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Integrated Approaches to Mammal Conservation in Myanmar: From Assessment of Species Diversity and Distribution to Habitat Identification for Threatened Species

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Integrated Approaches to Mammal Conservation in Myanmar: From Assessment of Species Diversity and Distribution to Habitat Identification for Threatened Species

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Abstract

This study provided an updated checklist of mammals of Myanmar which includes 365 (33 marine and 332 terrestrial) species belonging to 13 orders, 49 families and 173 genera, alongside their IUCN conservation statuses and legal protections within Myanmar. The diverse mammalian fauna of Myanmar can be exemplified by two disparate species, ranging from the tiny 2-gram bumblebee bat, *Craseonycteris thonglongyai*, to the massive 150-ton blue whale, *Balaenoptera musculus*. Notably, we document the first photographic evidence of the banded civet in Myanmar since 1914, indicating the potential for undiscovered mammalian presence within the country. In addition, the eastern and western area (Shan, Chin and Rakhine States) of Myanmar need to conduct more biological inventories to better describe mammal diversity of Myanmar. Number of recorded species were highest (≥ 100 mammal species) in the northern (Kachin State and Sagaing Region) and the southern (Tanintharyi Region). In Shwesettaw Wildlife Sanctuary, human settlements had strong negative impacts on the detection probability of studied mammals, except for golden jackal and Eld's deer which reflects animals' elusiveness in proximity of a direct and permanent source of human disturbance. All studied mammal species shifted to nocturnal activity or did not show any clear activity pattern during the cool-dry season when the presence of free-ranging dogs increased. This case study highlighted the impacts of free-ranging dogs on the temporal habitat use of wildlife and the need for better practices in the management of free-ranging dogs/other domestic animals within protected areas. Further research should also aim to fill knowledge gaps related to the ecology and behavior of poorly understood species, as well as the cumulative impacts of climate and land use change on mammalian diversity, especially for those identified as critically endangered, endangered, or vulnerable species.

Keywords: Activity pattern, Anthropogenic disturbances, Checklist, Endemic, Marine, Species Diversity and Distribution, Terrestrial

မြန်မာနိုင်ငံတွင် ကျက်စားနေထိုင်သည့် နို့တိုက်သတ္တဝါ မျိုးစိတ်များအား ဘက်စုံကာကွယ် ထိန်းသိမ်းရေးဆိုင်ရာ နည်းလမ်းများအား ဖော်ထုတ်နိုင်ရန်အတွက် နို့တိုက်သတ္တဝါ မျိုးစိတ် ကြွယ်ဝမှုနှင့် ပျံ့နှံ့ကျက်စားမှု ဆန်းစစ် အကဲဖြတ်ခြင်းမှသည် မျိုးသုဉ်းရန် အန္တရာယ်ရှိသည့် မျိုးစိတ်များအတွက် ကောင်းမွန်သင့်တော်သည့် နေရင်းဒေသများအား ဆန်းစစ်လေ့လာဖော်ထုတ်ခြင်း

ဒေါက်တာအေးမြတ်သူ၊ ဦးစီးအရာရှိ
သစ်တောဦးစီးဌာန

စာတမ်းအကျဉ်း

ဤသုတေသနစာတမ်းသည် မြန်မာနိုင်ငံရှိ နို့တိုက်သတ္တဝါမျိုးစိတ်များအား ထိရောက်စွာ ထိန်းသိမ်းကာကွယ်ရေး လုပ်ငန်းများဆောင်ရွက်ရန်အတွက် ပထမဦးစွာ အခြေခံကျသည့် နို့တိုက် သတ္တဝါမျိုးစိတ်ကြွယ်ဝမှုစာရင်းနှင့် ပျံ့နှံ့တည်ရှိမှု စသည်တို့ကို ဦးစွာဖော်ထုတ်ခြင်းနှင့်အတူ ကမ္ဘာ့လူဦး ရေများပြားလာခြင်းနှင့် လူတို့မွေးမြူထားသည့် ခွေးနှင့်ကြောင်ကဲ့သို့သော အိမ်မွေးတိရစ္ဆာန် များသည် ထိန်းသိမ်းရေးနယ်မြေနှင့် တောရိုင်းတိရစ္ဆာန် ဘေးမဲ့တောထဲသို့ ကျူးကျော်ဝင်ရောက်ခြင်းကြောင့် တောရိုင်းတိရစ္ဆာန်များ၏ အမူအကျင့်များအပေါ် မည်ကဲ့သို့ နှောင့်ယှက်ထိခိုက်စေမှုစသည်တို့ကို လေ့လာဆောင်ရွက်ခဲ့ပါသည်။ မြန်မာနိုင်ငံရှိ နို့တိုက်သတ္တဝါမျိုးစိတ်စာရင်းနှင့် ပျံ့နှံ့ကျက်စားမှုတို့ကို သုတေသနပြုလေ့လာခဲ့ခြင်းမှ မြန်မာနိုင်ငံတွင် တောရိုင်းနို့တိုက်သတ္တဝါမျိုးစိတ်ပေါင်း ၃၆၅ မျိုး (ကုန်းနေမျိုးစိတ် ၃၃၂ မျိုးနှင့် အဏ္ဏဝါ မျိုးစိတ် ၃၃ မျိုး)၊ မျိုးစု ၁၇၃ မျိုး၊ မျိုးရင်း ၄၉ မျိုးနှင့် မျိုးစဉ် ၁၃ မျိုးတွင် ပါဝင်ကြောင်း လေ့လာ ဖော်ထုတ် နိုင်ခဲ့ပါသည်။ မြန်မာနိုင်ငံမြောက်ပိုင်း (ကချင်နှင့် စစ်ကိုင်းတိုင်း)နှင့် တောင်ပိုင်း ဒေသ(တနင်္သာရီ)တို့သည် နို့တိုက်သတ္တဝါ မျိုးစိတ်ကြွယ်ဝမှု (မျိုးစိတ် ၁၀၀ နှင့်အထက်) ရှိသော နေရာဒေသများအဖြစ် မှတ်တမ်းတင်နိုင်ခဲ့ပြီး ရှမ်း၊ ချင်းနှင့် ရခိုင်ပြည်နယ်တို့တွင် နို့တိုက် သတ္တဝါမျိုးစိတ် စာရင်းကောက်ယူမှု ပိုမိုဆောင်ရွက်သင့်ကြောင်း လေ့လာတွေ့ရှိခဲ့ရပါ သည်။ ထို့ပြင် လေညာအဆိုပြု အမျိုးသားဥယျာဉ်အနီးရှိ တောင်ဖရူးကြီးဝိုင်းအတွင်း တပ်ဆင်ခဲ့သည့် ကင်မရာထောင်ချောက်တပ်ဆင်လေ့လာမှုမှ မြန်မာနိုင်ငံတွင် ၁၉၁၄ခုနှစ် နောက်ပိုင်းမှစ၍ မှတ်တမ်းတင်နိုင်ခြင်း မရှိခဲ့သည့် ကြောင်ဝံစင်းကျားမျိုးစိတ်အား ပြန်လည်မှတ်တမ်း တင်နိုင် ခဲ့ပါသည်။ ထို့ပြင် မြန်မာနိုင်ငံတွင်သာတွေ့ရှိနိုင်သည့် မြန်မာ့မျိုးရင်း နို့တိုက်သတ္တဝါမျိုးစိတ် (၉)မျိုး ရှိကြောင်းကိုလည်း ဖော်ထုတ်မှတ်တမ်းတင်နိုင်ခဲ့ပါသည်။ လူနှင့်လူသားတို့မွေးမြူထား သည့် အိမ်မွေးတိရစ္ဆာန်များမှ သဘာဝထိန်းသိမ်းရေးနယ်မြေများတွင် ကျူးကျော်ဝင်ရောက်မှု

