	R			x	x	x	x	x	Obs
WSHOT	Muscicapidae	White-browed Shortwing	*Brachypteryx montana*	EFS	O	M	IN	R	VU		x					Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
WTBUL	Pycnonotidae	White-throated Bulbul	*Alophoixus flaveolus*	EFS	O	L	IN	R				x				Mobs
WTFC	Muscicapidae	White-tailed Flycatcher	*Cyornis concretus*	EFS	I	W	W	U	NT					x	x	Mc
WTFT	Rhipiduridae	White-throated Fantail	*Rhipidura albicollis*	EDS	I	W	W	R			x	x		x		Mobs
WTKF	Alcedinidae	White-throated Kingfisher	*Halcyon smyrnensis*	NOF	O	W	W	R			x	x	x	x	x	Mc
WTRO	Muscicapidae	White-tailed Robin	*Myiomela leucura*	EBS	O	W	W	R			x	x				Mobs
WWAG	Motacillidae	White Wagtail	*Motacilla alba*	EOS	I	W	W	NR			x					Obs
YBBUL	Pycnonotidae	Yellow-bellied Bulbul	*Alophoixus phaeocephalus*	EFS	O	L	SN	R							x	Mobs
YBEFP	Dicaeidae	Yellow-bellied Flowerpecker	*Dicaeum melanoxanthum*	EFS	F	M	SN	R	NT		x				x	Obs
YBFFC	Stenostiridae	Yellow-bellied Fairy-flycatcher	*Chelidorhynx hypoxantha*	EFS	I	M	IN	R			x					Mobs
YBFP	Dicaeidae	Yellow-breasted Flowerpecker	*Prionochilus maculatus*	EDS	N	W	W	R			x		x	x	x	Mobs
YBTIT	Paridae	Yellow-browed Tit	*Sylviparus modestus*	EDS	I	W	W	R			x					Obs
YBWB	Cettiidae	Yellow-bellied Warbler	*Abroscopus superciliaris*	EBS	I	W	W	R			x	x		x		Mobs
YCBB	Megalaimidae	Yellow-crowned Barbet	*Megalaima henricii*	EDS	F	W	W	R		NT					x	Obs
YCTIT	Paridae	Yellow-cheeked Tit	*Parus spilonotus*	EDS	I	M	IN	R			x					Mobs

Species Code	Family	Common name	Scientific name	Ecological subgroup					Current Conservation Status		Distribution within subregion					Remarks
				Hab	Feed	Ele	Geo	Mig	Thai	IUCN	DI	HK	KY	KK	HL	
YEBAB	Sylviidae	Yellow-eyed Babbler	*Chrysomma sinense*	EFS	I	L	S	R			x					Obs
YLWB	Phylloscopidae	Yellow-browed Leaf Warbler	*Phylloscopus inornatus*	NOF	I	W	W	N			x	x	x	x	x	Mobs
YRFC	Muscicapidae	Yellow-rumped Flycatcher	*Ficedula zanthopygia*	EOS	I	W	W	P			x	x			x	Mobs
YSPH	Nectariniidae	Yellow-eared Spiderhunter	*Arachnothera chrysogenys*	EFS	N	L	S	R							x	Obs
YTWB	Phylloscopidae	Yellow-streaked Warbler	*Phylloscopus armandii*	EFS	I	L	S	N			x					Obs
YVBUL	Pycnonotidae	Yellow-vented Bulbul	*Pycnonotus goiavier*	NOF	O	W	W	R							x	Mc
YVFP	Dicaeidae	Yellow-vented Flowerpecker	*Dicaeum chrysorrheum*	EDS	F	W	W	R				x	x	x	x	Mobs

Appendix Table 1.1

Sources of collation data used in this thesis:

Data source (ID): 1 = my own data; 2 and 3 = long-term monitoring projects at Khao Yai by the King Mongkut's University of Technology corapolated with Mahidol University (persernal contact with George A. Gale and Phillip D Round); 4 = long-term monitoring projects at Huai Kha Khaeng by the King Mongkut's University of Technology corapolated with Mahidol University (persernal contact with George A. Gale and Phillip D Round); 5 = research project by the Division of Research and Education of Kaeng Krachan National Park (personal contact with Suporn Polpun); 6 = research project by the Hala Bala wildlife research station (personal contact with Sunet Karaphan); and 7 = yearly birding by the Lanna bird club, Chaing Mai (personal contact with Rangsrit Kanjanavanit and Woraphot Bunkwamdi).

Subregions: DI = Doi Inthanon; HK = Huai Kha Khaeng; KY = Khao Yai; KK = Kaeng Krachan; and HL = Hala Bala.

ID	Data source	Survey method	Time period of survey	Total records	Total species	Total species > 10 records	Total sites	Subregions					Notes
								DI	HK	KY	KK	HL	
1	Empirical sampling	line transect	2013-2014	22764	435	151	96	x	x	x	x	x	2 times/year
2	KMUTT of KY with Line transect survey	line transect	2003-2006	23079	112	81	244			x			8 transect collected every month for 3 years
3	KMUTT of KY with point count survey	point count	2003-2006	7593	93	57	24			x			2 times/year
4	KMUTTof HK	point count	2009	193	35	0	7		x				elv.900-1200
5	Kaeng Krachan National Park	line transect	2012-2013	7259	335	2	26				x		survey since 2009/survey in every forest type
6	Hala-Bala Wildlife Sanctuary	line transect	2008-2009	5902	200	63	34					x	every two months
7	Lanna bird club	line transect	2000-2013	27322	345	26	14	x					Every February
	Total			**94112**	**612**	**314**	**461**						

Appendix Figure 3.1

The contribution of climatic variables based on combined climate and land-cover (orange), climate only (blue), and land-cover only (green) for the 304 species split into a variety of ecological subgroups including:

3.1a. Habitat groups: EFS = evergreen forest specialist; EDS = evergreen forest specialist but occur in deciduous forest; EBS = evergreen forest specialist but occur in bamboo forest; EOS = evergreen forest specialist but occur in edge forest, open area, and other (not include forest); GEN - occur in evergreen forest but common in other forest, occur in evergreen forest but common in edge forest, open area and other (not include forest area); and NOF = never occur in evergreen forest). Habitat preferences follow the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012).

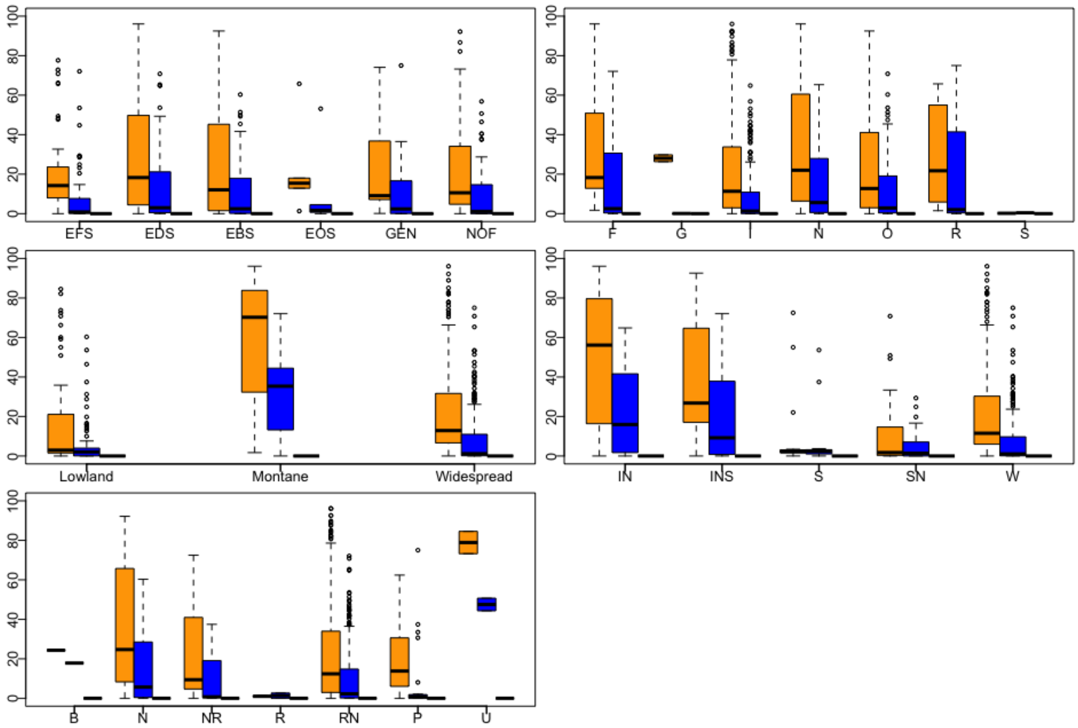
3.1b. Feeding guilds: F = frugivorous; G = granivorous; I = insectivorous; N = nectarivorous; O = omnivorous; R = raptor, and S = scavenger). Feeding guilds defined by Lekagul and Round (1991), Round et al., (2003), and Napheethapat et al. (2012).