ကြောင့် တောရိုင်းတိရစ္ဆာန်များ၏ အမူအကျင့်နှင့် ဂေဟစနစ်အပေါ် နှောင့်ယှက်ထိခိုက်စေမှုအား ရွှေစက်တော် တောရိုင်းတိရစ္ဆာန် ဘေးမဲ့တောတွင် ဆန်းစစ်လေ့လာခဲ့ရာမှ ဘေးမဲ့တောအနီးဝန်းကျင်တွင် နေထိုင်သည့်ဒေသခံများ မွေးမြူထားသည့် အိမ်မွေးခွေးများ ဘေးမဲ့တောအတွင်း ဝင်ရောက်ခြင်းကြောင့် ယင်းဘေးမဲ့တောတွင် ကျက်စားနေထိုင်လျက်ရှိသည့် တောရိုင်းတိရစ္ဆာန်များ၏ နေရင်းဒေသ အသုံးပြုမှုအပေါ် ထိခိုက်မှုရှိကြောင်း လေ့လာတွေ့ရှိခဲ့ရသည့်အတွက် သဘာဝထိန်းသိမ်းရေး နယ်မြေအနီးဝန်းကျင်တွင် နေထိုင်သူများအား ၎င်းတို့မွေးမြူထားသည့် အိမ်မွေးတိရစ္ဆာန်များ၏ သဘာဝထိန်းသိမ်းရေးနယ်မြေများအား အသုံးပြုမှုအပေါ် ထိန်းချုပ်သင့်ကြောင်း လေ့လာတွေ့ရှိခဲ့ရပါသည်။ ဤသုတေသနစာတမ်းသည် မြန်မာနိုင်ငံ၏ နို့တိုက်သတ္တဝါမျိုးစိတ်စာရင်းကို ခေတ်နှင့်အညီ မွမ်းမံပြင်ဆင်ထားသည့် မျိုးစု၊ မျိုးရင်း၊ မျိုးစဉ်ဇယားဆိုင်ရာ အချက်အလက်များကို ဖော်ထုတ်တင်ပြနိုင်ခဲ့သော်လည်း မျိုးခွဲခြင်းဆိုင်ရာ နည်းစနစ်များ၏ အမြဲပြောင်းလဲတတ်သည့် သဘောသဘာဝအရ နှစ်စဉ် မွမ်းမံပြင်ဆင်တင်ပြရန် လိုအပ်လျက် ရှိပါကြောင်းနှင့် သဘာဝထိန်းသိမ်းရေး နယ်မြေအနီးတွင် နေထိုင်သူများမှ မွေးမြူထားသည့် အိမ်မွေး ခွေး/ခွေးလေ ခွေးလွှင့်များမှ သဘာဝထိန်းသိမ်းရေး နယ်မြေအတွင်းရှိ တောရိုင်းတိရစ္ဆာန်များ၏ နေရင်းဒေသများ၌ ကျူးကျော်ဝင်ရောက် အသုံးပြုခြင်းများကို ထိန်းချုပ်သင့်ကြောင်း စသည်ဖြင့် မှတ်တမ်းတင် လေ့လာဖော်ထုတ်နိုင်ခဲ့ပါသည်။

Integrated Approaches to Mammal Conservation in Myanmar: From Assessment of Species Diversity and Distribution to Habitat Identification for Threatened Species

1. Introduction

Mammals play significant roles in all ecosystems, undertaking a diverse array of critical ecosystem functions (Lacher et al., 2019). Overall, mammals are crucial in shaping community structure by influencing nutrient dynamics, species interactions, and habitat modification. There are approximately 6,718 species of mammals globally (107 recently went extinct, 6,611 extant) belonging to 1,351 genera, 167 families, and 27 orders (Mammal Diversity Database, 2024). Extinctions are spread across the 11 orders of mammals: Dasyuromorphia (1 species), Lagomorpha (1 species), Sirenia (1 species), Primates (4 species), Artiodactyla (6 species), Carnivora (7 species), Diprotodontia (8 species), Peramelemorphia (8 species), Chiroptera (9 species), Eulipotyphla (10 species), and Rodentia (52 species) (Mammal Diversity Database, 2024). Rates of recent mammalian extinctions, therefore, highlight the need to increase the efforts to conserve them (Pimm et al., 2014).

According to the International Union for Conservation of Nature and Natural Resources (IUCN, 2022), 26% of all the threatened species correspond to mammalian species. The loss of terrestrial mammals is primarily due to the overexploitation of natural resources, large-scale destruction of natural habitats and the competition and predation from invasive alien species (Maxwell et al., 2016). According to Ceballos et al. (2017), 177 mammal species have experienced a loss of at least 30% of their habitat, with over 40% of them facing significant population declines because of shrinking geographic ranges. A recent study has shown that the combined effect of habitat loss and fragmentation can lead to the extinction of mammal species, with up to 86 species at risk (Kuipers et al., 2021). The loss of suitable habitats has been observed in various mammalian taxa, particularly within the order Carnivora and Cingulata (Butti et al., 2022). These findings highlight the urgent need for comprehensive strategies to combat habitat loss and address the impacts of human activities on mammal populations (Brodie et al., 2021).

Due to the political and economic instability in Myanmar over the past 70 years (Nwe et al., 2020), many parts of Myanmar have been largely unavailable for field exploration and scientific research investigation. Hence, baseline information on species diversity and distribution status is urgently needed in Myanmar. Many local and international non-governmental organizations are conducting many different conservation assessments in Myanmar; the number of publications is less comparable and the accessibility of the data and database is limited. In addition, most of the conservation research in Myanmar is small-scale, geographically biased, and scattered throughout the country. Moreover, the sampling intensity and effort are unequal not only for the region but also for the different taxonomic groups. Although mammals are relatively well-studied than other taxa, they have severely suffered from human impacts in the recent years despite having a crucial role in providing and maintaining services and functions associated with sustaining balanced ecosystems (Pacifici et al., 2020). In addition, it is also very challenging to study mammals because many mammal species, especially those indigenous to tropical forests, are cryptic, occur at low densities, nocturnal, or inherently difficult to observe (Dirzo et al., 2009). The loss of mammalian diversity could alter ecosystems in specific ways we do not yet comprehend and the absence and rarity of mammals in a given ecosystem have severe consequences due to the functional roles that they perform are lost (Geleta and Bekele, 2016; Ripple et al., 2017). Thus, understanding the key patterns and drivers of extinction risk has been a major goal of conservation biology. However, the lack of data on their status and population trends hinders our capacity to conserve them. Hence, surveys of mammalian diversity and distribution conditions are the some of the first steps for conservation action and provide information to establish appropriate conservation strategies (Atnafu and Yihune, 2018). Below, I outline the two main aspects addressed in this study.

1.1 Assessment Of Mammal Species Diversity, Geographical Distribution And Conservation Status In Myanmar

Accurate taxonomy is key to the study of biological diversity, as it provides the needed evolutionary framework for taxon sampling and interpreting results (Burgin et al., 2018). It is crucial to inventorize the species diversity before we can devise policies to protect them by maintaining their preferred and suitable habitats in line with the sustainable natural resource management (Li and Quan, 2017). Fundamentally, we must know where individual species live, which ones are vulnerable, where human actions threaten them, and the level of protection devoted to them (Jenkins et al., 2013). Several recent studies have focused on global scale mapping of biodiversity and priorities for conservation (Jenkins et al., 2013; Pimm et al., 2014). Such efforts can be useful, particularly in guiding international conservation attention however, much of conservation planning takes place not at the global scale but rather at national, regional or local scales (Jenkins et al., 2015). In addition, the recommendations and strategies from global studies may not be applicable for regional or local conservation planning due to unequal sampling intensity, the generalization of the pattern and the data gaps for targeted species. We explored the specific case of Myanmar, located in the Indo-Burma biodiversity hotspot and one of the most biodiverse countries in the mainland Southeast Asia (Nwe et al., 2020). It is a basic and crucial step particularly for Myanmar since there is no baseline data on species diversity for most of the major taxonomic groups, and the available data of the current status of the country's diversity is mainly about the globally threatened species that are currently listed in the IUCN Red List of Threatened Species.