3.1c. Elevational groups: L = lowland ; M = montane ;W = widespread. Elevational range limits defined on published elevational range limits (Round et al., 2003, Napheethapat et al., 2012).

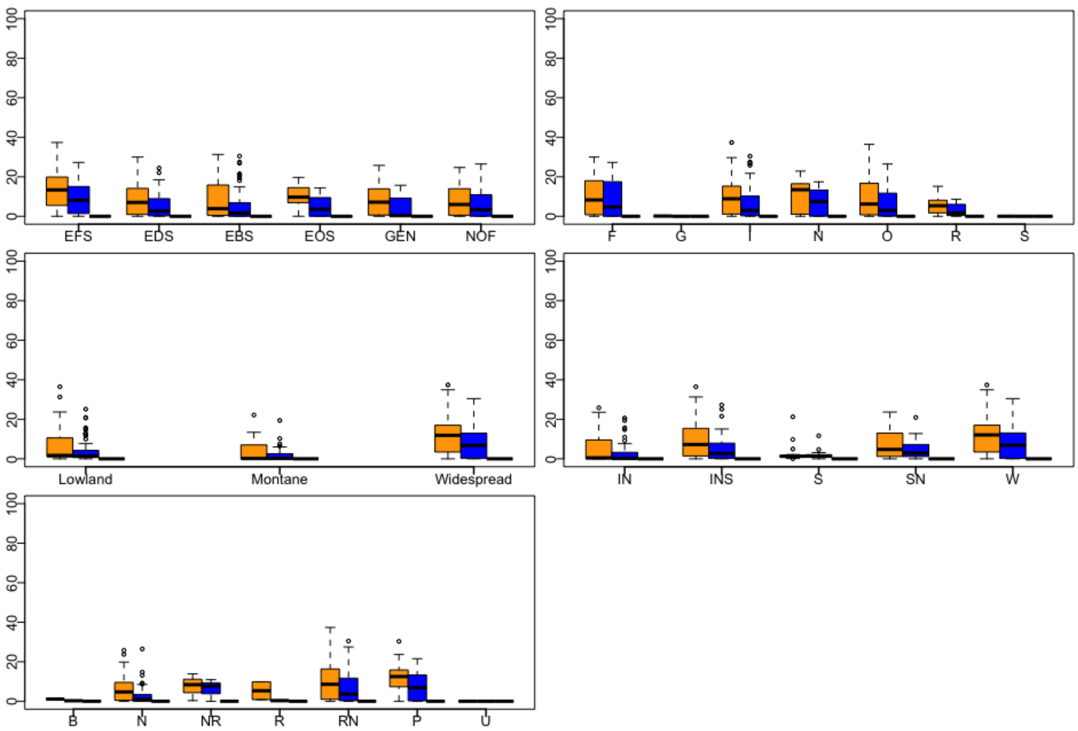
3.1d. Biogeographic subregions: IN = Indochinese; INS = Indochinese-southern cross; S = Sundaic; SN = Sundaic-northern cross; and W = widespread. Thailand's birds occur in an overlap zone between two major zoogeographic clades of birds - the Indochinese and Sundaic subregions of the Oriental zoogeographic region, defined groups based on the definitions provided by Hughes et al. (2003), Round et al. (2003) and the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012).

3.1e. Seasonal migratory classes: B = breeding visitor; N = non-breeding visitor; NR = mainly non-breeding visitor but maybe resident; R= resident or presumed resident; RN = mainly resident but maybe non-breeding visitor; P = mainly spring and autumn passage migrant, and U = uncertainty according to the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012, BCST, 2016).

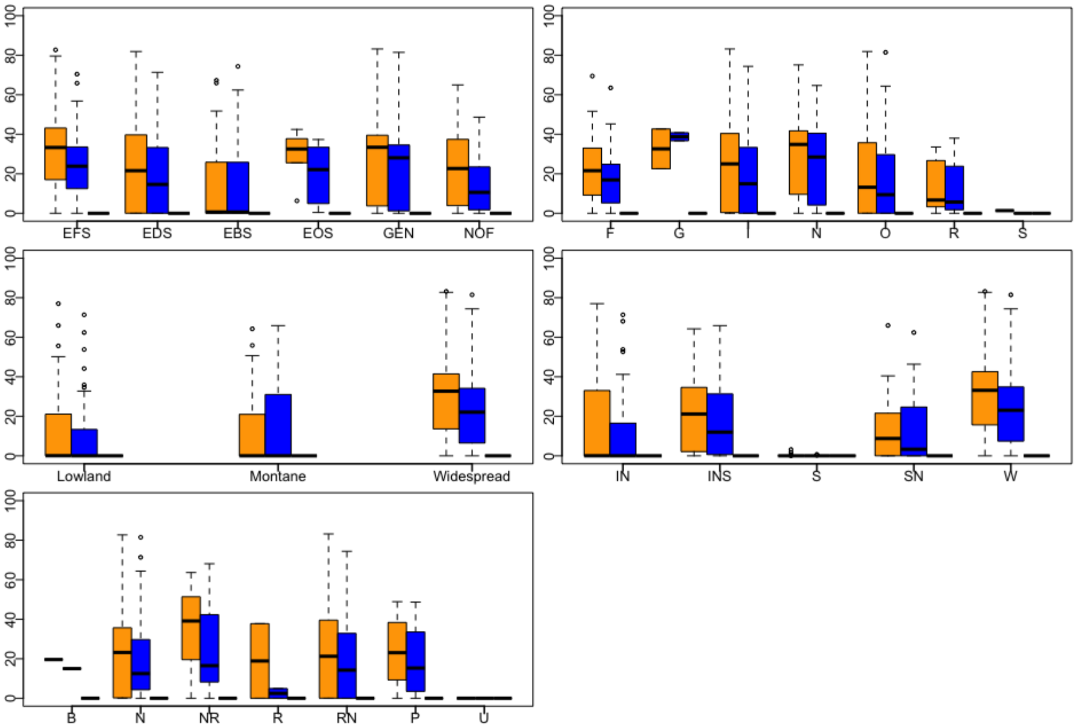
Appendix Figure 3.1a The contribution of Annual mean temperature (BIO1)



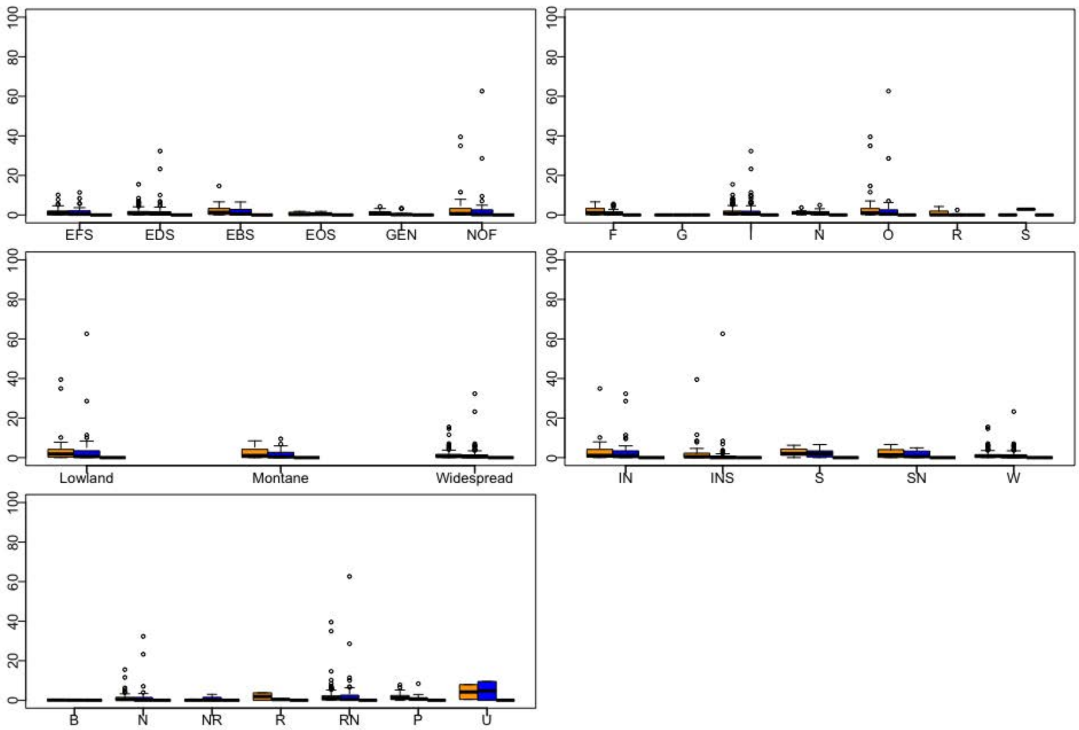
Appendix Figure 3.1b The contribution of Temperature seasonality (BIO 4)