To date, apart from a book published in 1993 which revised and updated the Wild Animals of Burma (the former name of Myanmar) by U Tun Yin in 1967, there is no update to the mammal species list in Myanmar. Furthermore, no countrywide assessment of the mammal diversity and distribution in Myanmar has yet been established. This study therefore focused on the diversity, geographical distribution and conservation status of the mammal species of Myanmar by using data from extensive camera trap survey in five Protected Areas (PAs) and two Reserved Forests (RF) (together represents about 30 % of the total PAs of the country), a comprehensive literature survey and citizen-recorded wildlife species data.

1.2 The Ecological Impacts of Anthropogenic Disturbances on Spatio-Temporal Responses of Mammals

Safeguarding species against threatening processes is a major global priority (Howard et al., 2020). Species extinction is often driven by anthropogenic activities and therefore, increasing human footprint on the landscape is a key threat to wildlife not only through habitat loss and fragmentation, but also because urbanized areas represent concentrations of anthropogenic disturbances which may be actively avoided by wildlife (Nickel et al., 2020). Thus, monitoring the impacts of anthropogenic threats and interventions is fundamental to mitigate these threats and to effectively conserve biodiversity (Christie et al. 2019).

Urbanization of natural landscapes with steadily increasing human population in Myanmar over the recent decades has brought humans and our companion animals into closer contact with wildlife, even within the protected areas. With increasing human population, invasive species are becoming a major concern and threat to wildlife, since people purposefully and accidentally introduce invasive carnivores such as domestic dogs *Canis familiaris* and cats *Felis catus* (Farris et al., 2017). Although the impacts of invasive species on wildlife, including their role in species extirpations and extinctions, are well documented in many areas of the world, little is known about their ecological impacts in Southeast Asia particularly in Myanmar.

Furthermore, most of the current knowledge of the invasive species in Southeast Asia have been based on anecdotal observations (Peh et al., 2010). As the presence of invasive carnivores in ecosystems across the world is a leading driver of native species' declines, quantifying their impacts on native wildlife is of vital importance (Murphy et al., 2018). However, scientific investigation of the ecological impacts of anthropogenic disturbances on wildlife has rarely been conducted in Myanmar. Many protected areas of Myanmar are threatened by hunting, grazing, collection of non-timber forest products, and the presence of permanent settlements by surrounding rural communities (Rao et al. 2002). It is therefore critical to understand the effects of anthropogenic disturbances and how well native wildlife species might survive in human-dominated landscapes to provide guidance for human-wildlife coexistence.

2. Objectives of The Study

The main objective of this study is to provide empirical research-based data to enhance the conservation and management practices of Protected Areas (PAs) in Myanmar. This study aims to update the information of mammals of Myanmar and to provide the guidance on mechanisms for human-wildlife coexistence in Myanmar during the Anthropocene era. Based on the gaps in our knowledge mentioned above, this study aimed to address the following research objectives;

1) To conduct a systematic and comprehensive assessment of mammalian biodiversity and distribution in Myanmar by identifying the number of species across different orders and families, delineating their global and Myanmar distribution ranges, and assessing their conservation status by IUCN Red List status and legal protection status under *the Conservation of Biodiversity and Protected Areas Law (2018)* of Myanmar.
2) To understand the impact of different anthropogenic disturbances upon the space use and temporal activity patterns of terrestrial mammal species particularly for those living in human dominated landscapes of Myanmar.

3. Materials and Methods

3.1 Methods on Mammal Species Diversity, Distribution And Conservation Status

The checklist of mammals was updated mainly based on "Wild Mammals of Myanmar" (Tun Yin 1993) which was the most recently published comprehensive list of mammals of Myanmar. In addition, we complied and updated this checklist by reviewing the eight volumes of the Handbook of the Mammals of the World: Vol.1 (Carnivores: Wilson and Mittermeier 2009), Vol. 2 (Hoofed Mammals: Wilson and Mittermeier 2011), Vol. 3 (Primates: Mittermeier et al. 2013), Vol. 4 (Sea Mammals: Wilson and Mittermeier 2014), Vol. 6 (Lagomorphs and Rodents I: Wilson et al. 2016), Vol. 7 (Rodents II: Wilson et al. 2017), Vol. 8. Insectivores, Sloth and Colugos: Wilson and Mittermeier 2018) and Vol.9 (Bats: Wilson and Mittermeier 2019). To update the Marine mammals, we mainly rely the data of the report *"Marine Conservation in Myanmar: The current knowledge of marine systems and recommendations for research and conservation"* which complied more than 600 literatures including the research that have been primarily conducted by Myanmar scientists on the country's marine biodiversity and habitats (Holmes et al., 2014; Thu et al., 2024). In addition, we compiled and updated this checklist by using the following references: 1) *Field Guide to the Mammals of Southeast Asia* (Francis 2019), *Mammals of China* (Smith and Xie 2013), and 3) *Primates of the Greater Mekong: Status, Threats and Conservation Efforts* (Freund et al. 2021).

Morevoer, we collected distributional and occurrence data from the following available online databases: 1) IUCN Red List of Threatened Species 2022 (https:// www.iucnredlist.org), 2) Mammal Diversity Database 2022 (https:// www. Mammal diversity.org), 3) Global Biodiversity Information Facility (https:// www.gbif.org/), 4) iNaturalist (https://www.inaturalist.org), 5) Smithsonian National Museum of Natural History (https://naturalhistory.si.edu/), 6) American Museum of Natural History (https://www.amnh.org/), 7) The Field Museum (https://www. fieldmuseum.org/), 8) VERTNET (http://www.vertnet.org), and also from the citizen-recorded wildlife species groups on Facebook (Native Species Conservation and Identification, Wildlife of Myanmar, and Myanmar Biodiversity), and unpublished reports from the Forest Department of Myanmar.

A comprehensive literature review was conducted using online databases such as Web of Science and Google Scholar, employing keywords including “Myanmar,” “Burma,” “mammals,” “wildlife,” “marine,” “terrestrial,” “Fauna,” “distribution,” and “Zoogeography” to gather relevant research articles on the mammal species diversity and distribution in Myanmar. To gather data on the distribution of mammals and to produce the maps showing which political units of Myanmar have how many recorded numbers of species, we reviewed a total of 275 literatures, including reports and documents written in Myanmar language. In addition, we used the distributional data of mammals from our camera trap survey (a total of 406 camera traps from December 2015 to May 2022) in Hkakaborazi National Park (NP) (2,700 km^2), Hponkanrazi Wildlife Sanctuary (WS) (3,810 km^2) and the Madwalrazi area (4,778 km^2), Htamanthi WS (2,151 km^2), Natmataung NP (713.5 km^2), Shwesettaw WS (552.7 km^2) and Htaung Pru Reserved Forest (RF) (190 km^2 in Tanintharyi Region). We set up all camera traps placing at animal-trails, salt-licks, small streams and water holes area where signs of animals were evident. The cameras were attached to the trees/poles approximately 0.5-2 m above ground, depending on the topography and vegetation cover to be clearly visible in the photographs.

We collected 10,123 records of distribution of all mammals in Myanmar; however, the final dataset comprises about 5,000 valid data points after meticulous data cleaning and the exclusion of duplicate points (Figure 2.1). In our updated checklist, we listed all native and non-native species of mammals known to occur in Myanmar regularly. For native species, we also include recently extinct species that used to occur in Myanmar regularly. For each species, we provide the following information: scientific and common names, both in English and Myanmar, brief description of global and local distribution range, and remarks on taxonomy and conservation related information such as their IUCN threatened status (only for critically endangered, endangered and vulnerable) and legal protection status (completely protected, normally protected and seasonally protected) in Myanmar by *The Conservation of Biodiversity and Protected Areas Law 2018*. A checklist of mammalian taxa in phylogenetic order with their IUCN threatened status (only for critically endangered, endangered and vulnerable) and Myanmar’s legal protection status are also provided.