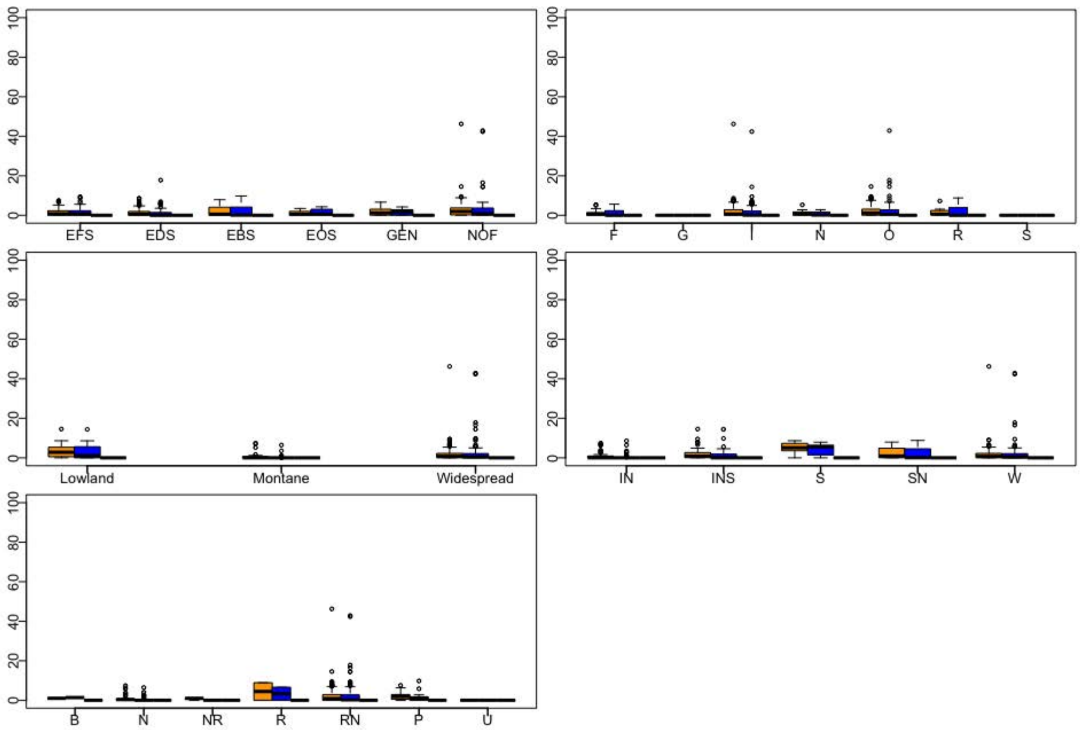
Appendix Figure 3.1c The contribution of Maximum temperature of warmest period (BIO 5)



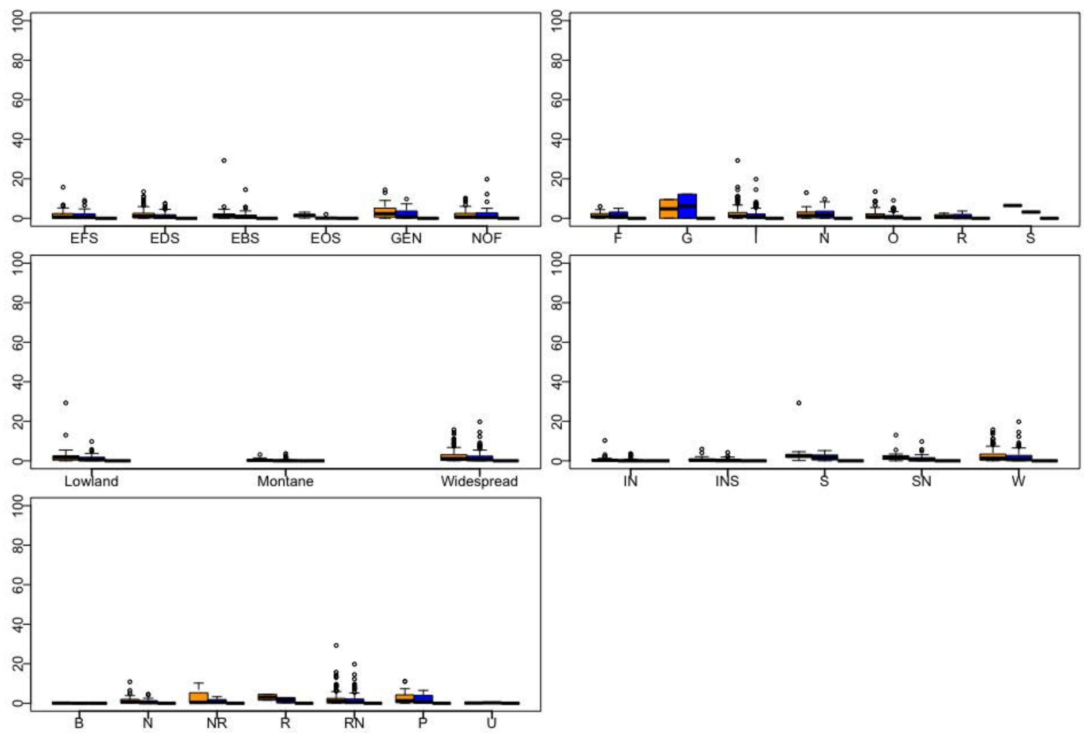
Appendix Figure 3.1d The contribution of Minimum temperature of coldest period (BIO 6)



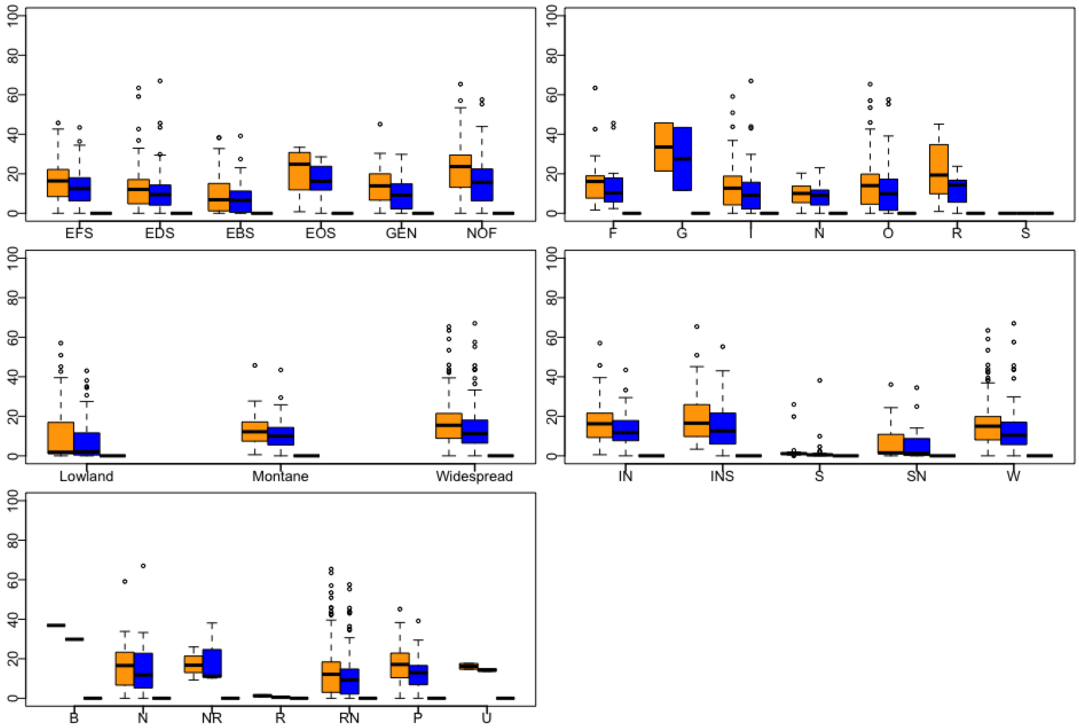
Appendix Figure 3.1e The contribution of Annual precipitation (BIO 12)



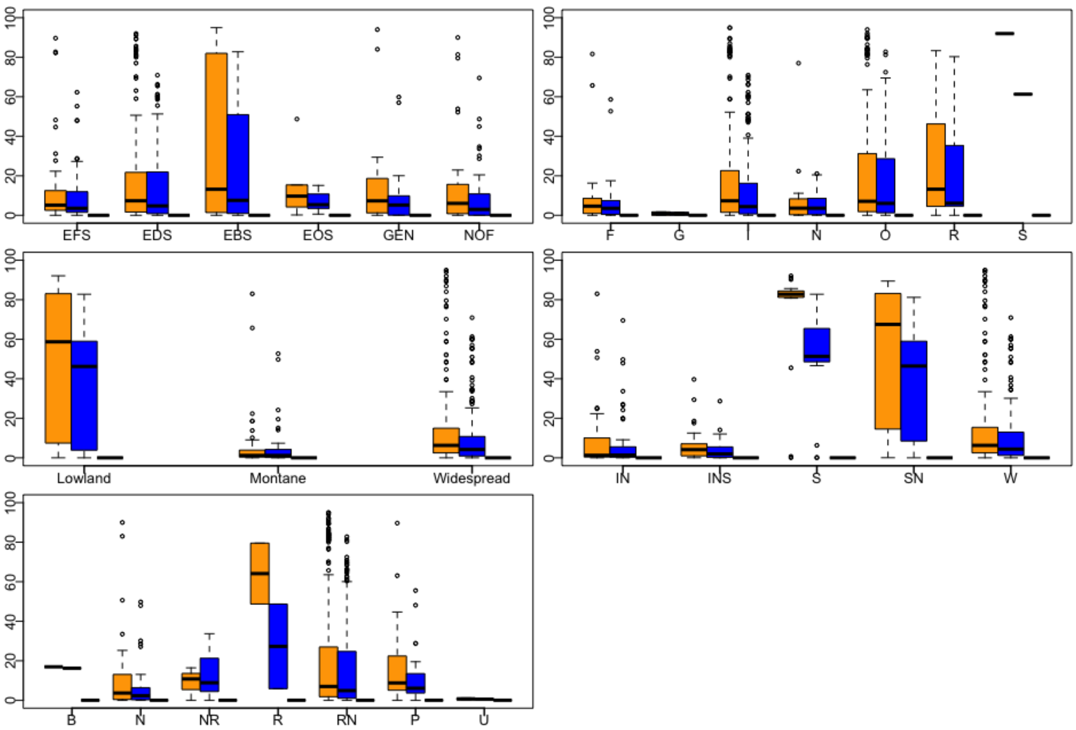
Appendix Figure 3.1f The contribution of Precipitation seasonality (BIO 15)



Appendix Figure 3.1g The contribution of Precipitation of wettest quarter (BIO 16)

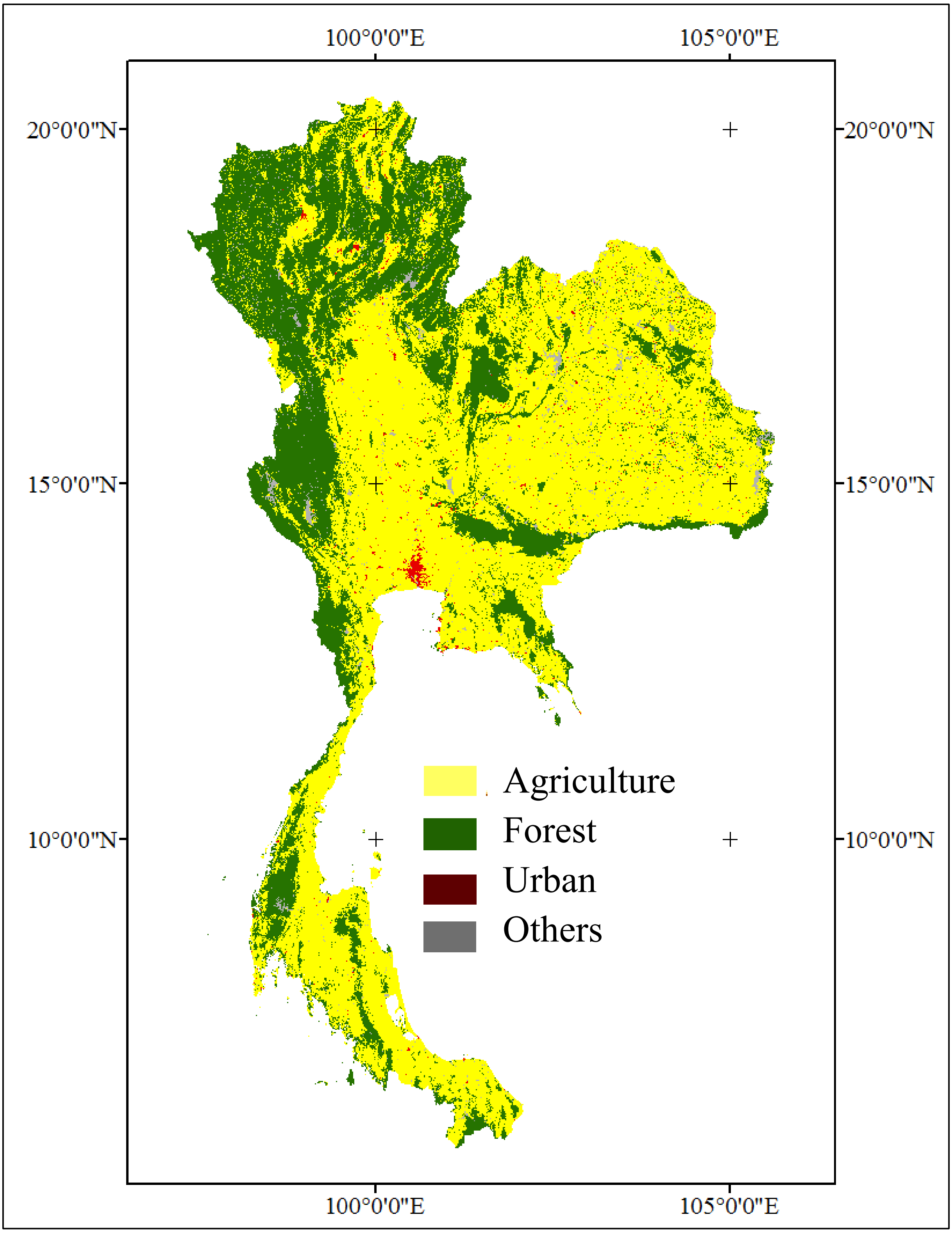


Appendix Figure 3.1h The contribution of Precipitation of driest quarter (BIO 17)