3.2 Camera trap survey

We deployed 80 camera traps (Yianws L710-940) in Shwesettaw Wildlife Sanctuary (20.12ºN and 94.35ºE) between September 2017 and October 2018 (Figure. 1). We could use only 53 camera traps for our final analysis because seven were burnt by wildfire and 20 were malfunctioned. We set up the camera traps for year-round deployment. We checked the camera traps once every three months to replace the batteries and, when necessary, to clear understory growth to reduce false triggering and vegetation-obstructed photographs. The distance between any pair of two cameras was at least 700 m and the sampling-protocol was designed to enhance the geographic spread of the sample as much as possible. All the camera traps were placed at animal-trails, saltlicks, small streams, or water holes, where signs of animals were evident. The cameras were attached to trees 0.5–2 m aboveground, depending on the topography and vegetation cover, to guarantee that animals were clearly visible in the photo. The minimum refractory period between two successive triggers was set to five seconds with each trigger taking three consecutive images. We did not use bait and all cameras were set to work 24 hours per day.

We recorded the location of camera traps with a hand-held GPS (Garmin 62S) and all camera trap photos included a timestamp. We downloaded the geospatial data of the highway road, towns, and villages in our study area from the Myanmar Information Management Unit. Hereafter, we use the term “settlements” for both “towns and villages”. We considered the following four environmental covariates at each camera site: (1) distance from highway (m), (2) distance from human settlements (m), (3) human presence, and (4) free-ranging dog (hereafter “dog”) presence. We measured the Euclidean distances of each camera station to road and settlements in ArcGIS 10.7 (ESRI Inc., Redlands, CA, USA), which averaged 4550 ± 520 m and 9330 ± 610 m respectively. Human and dog presence indicate that they were detected by the camera trap in that location.

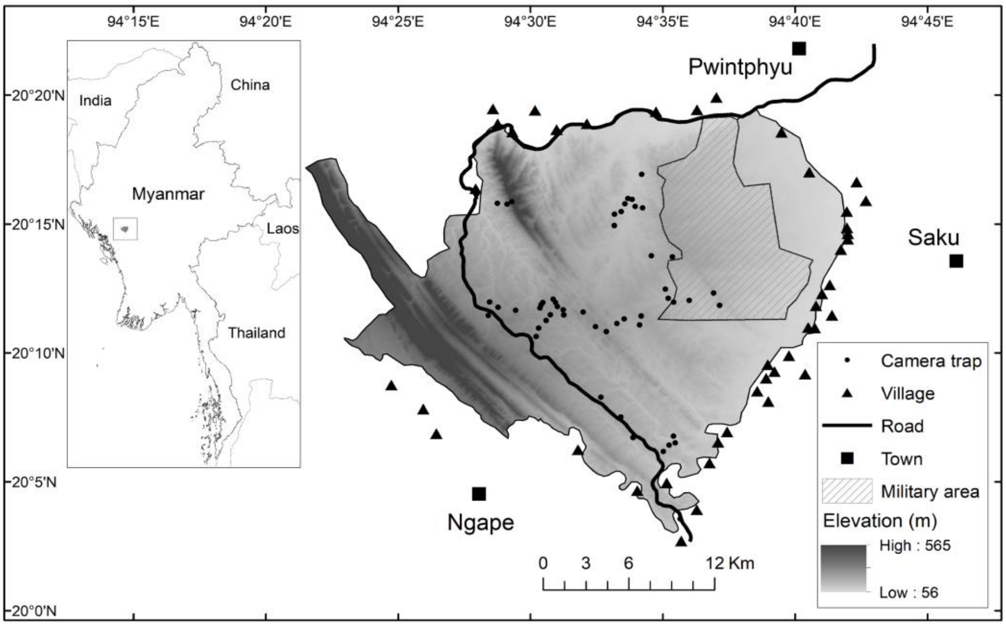

Figure 1. The geographic location of the study area in Myanmar (left) and map of the study area, Shwesettaw Wildlife Sanctuary (right)

3.3 Data analysis

We considered as independent events consecutive images of the same species, including humans and dogs, taken more than 0.5 hours apart at the same camera station (O’Brien et al., 2003). For each species, Relative abundance index (RAI) was calculated as the number of independent events divided by the number of camera-trap days and multiplied by 100 (O’Brien et al., 2003). Naïve occupancy for each species was computed as the number of camera trap sites occupied on sites sampled (Rovero et al., 2014). We also built a rarefied species accumulation curve using the package "vegan" in R (version 3.6.1) to evaluate the survey effort (Gotelli and Colwell, 2001).

We performed occupancy analysis using the package "unmarked" in R for nine species that were detected in more than 30 independent events (Fiske and Chandler, 2011). Occupancy (Ψ) is defined as the proportion of points in a site where a species was expected to occur, and detection probability (p) is defined as the likelihood of detecting an individual, or species, during a sampling occasion (MacKenzie et al., 2006). For each species, we constructed detection/non detection matrices of sites by surveys grouping 10 consecutive camera trap days into one sampling occasion to reduce zero inflation in the dataset (Alexander et al., 2016; Boron et al., 2019). This resulted in 36 sampling occasions for each species. We tested for collinearity among the four covariates using a threshold value of Pearson's $r = 0.5$ and no covariate was highly correlated. Prior to the analysis, we standardized all the covariates to have a mean of zero and unit variance. We used Akaike Information Criterion (AIC) and model selection to rank competing models, and reported those with AIC < 2.0 (Burnham and Anderson, 2002). 'AICmodavg' R package was use to calculate the relative importance of the model parameters (Mazerolle, 2012).

To examine the temporal relationships of recorded wildlife species with humans and dogs, we investigated seasonal changes in diel activity overlap. Myanmar has three distinguishable seasons: cool dry season (November–February), hot dry season (March–May), and rainy season (June–October). We first calculated the number of independent captures of humans and dogs in each season to examine their seasonal activity variation by using ANOVA. We then estimated the levels of temporal activity overlap of recorded wildlife species with humans and dogs in each season. By using the Non-parametric circular kernel-density function, a coefficient of overlapping (Δ) were calculated to measure the extent of overlap between two kernel-density estimates (Ridout and Linkie, 2009). Overlap was assumed as the area falling under both density curves. Δ ranged from 0 (no overlap) to 1 (complete overlap) (Ridout and Linkie, 2009). We used $\Delta 4$ for large samples (> 75 camera records) otherwise we used $\Delta 1$ (Meredith and Ridout, 2018). We considered Δ values: 1–0.80 as a high level of overlap, 0.50–0.79 as a medium overlap, and 0.0–0.49 as a low overlap/no overlap (Lynam et al., 2013). We calculated 95% confidence intervals of each overlap index using smoothed bootstrap with 10,000 resamples and used 'overlap' R package for this analysis (Ridout and Linkie, 2009).

4. Results

4.1 Mammal Species Diversity, Distribution And Conservation Status

We found that Myanmar supports 365 mammalian fauna (33 marine and 332 terrestrial) belonging to 173 genera, 49 families and 13 orders (Proboscidea, Sirenia, Scandentia, Dermoptera, Primates, Rodentia, Lagomorpha, Eulipotyphla, Chiroptera, Pholidota, Carnivora, Perissodactyla and Artiodactyla (including Cetacea) (Table1 and Figure 2). The comprehensive data of the 365 mammal species, including their scientific and common names in English and Myanmar, concise descriptions of their global and local distribution, as well as insights on taxonomy and conservation-related details such as IUCN threatened status and legal protection, are available in https://doi.org/10.1515/mammalia-2023-0098. The distribution of occurrence records for all mammals, along with the political units of Myanmar showing the number of recorded mammalian species, are illustrated in Figure 3 and Figure 4, respectively. Due to limited distribution records of marine mammals, the distribution records of orders Sirenia and Artiodactyla (Cetacea) are not depicted in those figures. The number of recorded species were highest ($\geqslant$ 100 mammal species) in the northern (Kachin State and Sagaing Region) and the southern (Tanintharyi Region) Myanmar. The order Chiroptera has the highest number of mammalian species (112 species) followed by the order Rodentia (90 species) and the order Carnivora (41 species) (Figure 2). We found that Muridae represents the richest family (50 species), followed by Vespertilionidae (48 species), and Sciuridae (30 species) (Table 2.1). We found that 63 globally threatened species (8 CR, 27 EN and 28 VU) are listed in Myanmar. A total of 131 species are legally protected under *The Conservation of Biodiversity and Protected Areas Law 2018 of Myanmar*. However, all bat species within the order Chiroptera are not legally protected in Myanmar (Table 1 and Figure 2).

We found that Myanmar is home to nine endemic mammal species: Eld's deer *Rucervus eldii thamin*, Cranbrook's goral *Naemorhedus cranbrooki*, Popa langur *Trachypithecus popa*, Popa soft-furred rat *Millardia kathleenae*, Blyth's mouse *Mus nitidulus*, little Burmese field mouse *Mus lepidoides*, Cranbrook's white-toothed shrew *Crocidura cranbrooki*, Burmese pipistrelle *Hypsugo lophurus* and Hkakaborazi tube-nosed bat *Murina hkakaboraziensis*.

In addition, from our camera-trap survey in Htaung Pru RF (11° 46′ N and 99° 06′ E), which is located outside of the northwestern part of the proposed Lenya National Park extension in Tanintharyi Region, we recorded banded civet *Hemigalus derbyanus* (Gray, 1837), a Near Threatened small carnivore species (Figure 5 A and B). Apart from these historical records, the presence and distribution of banded civet in Myanmar was not confirmed by a countrywide survey between 1999 and 2005, even in their known locality and distribution range from the historical records (Zaw et al. 2008). Therefore, no record for banded civet has yet been declared in Myanmar since 1914. This is the first photographic evidence of banded civet in its previous known location in Myanmar. Our records of this species can be used to refine the known distribution of this species and contributes to our knowledge of the current distribution of banded civet in Southeast Asia.

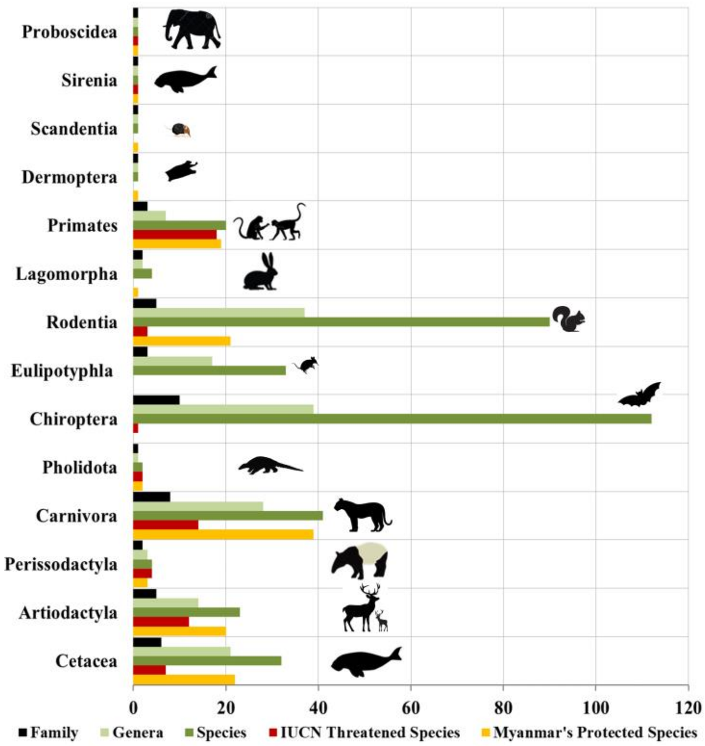

Figure 2. The recorded number of mammalian family, genera, species in each order including their IUCN Red List of threatened categories
(CR: critically endangered; EN: endangered and VU: vulnerable) and legal protection status (CP: completely protected, NP: normally protected and SP: seasonally protected) by the *Conservation of Biodiversity and Protected Areas Law (2018)* of Myanmar

Table 1. Checklist of mammals in phylogenetic order and summary of the number of species for each order and family included in the IUCN Red List of threatened categories

Higher level classification	Family	Genera	Species	IUCN Redlist Status (CR, EN, VU)	Myanmar Protection Status (CP, NP, SP)
Order Proboscidea	Elephantidae	1	1	1	1
Order Sirenia	Dugongidae	1	1	1	1
Order Scandentia	Tupaiidae	1	1	-	1
Order Dermoptera	Cynocephalidae	1	1	-	1
Order Primates					
Suborder Strepsirrhini	Lorisidae	1	1	1	1
Infraorder Lorisiformes					
Suborder Haplorrhini					
Superfamily Cercopithecoidea	Cercopithecidae	4	15	13	14
Superfamily Hominoidea	Hylobatidae	2	4	4	4
Order Lagomorpha	Ochotonidae	1	2	-	-
	Leporidae	1	2	-	1
Order Rodentia					
Suborder Sciuromorpha	Sciuridae	13	30	1	19
Suborder Myomorpha	Spalacidae	2	4	-	-
Superfamily Muroidea					
	Cricetidae	3	4	-	-
	Muridae	17	50	2	-
Suborder Hystricomorpha	Hystricidae	2	2	-	2
Infraorder Hystricognathi					
Order Eulipotyphla	Galericidae	3	3	-	-
	Soricidae	10	22	-	-
	Talpidae	4	8	-	-
Order Chiroptera					
Suborder Yinpterochiroptera	Pteropodidae	7	11	-	-
	Rhinolophidae	1	22	-	-
	Hipposideridae	3	16	1	-
	Megadermatidae	2	2	-	-
	Craseonycteridae	1	1	-	-
Suborder Yangochiroptera	Emballonuridae	3	6	-	-
	Nycteridae	1	1	-	-
	Molossidae	2	2	-	-
	Miniopteridae	1	3	-	-
	Vespertilionidae	18	48	-	-

Higher level classification	Family	Genera	Species	IUCN Redlist Status (CR, EN, VU)	Myanmar Protection Status (CP, NP, SP)
	Manidae	1	2	2	2
Order Pholidota					
Order Carnivora	Felidae	6	8	4	8
Suborder Feliformia	Prionodontidae	1	2	-	2
	Viverridae	7	8	2	8
	Herpestidae	1	3	-	2
	Canidae	3	4	1	4
Suborder Caniformia	Ursidae	2	2	2	2
	Ailuridae	1	1	1	1
	Mustelidae	7	13	4	12
	Tapiridae	1	1	1	1
Order Perissodactyla	Rhinocerotidae	2	3	3	2
Order Artiodactyla					
Suborder Suina	Suidae	1	1	-	-
Suborder Ruminantia	Tragulidae	1	3	-	2
	Moschidae	1	1	1	1
	Cervidae	5	8	3	8
	Bovidae	6	10	8	9
Suborder Whippomorpha					
Infraorder Cetacea	Balaenopteridae	2	7	3	7
Parvorder Mysticeti	Delphinidae	13	16	2	6
Parvorder Odontoceti	Kogiidae	1	2	-	2
	Phocoenidae	1	1	1	1
	Physeteridae	1	1	1	1
	Ziphiidae	3	5	-	5
	Total (species)	**173**	**365**	**63**	**131**

(CR: critically endangered; EN: endangered and VU: vulnerable) and legal protection status (CP: completely protected, NP: normally protected and SP: seasonally protected) by the Conservation of Biodiversity and Protected Areas Law (2018) of Myanmar