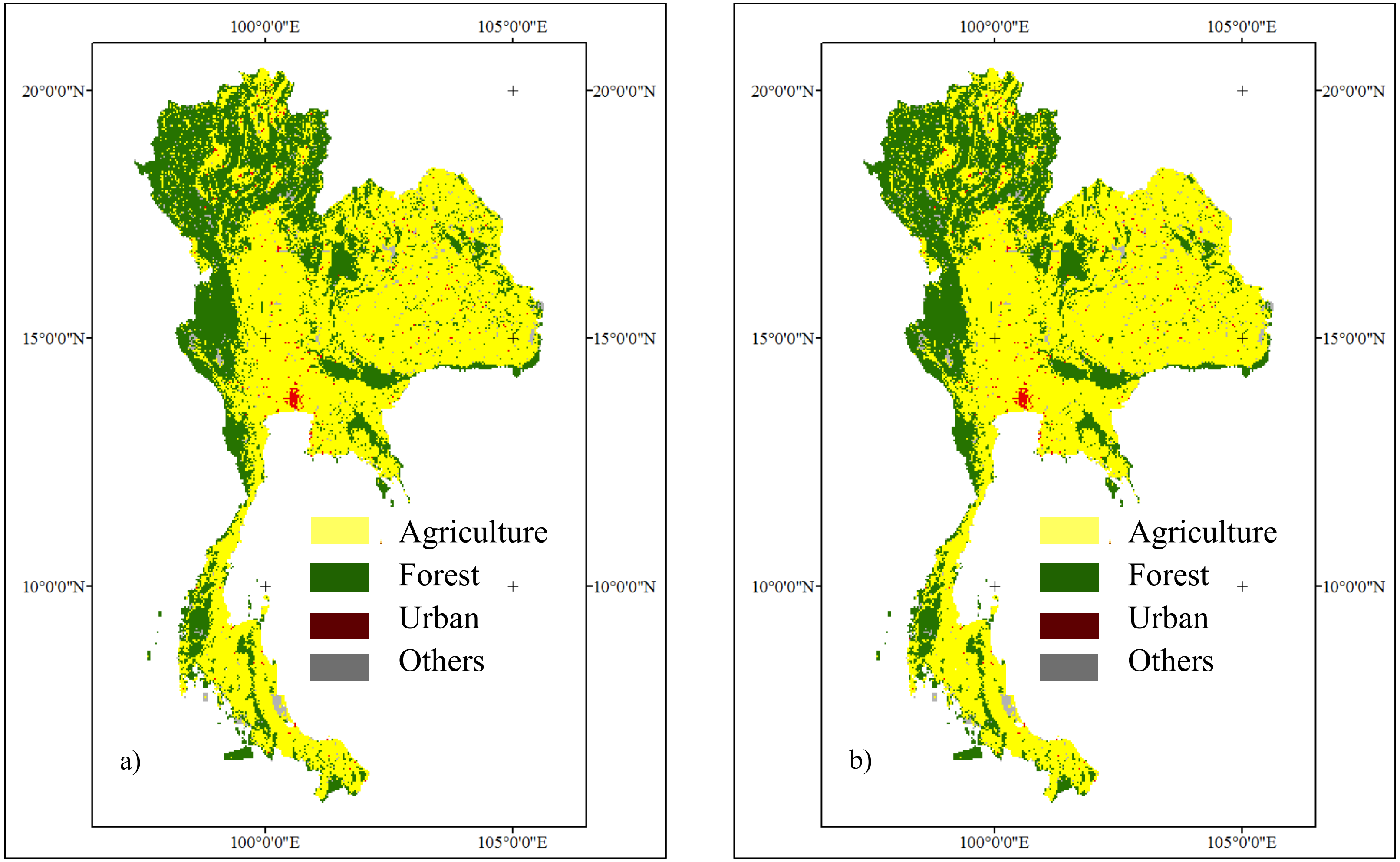
Appendix Figure 5.1

Map of the past land-cover (2000) classed as agriculture area (yellow), forest area (green), usban area (red), and other area (grey) modifiled from land cover 2000 (RFD, 2001)



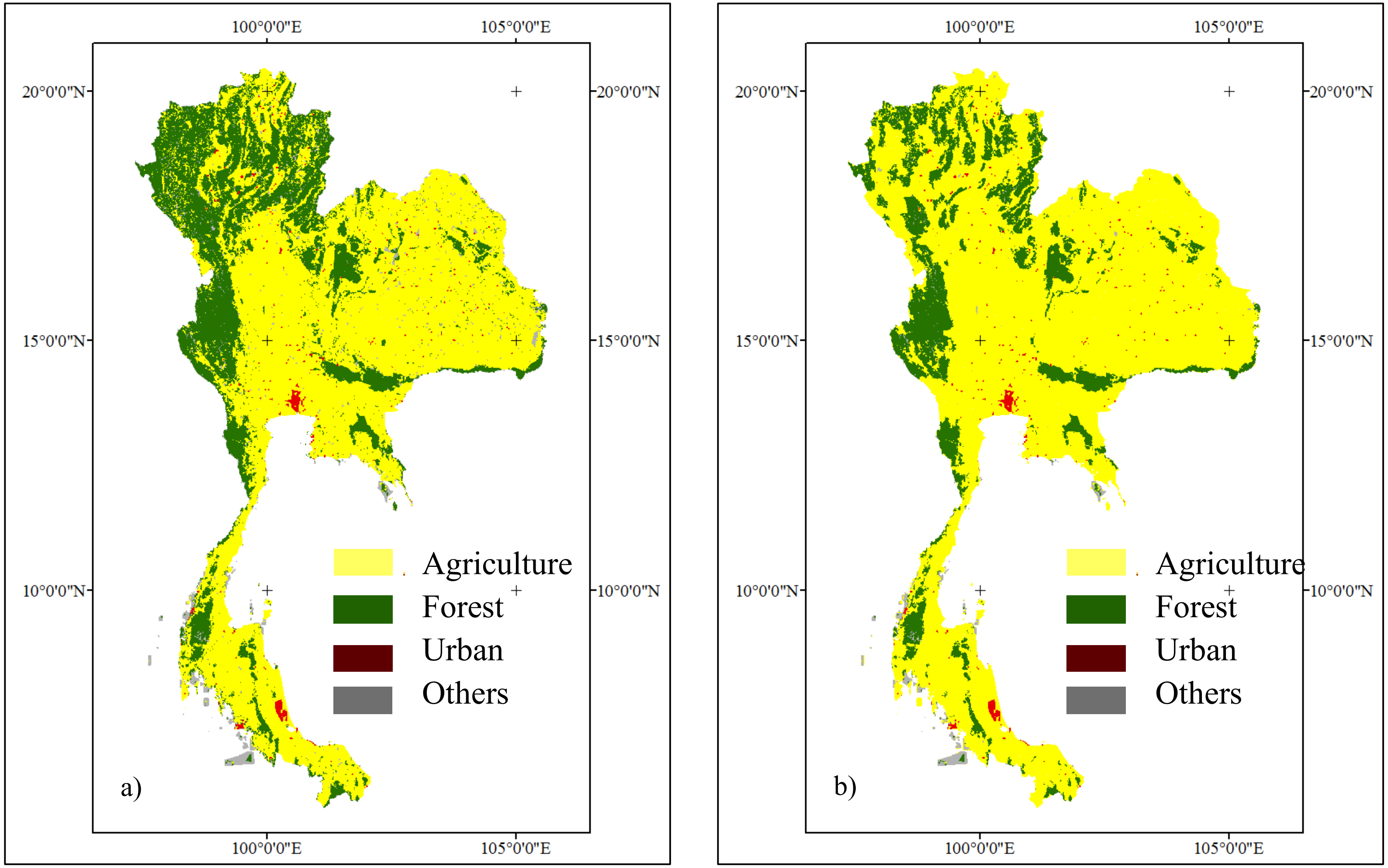
Appendix Figure 5.2

Map of predicted land-cover (a) by 2050, and (b) 2070 for the mild scenario: Sustainable development and limited resources degradation scenario (SD). Land-cover classified as agriculture area (yellow), forest area (green), usban area (red), and other area (grey).