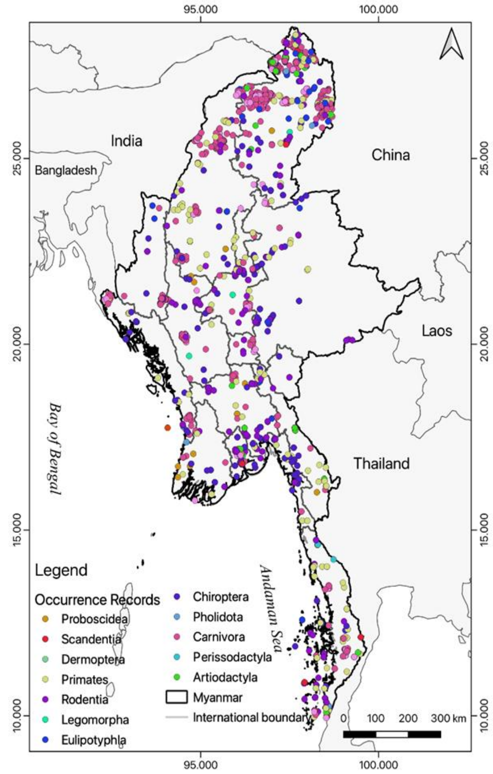

Figure 3. Geographic location of Myanmar and the distribution of all occurrence records of mammals in Myanmar (excluding the orders Sirenia and Artiodactyla (Cetacea), due to the limited distribution records of marine mammals)

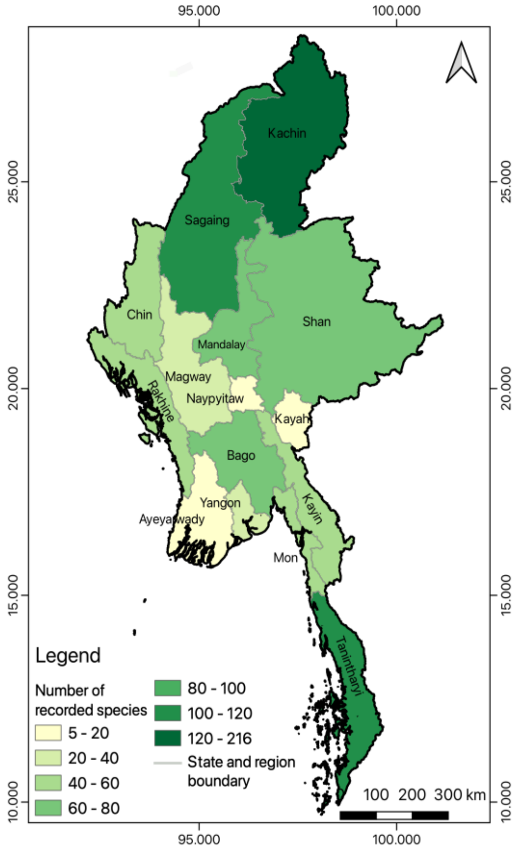

Figure 4. Number of mammalian fauna recorded in the political units of Myanmar (excluding the orders Sirenia and Artiodactyla (Cetacea), due to the limited distribution records of marine mammals).

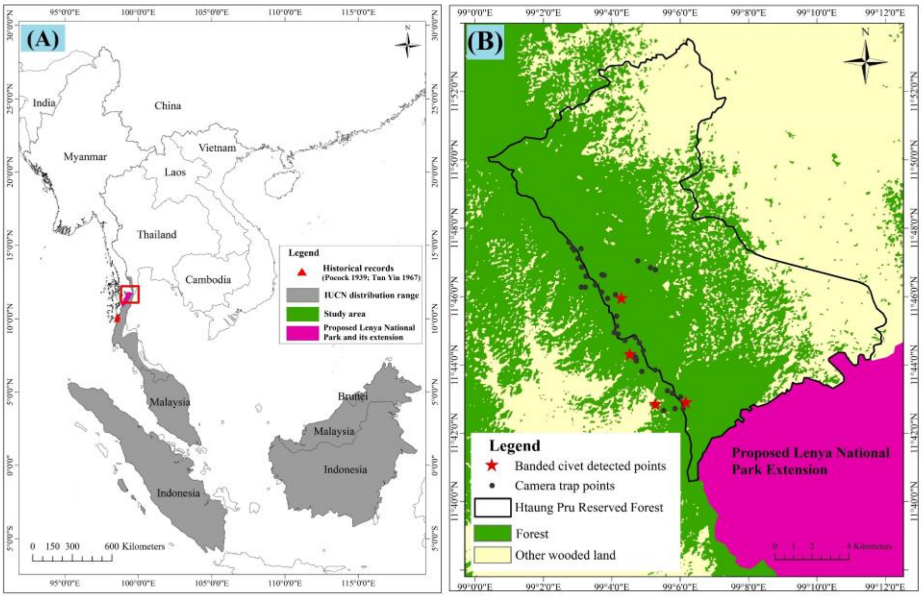

Figure 5. Historical records of banded civet Hemigalus derbyanus in Myanmar and IUCN distribution range (A). Distribution of camera traps and banded civet detected points in Htaung Pru Reserve Forest, Tanintharyi Region of Myanmar (B)

4.2 Trapping Effort

The total sampling effort resulted in 4,528 independent events from 16,444 trap exposure days and consisted of 87.04% of wild native mammals, 2.3% of birds, 8.39% of humans, and 2.27% of dogs. Commonly detected species were northern red muntjac, Eld's deer, and wild boar (with 1960, 888, and 421 independent detections, respectively). We recorded 372 and 103 independent detections of humans and dogs, ten detections of which were co-occurrences. The randomized species accumulation curve demonstrated that we reached the species accumulation plateau with our sampling effort (Figure 6).

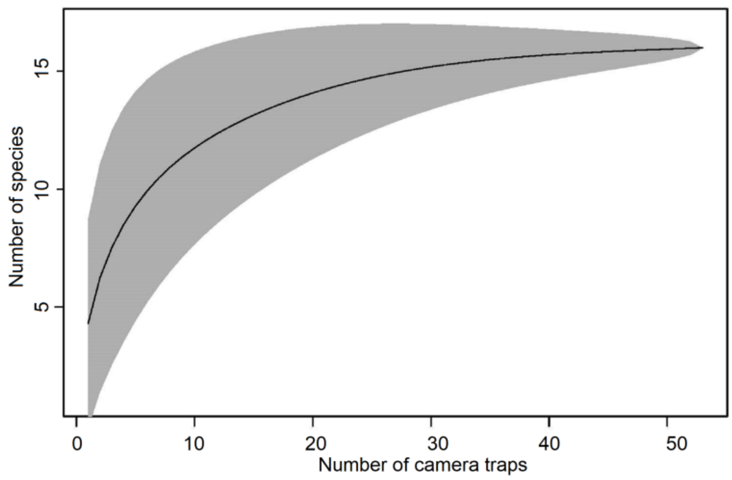

Figure 6. Randomized species accumulation curve (solid line) in Shwesettaw Wildlife Sanctuary of Myanmar. Shaded area indicates 95% confidence intervals

4.3 Effects of Anthropogenic Disturbances on Wildlife Occupancy and Detection Probability

The detection probability ranged from 0.068 for common palm civet to 0.488 for Irrawaddy squirrel, while species occupancy ranged from 0.008 for Irrawaddy squirrel to 0.934 for northern red muntjac. The null model was not supported for any of the species and at least one of the covariates was retained as influential on the species occupancy and detection probability (Table 2). Details of the model selection for each species are shown in Appendix Table 1. Eld's deer occupancy increased with distance to human settlements, while northern red muntjac's showed the opposite pattern, increasing close to settlements (Figure 7 and 8, Table 2). The occupancy of wild boar, common palm civet and small Indian civet decreased with distance to road, while golden jackal's occupancy increased with distance to road (Figure 9, 10, 11, 12 and Table 2). Only Burmese hare exhibited a positive relationship between their occupancy and human presence (Figure 13 and Table 2). The presence of dogs did not show any significant effect on the occupancy of native wildlife species (Table 2). Human settlements had strong negative effects on the detection probability of all studied species except for golden jackal and Eld's deer (Figs. 7 – 15 and Table 2).

Road had strong positive effects on the detection probability of northern red muntjac, wild boar, common palm civet and golden jackal (Table 2). Human presence had positive effect on the detection of wild boar, Eld's deer, and Burmese hare; and negative effect on northern red muntjac and golden jackal. The presence of dogs had positive effect on the detection of northern red muntjac and golden jackal and negative effect on wild boar, Eld's deer, and Irrawaddy squirrel (Table 2).

Table 2. Summary of species-specific detection probability (P) and occupancy estimates (Ψ) for the ten most commonly detected species in Shwesettaw Wildlife Sanctuary, Myanmar (Fig. 1), by camera traps, ordered by decreasing estimated occupancy. Reported results are the mean values of predicted occupancy and detection probability from the final models. Significant outcomes of the effects of covariates on Ψ and P are indicated with their direction (positive or negative effect); a blank cell indicates no significant effect.

			P				**Ψ**			
Species	**P±SE**	**Ψ ± SE**	**Road**	**Settlement**	**Human**	**Dog**	**Road**	**Settlement**	**Human**	**Dog**
Northern red muntjac	0.435 ± 0.019	0.934± 0.042	–	+	–	+	–	–		
Wild boar	0.161± 0.015	0.928± 0.095	–	+	+	–	–			
Rhesus macaque	0.102± 0.017	0.747± 0.239		+						
Eld's deer	0.202± 0.013	0.829± 0.080			+	–		+		
Common palm civet	0.068± 0.017	0.542± 0.174	–	+			–			
Small Indian civet	0.072± 0.018	0.0264± 0.119		+			–			
Golden jackal	0.077± 0.022	0.145± 0.106	–	–	–	+	+			
Burmese hare	0.201± 0.042	0.063± 0.039		+	+				+	
Irrawaddy squirrel	0.488± 0.504	0.008± 0.017		+		–				

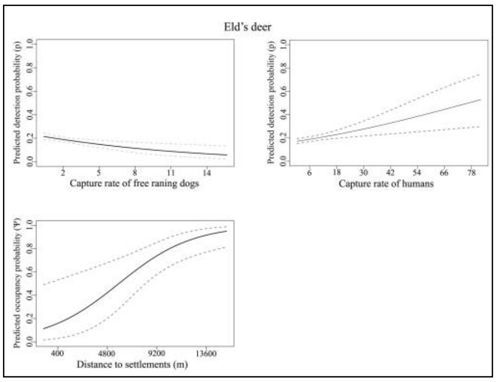

Figure 7. Effects of anthropogenic disturbances on the detection probability and occupancy of Eld's deer Rucervus eldii thamin in Shwesettaw Wildlife Sanctuary, Myanmar. Confidence intervals are indicated by dashed lines

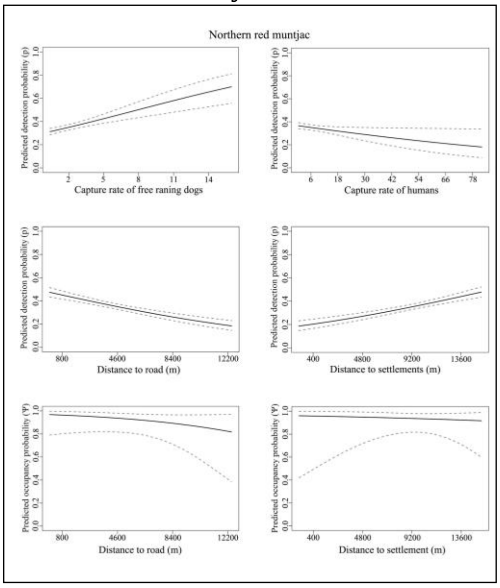

Figure 8. Effects of anthropogenic disturbances on the occupancy and detection probability of northern red muntjac Muntiacus vaginalis in Shwesettaw Wildlife Sanctuary of Myanmar. Confidence intervals are indicated by dashed lines

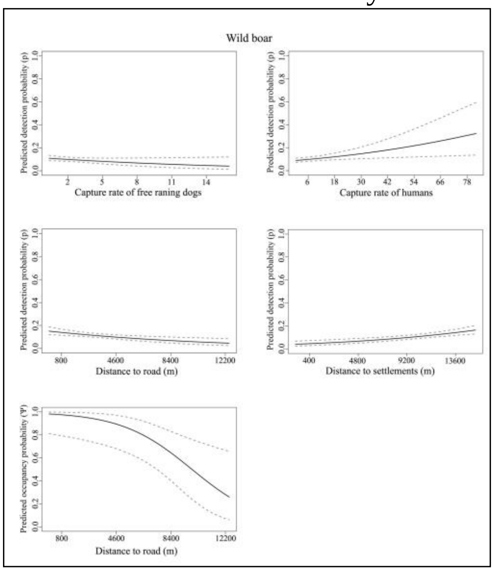

Figure 9. Effects of anthropogenic disturbances on the occupancy and detection probability of wild boar Sus scrofa in Shwesettaw Wildlife Sanctuary of Myanmar. Confidence intervals are indicated by dashed lines

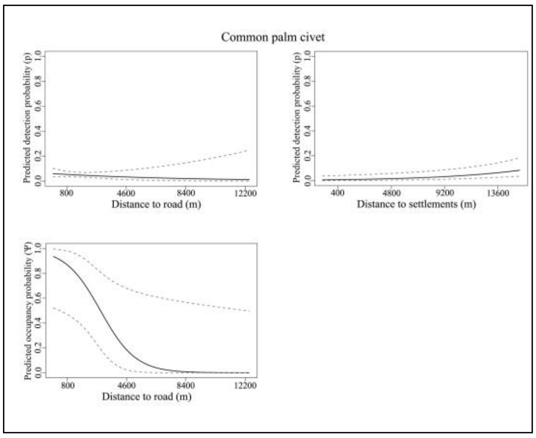

Figure 10. Effects of anthropogenic disturbances on the occupancy and detection probability of common palm civet Paradoxurus hermaphrodites in Shwesettaw Wildlife Sanctuary of Myanmar. Confidence intervals are indicated by dashed lines

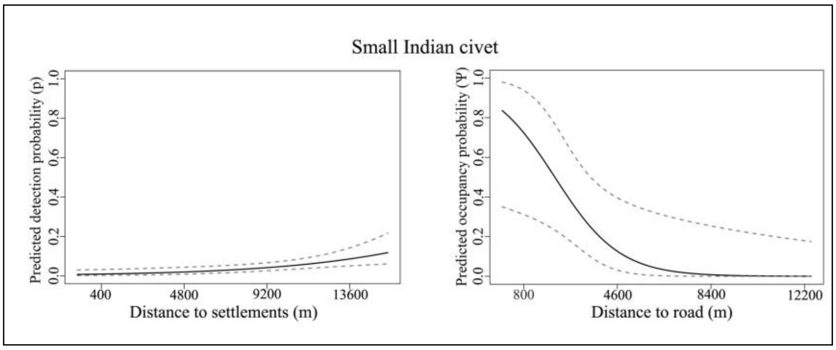

Figure 11. Effects of anthropogenic disturbances on the occupancy and detection probability of small Indian civet Viverricula indica in Shwesettaw Wildlife Sanctuary of Myanmar. Confidence intervals are indicated by dashed lines