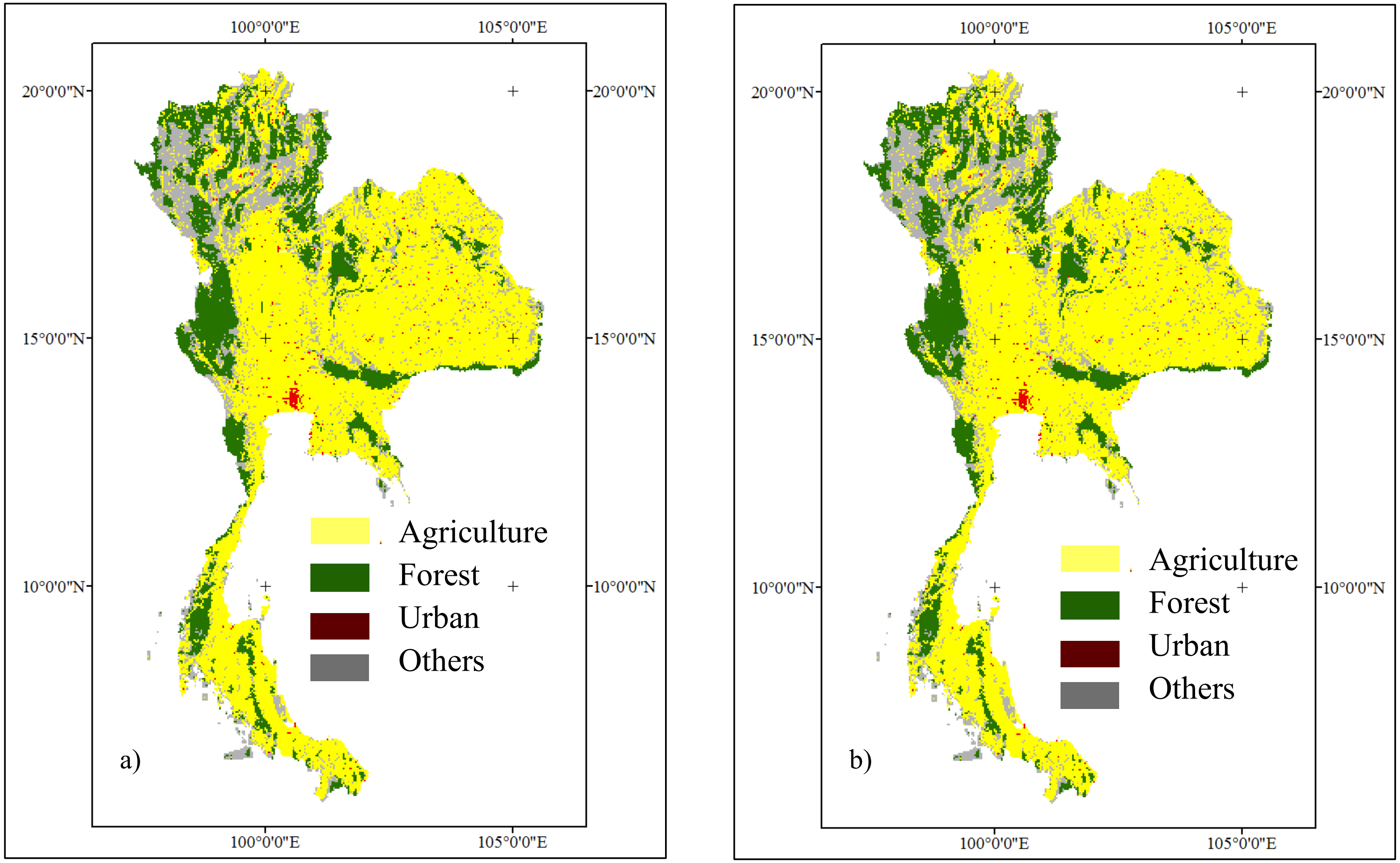
Appendix Figure 5.3

Map of predicted land-cover (a) by 2050, and (b) 2070 for the moderate scenario: Sustainable poverty and stable resources scenario (SP). Land-cover classified as agriculture area (yellow), forest area (green), usban area (red), and other area (grey).



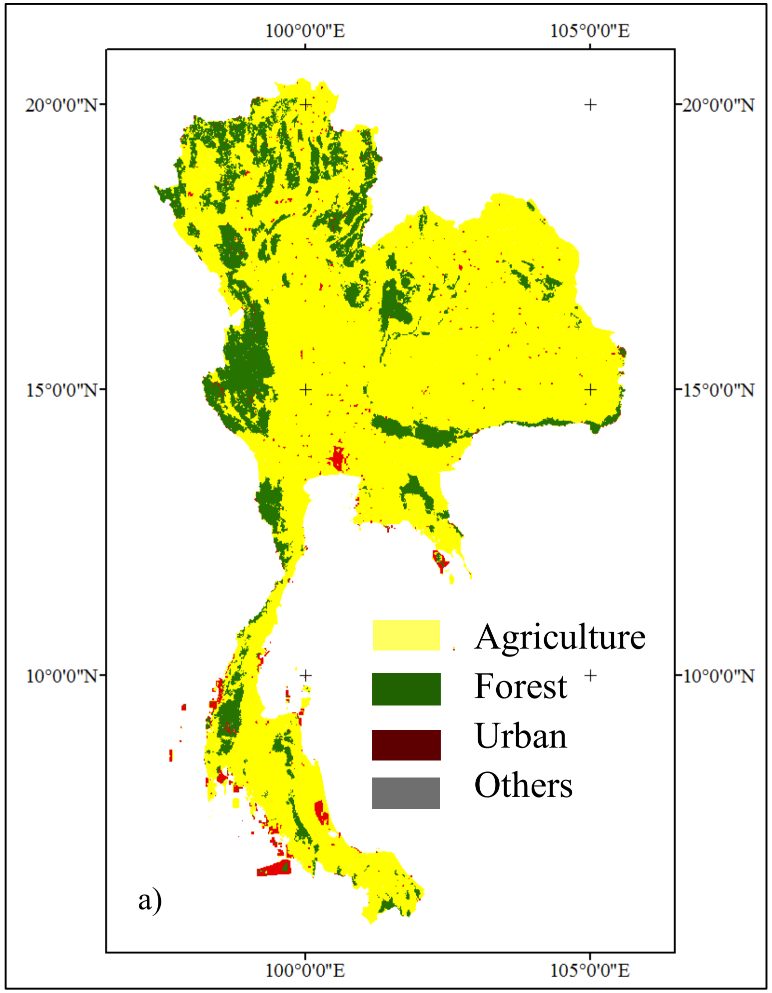
Appendix Figure 5.4

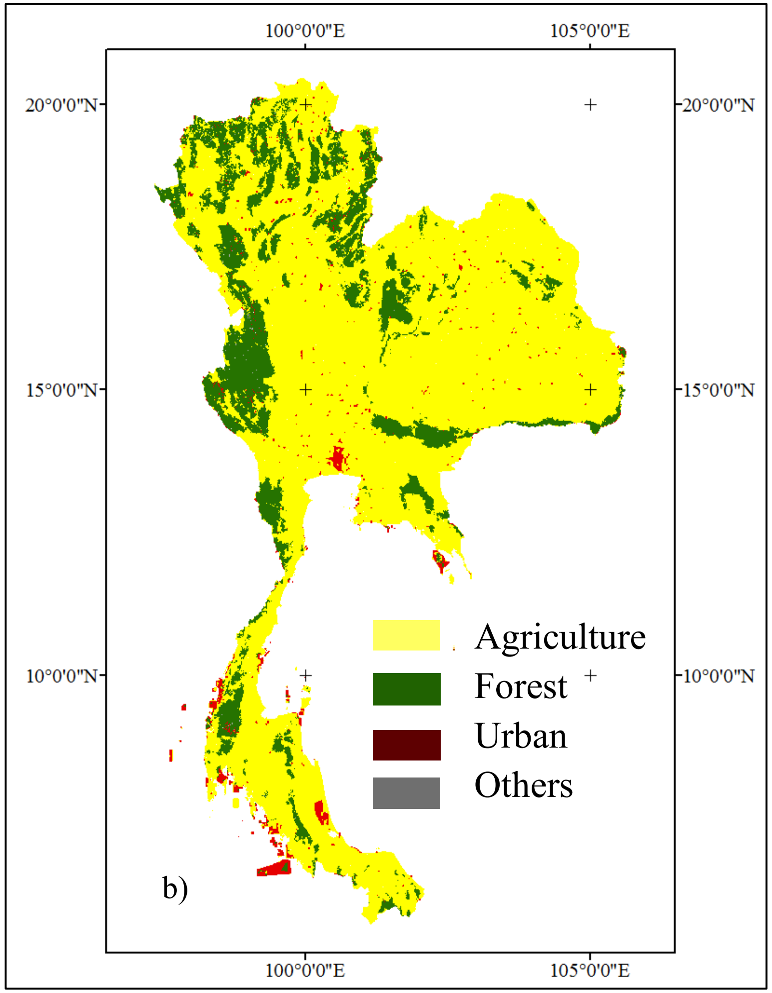
Map of predicted land-cover (a) by 2050, and (b) 2070 for the severe scenario: Low economic decline and localized resource degradation (LE). Land-cover classified as agriculture area (yellow), forest area (green), usban area (red), and other area (grey).



Appendix Figure 5.5

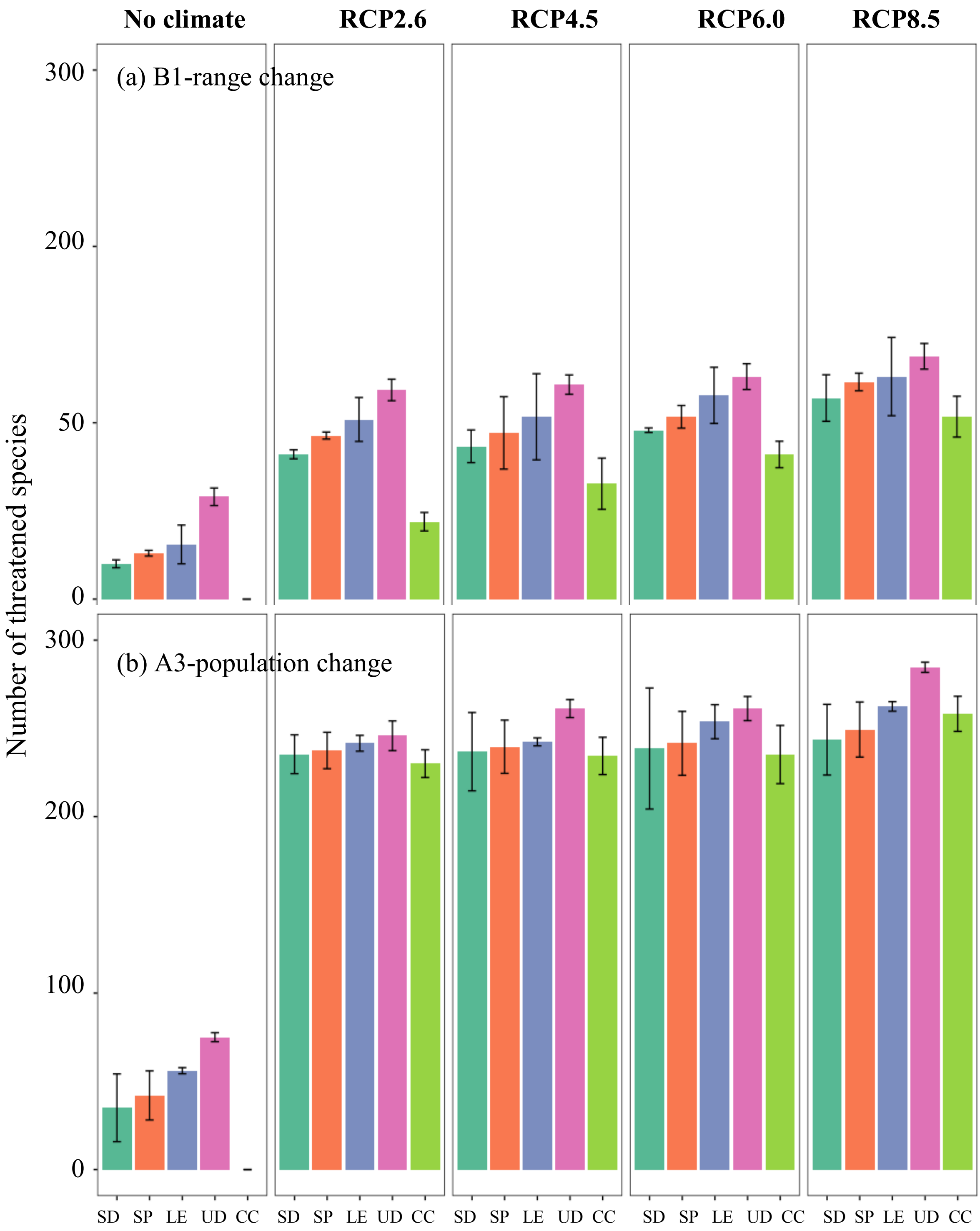
Map of predicted land-cover (a) by 2050, and (b) 2070 for the most severe scenario: Unsustainable economic development and serious resource degradation (UD). Land-cover classified as agriculture area (yellow), forest area (green), usban area (red), and other area (grey).





Appendix Figure 5.6

The threatened species were expected by future environmental change prospective as the conservation status based on the IUCN criteria (a) B1-decline in range size and (b) A3- future reduction of population size by 2050; SD = Sustainable development and limited resources degradation land use scenario; SP = Sustainable poverty and stable resources land use scenario; LE = Low economic decline and localized resources degradation land use scenario; UD = Unsustainable economic development and serious resources degradation land use scenario; and CC = Climate change only. No climate = model land-cover change only; RCP2.6 = scenaio of RCP2.6 combined with each land-cover change scenario and climate change only; RCP4.5= scenaio of RCP4.5combined with each land-cover change scenario and climate change only; RCP6.0= scenaio of RCP6.0combined with each land-cover change scenario and climate change only; and RCP28.5 = scenaio of RCP8.5 combined with each land-cover change scenario and climate change only.



No climate
RCP2.6
RCP4.5
RCP6.0
RCP8.5
(a) B1-range change
(b) A3-population change
Number of threatened species
300
200
50
0
300
200
100
0
SD SP LE UD CC
SD SP LE UD CC
SD SP LE UD CC
SD SP LE UD CC
SD SP LE UD CC

List of electronic supplementary appendices

All elctronic appendices and supplementary information can be accessed using the following link:

https://www.dropbox.com/sh/5b8ghb1u1xlhcnk/AAAYk2ylsAiT-MbREOUYKyGua?dl=0

Appendix Table E1

Details of the number of bird surveys conducted date at each sampling site showing the available elevational range present in each mountain range: DI=Doi Inthanon; HK=Huai Kha Khaeng; KY=Khao Yai; KK=Kaeng Krachan; and HL=Hala Bala. Structure within table are:

Times = Survey period contain four periods.

SAMPLE_ID = ID of sample referenced data sheet.

SITE = Study site total 32 sites across five protected areas; first two character = protected area, number = level of elevation, last character (A/B) = site specific of this location

SITE_ID = ID of line transect of each sites had three line transects

DATE = date of survey

OBS = name of obsever

START = time of started survey

FINISH = time of finished survey

DIST = total of distance survey

CLOUD = cloud cover level (0-10) during survey

RAIN = rain level (0-10) during survey

WET = groud cover humidity (0-3) during survey

WIND = wind level (0-10) during survey

MIST = mist level (0 – 5) during survey

Noise = noise level (0 – 100) during survey

AIR_TEMP = air temperture (˚C) during survey

%HUM = % humidity during survey used hygrometer

FLOWER = flower during survey

FRUIT = fruit during survey

SEASON = season of survey

NOTES = notes any interesting

Appendix Table E2

The responses to global changes; change in distribution and population size, and predicted vulnerability status of each species of each model scenario.

This table contain species code, common name, scientific name, ecological subgroup, and percent change in distribution area and population size from current to 2050, and current to 2070; also the vulnerable status assessed by IUCN criteria within each future global change scenario. Titles of table are:

Code = species code used in this model and related to all of results including distribution maps

Common = common name

Sci name = Scientific name

List of ecological subgroup:

1. Habitat groups: EFS = evergreen forest specialist; EDS = evergreen forest specialist but occur in deciduous forest; EBS = evergreen forest specialist but occur in bamboo forest; EOS = evergreen forest specialist but occur in edge forest, open area, and other (not include forest); GEN - occur in evergreen forest but common in other forest, occur in evergreen forest but common in edge forest, open area and other (not include forest area); and NOF = never occur in evergreen forest). Habitat preferences follow the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012).

2. Feeding guilds:F = frugivorous; G = granivorous; I = insectivorous; N = nectarivorous; O = omnivorous; R = raptor, and S = scavenger). Feeding guilds defined by Lekagul and Round (1991), Round et al., (2003), and Napheethapat et al. (2012).

3. Elevational range limits: L = lowland ; M = montane ;W = widespread. Elevational range limits defined on published elevational range limits (Round et al., 2003, Napheethapat et al., 2012).

4. Biogeographic subregions: IN = Indochinese; INS = Indochinese-southern cross; S = Sundaic; SN = Sundaic-northern cross; and W = widespread. Thailand's birds occur in an overlap zone between two major zoogeographic clades of birds - the Indochinese and Sundaic subregions of the Oriental zoogeographic region, defined groups based on the definitions provided by Hughes et al. (2003), Round et al. (2003) and the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012).

5. Seasonal migratory classes: B = breeding visitor; N = non-breeding visitor; NR = mainly non-breeding visitor but maybe resident; R= resident or presumed resident; RN = mainly resident but maybe non-breeding visitor; P = mainly spring and autumn passage migrant, and U = uncertainty according to the Thailand Bird Guide (Lekagul and Round, 1991, Napheethapat et al., 2012, BCST, 2016).

Results percentage of changes:

RANGE26SD50P = change in distribution range (B1) predicted by RCP2.6 combined with land-cover change SD scenario at 2050.

POP26SD50P = change in population size (A3) predicted by RCP2.6 combined with land-cover change SD scenario at 2050.

RANGE = change in distribution range

POP = change in population size

26 = climate change scenarion RCP 2.6

SD = land-cover change scenario SD

50 = for year 2050

P = percentage of change

Assess vulnerability;

RANGE26SD50V = vulnerability status assessed by change in distribution range (B1) predicted by RCP2.6 combined with land-cover change SD scenario at 2050.

POP26SD50V = vulnerability status assessed by change in population size (A3) predicted by RCP2.6 combined with land-cover change SD scenario at 2050.

RANGE = change in distribution range

POP = change in population size

26 = climate change scenarion RCP 2.6

SD = land-cover change scenario SD

50 = for year 2050

V = vulnerability status

Climate change scenario:

26 = RCP 2.6

45 = RCP 4.5

60 = RCP 6.0

85 = RCP 8.5

Land-cover change scenarios:

SD = mild scenario: Sustainable development and limited resources degradation scenario

SP = moderate scenario: Sustainable poverty and stable resources scenario

LE = severe scenario: Low economic decline and localized resource degradation

UD = most severe scenario: Unsustainable economic development and serious resource degradation

Conservation status:

IN = increase

NT = near threatened

VU = vulnerable

EN = endangered

CR = critically endangered

This supplement data included three datasets:

Appendix_Table_E2a_range_population_status_Combined

Appendix_Table_E2b_range_population_status_Climate

Appendix_Table_E2c_range_population_status_Land_cover

Appendix Figure E1

Map of predicting change in geographical distribution between the current distribution and the predicted distribution in 2050 and 2070, across each RCP scenario.

In this folder contain map of each species by species code (see full species in Appendix Table 1) with the green color in the map shows areas that are suitable in both current and future models, blue shows areas suitable in the future but not currently, grey shows area that are unsuitable in all three periods, and red highlights areas that are suitable in current climates but predicted to be unsuitable in the future.

This supplement data included two datasets:

Appendix Figure E1a: Predicted change in geographic distribution between the current distribution and the predicted distribution in 2050

Appendix Figure E1b: Predicted change in geographic distribution between the current distribution and the predicted distribution in 2070

Appendix Figure E2.1

Accumulation curves of all species within elevational band of each subregion: Relationship between observed species richness (S_{obs}) and the number of standardised surveys within each elevational band. Each point is the mean of 50 randomizations of the samples with 95% confidence intervals. Estimates of total species richness (S_{chao1}) within each elevational band are also provided. Numbers in the figures indicate elevation (m) of each sampling site.

This supplement data included five datasets:

Appendix Figure E2.1a: Doi Inthanon

Appendix Figure E2.1b: Huai Kha Khaeng

Appendix Figure E2.1c: Khao Yai

Appendix Figure E2.1d: Kaeng Krachan

Appendix Figure E2.1e: Hala Bala

Appendix Figure E2.2

The patterns of species richness along elevational gradients: observed richness (S_{obs}) and estimated richness (S_{chao1}) of resisent birds at each subregion;

DISobs = observed richness at Doi Inthanon

DISchao = chao1 estimated richness at Doi Inthanon

HKSobs = observed richness at Huai Kha Khaeng

HKSchao = chao1 estimated richness at Huai Kha Khaeng

KYSobs = observed richness at = Khao Yai

KYSchao = chao1 estimated richness at = Khao Yai

KKSobs = observed richness at Kaeng Krachan

KKSchao = chao1 estimated richness at Kaeng Krachan

HLSobs = observed richness at Hala Bala

HLSchao = chao1 estimated richness at Hala Bala

Appendix Figure E3.1

Current species distribution maps of all 304 species shows as species code with full species name in Appendix Table 1.

This supplement data included three datasets:

Appendix Figure E3.1a: Species distribution maps predicted by combined climate and land-cover

Appendix Figure E3.1b: Species distribution maps predicted by climate

Appendix Figure E3.1c: Species distribution maps predicted by land-cover

Appendix Figure E3.2

Spatial pattern of species richness of Thailand' forest birds based on habitat preferences subgroup. Blue areas indicate an increase in diversity while red areas indicate a decline.

EFS50com = species richness map of evergreen forest specialist group predicted by climate conbined land-cover at 2050

EFS = group of habitat preference
50 = year
com = prediction model variable
Habitat groups:
EFS = evergreen forest specialist;
EDS = evergreen forest specialist but occur in deciduous forest;
EBS = evergreen forest specialist but occur in bamboo forest;
EOS = evergreen forest specialist but occur in edge forest, open area, and other (not include forest);
GEN - occur in evergreen forest but common in other forest, occur in evergreen forest but common in edge forest, open area and other (not include forest area); and
NOF = never occur in evergreen forest).

Com = combine climate and land cover,
Climate = climate
Land = land cover

Appendix Figure E3.3

Spatial pattern of species richness of Thailand' forest birds based on feeding guild subgroup. Blue areas indicate an increase in diversity while red areas indicate a decline.

F50com = species richness map of evergreen forest specialist group predicted by climate conbined land-cover at 2050

F = group of feeding guild
50 = year
com = prediction model variable

Com = combine climate and land cover,
Climate = climate
Land = land cover

Feeding guilds:
F = frugivorous
G = granivorous
I = insectivorous
N = nectarivorous
O = omnivorous
R = raptor
S = scavenger

Appendix Figure E3.4
Spatial pattern of species richness of Thailand' forest birds based on elevational range limits subgroup. Blue areas indicate an increase in diversity while red areas indicate a decline.

Low50com = species richness map of evergreen forest specialist group predicted by climate conbined land-cover at 2050

Low = group of elevation range limit
50 = year
com = prediction model variable

Com = combine climate and land cover,
Climate = climate
Land = land cover

Elevational groups:
L = lowland
M = montane
W = widespread

Appendix Figure E3.5

Spatial pattern of species richness of Thailand' forest birds based on biogeographic subregions subgroup. Blue areas indicate an increase in diversity while red areas indicate a decline.

IN50com = species richness map of evergreen forest specialist group predicted by climate conbined land-cover at 2050

IN= group of biogeographic subregions
50 = year
com = prediction model variable

Com = combine climate and land cover,
Climate = climate
Land = land cover

Biogeographic subregions:
IN = Indochinese
INS = Indochinese-southern cross
S = Sundaic
SN = Sundaic-northern cross
W = widespread.

Appendix Figure E3.6

Spatial pattern of species richness of Thailand' forest birds based on Seasonal migratory classes subgroup. Blue areas indicate an increase in diversity while red areas indicate a decline.

R50com = species richness map of evergreen forest specialist group predicted by climate conbined land-cover at 2050

F = group of migratory status
50 = year
com = prediction model variable

Com = combine climate and land cover,
Climate = climate
Land = land cover

Seasonal migratory classes:
B = breeding visitor
N = non-breeding visitor
NR = mainly non-breeding visitor but maybe resident
R= resident or presumed resident
RN = mainly resident but maybe non-breeding visitor
P = mainly spring and autumn passage migrant
U = uncertainty.

Appendix Figure E5.1

Spatial pattern of species richness based on the mild scenario: Sustainable development and limited resources degradation scenario (SD)

File name 26SD50 = spatial pattern of species richness conducted by climate change (RCP2.6) combine with land-cover change scenario SD at 2050

26 = RCP

SD = land-cover scenario

50 = year of prediction

Thus, if predicted by scenario change only did not include first two number land-cover change, similary to if predicted by climate change only did not include SD in the file.

Appendix Figure E5.2

Spatial pattern of species richness based on the moderate scenario: Sustainable poverty and stable resources scenario (SP)

File name 26SP50 = spatial pattern of species richness conducted by climate change (RCP2.6) combine with land-cover change scenario SP at 2050

26 = RCP

SP = land-cover scenario

50 = year of prediction

Thus, if predicted by scenario change only did not include first two number land-cover change, similary to if predicted by climate change only did not include SP in the file.

Appendix Figure E5.3

Spatial pattern of species richness based on the severe scenario: Low economic decline and localized resource degradation (LE).

File name 26LE50 = spatial pattern of species richness conducted by climate change (RCP2.6) combine with land-cover change scenario LE at 2050.

26 = RCP

LE = land-cover scenario

50 = year of prediction

Thus, if predicted by scenario change only did not include first two number land-cover change, similary to if predicted by climate change only did not include LE in the file.

Appendix Figure E5.4

Spatial pattern of species richness based on the most severe scenario: Unsustainable economic development and serious resource degradation (UD).

File name 26UD50 = spatial pattern of species richness conducted by climate change (RCP2.6) combine with land-cover change scenario SD at 2050

26 = RCP

UD = land-cover scenario

50 = year of prediction

Thus, if predicted by scenario change only did not include first two number land-cover change, similary to if predicted by climate change only did not include UD in the file.