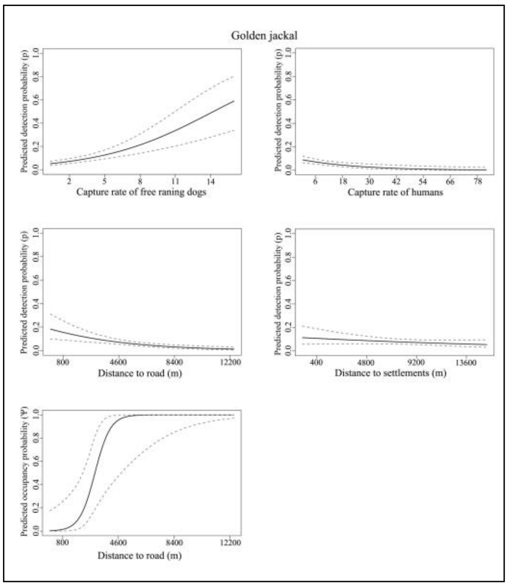

Figure 12. Effects of anthropogenic disturbances on the occupancy and detection probability of golden jackal Canis aureus in Shwesettaw Wildlife Sanctuary of Myanmar. Confidence intervals are indicated by dashed lines

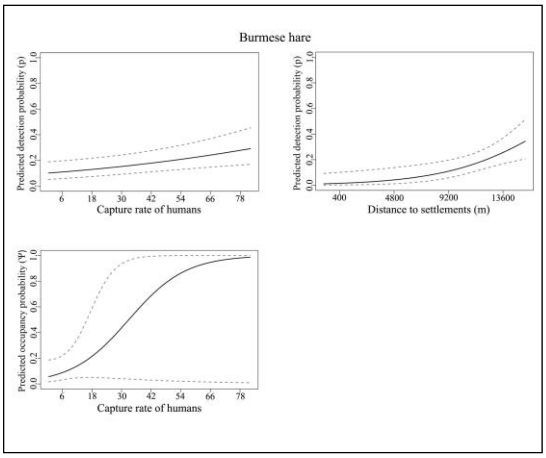

Figure 13. Effects of anthropogenic disturbances on the detection probability and occupancy of Burmese hare Lepus peguensis in Shwesettaw Wildlife Sanctuary, Myanmar. Confidence intervals are indicated by dashed lines

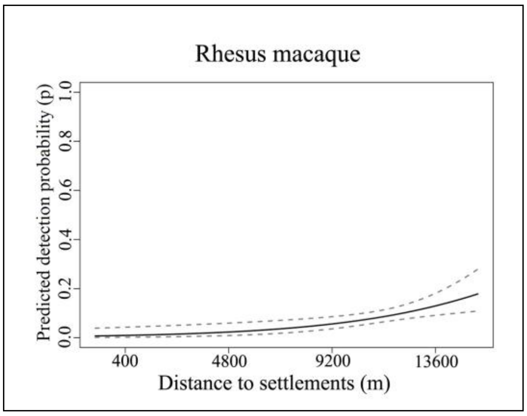

Figure 14. Effects of anthropogenic disturbances on the occupancy and detection probability of Burmese hare Lepus peguensis in Shwesettaw Wildlife Sanctuary of Myanmar. Confidence intervals are indicated by dashed lines

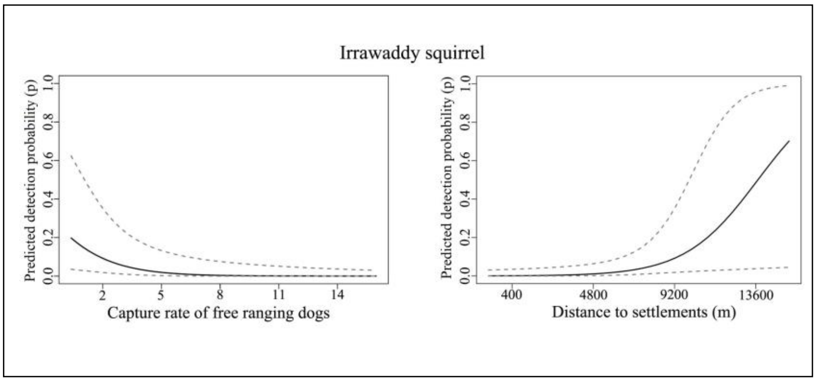

Figure 15. Effects of anthropogenic disturbances on the occupancy and detection probability of Irrawaddy squirrel Callosciurus pygerythrus in Shwesettaw Wildlife Sanctuary of Myanmar. Confidence intervals are indicated by dashed lines

4.4 Diel Activities Overlap Between Native Wildlife Species And Humans And, Free-Ranging Dogs

Both humans and dogs were active mainly during the daytime. While humans showed activity peaks at 06:00 – 11:00 and 12:30 – 14:30 h, dogs showed their peak at 05:30 – 11:30

h. Dogs did not exhibit significant seasonal variation in activity level (P = 0.74) with 8.5 ± 4.04 (mean ± SD; n = 34) independent captures in the cool-dry season, 8.25 ± 2.5 (n = 33) in the hot-dry season, and 7 ± 2.74 (n = 35) in the rainy season. Humans' activity level also did not show significant seasonal variation (P = 0.06), with 19.75 ± 7.27 (n = 79) captures in the cool-dry season, 26.67 ± 3.06 (n = 80) in the hot-dry season, and 35.8 ± 10.85 (n = 179) in the rainy season. All 10 studied species showed seasonal differences in level of diel activity overlap (Δ) with both humans and dogs (Table 3, Figure. 16 and 17). All the studied species exhibited a lower overlap with dogs during the cool-dry season, when dogs' mean activity level was higher (Table 3, Figure 17). Eld's deer, northern red muntjac, rhesus macaque, and small Indian civet showed lower diel activity overlap with human during the rainy season, when humans' mean activity level was higher (Table 3, Figure 16). Diel activity overlap with humans, however, was higher in the rainy season for wild boar, golden jackal, Burmese hare, Irrawaddy squirrel, and common palm civet (Table 3, Figure 16). None of the studied species showed high level of diel activity overlap (Δ < 0.80) with both humans and dogs in all three seasons (Table 3).

Table 3. Results of the seasonal coefficient of overlap (with 95% CIs) for the 10 most commonly detected species with humans and free-ranging dogs in Shwesettaw Wildlife Sanctuary, Myanmar (Figs 3 and 4). The cool-dry season is from November to February, the hot-dry season, from March to May and the rainy season from June to October. Blank cells indicate no diel activity overlap

Species	**Overlap (95% CI) with humans**			**Overlap (95% CI) with free-ranging dogs**		
	Cool-dry season	**Hot-dry season**	**Rainy season**	**Cool-dry season**	**Hot-dry season**	**Rainy season**
Northern red muntjac	0.62 (0.51–0.68)	0.41 (0.29–0.46)	0.51 (0.43–0.54)	0.55 (0.42–0.61)	0.59 (0.48–0.71)	0.59 (0.45–0.68)
Wild boar	0.62 (0.50–0.75)	0.40 (0.24–0.43)	0.69 (0.57–0.73)	0.45 (0.29–0.58)	0.47 (0.32–0.55)	0.75 (0.61–0.88)
Rhesus macaque	0.55 (0.32–0.65)	0.77 (0.63–0.99)	0.52 (0.44–0.61)	0.43 (0.22–0.57)	0.62 (0.46–0.90)	0.56 (0.37–0.65)
Eld's deer	0.63 (0.53–0.71)	0.59 (0.44–0.63)	0.43 (0.32–0.45)	0.52 (0.38–0.59)	0.68 (0.57–0.76)	0.53 (0.38–0.61)
Common palm civet	0.24 (0.02–0.50)		0.27 (0.02–0.46)		0.24 (0.03–0.34)	0.33 (0.07–0.53)
Small Indian civet		0.38 (0.14–0.55)	0.07 (0.00–0.08)		0.38 (0.18–0.57)	0.12 (0.01–0.17)
Golden jackal	0.46 (0.33–0.58)	0.34 (0.14–0.38)	0.62 (0.43–0.77)	0.32 (0.15–0.41)	0.43 (0.24–0.56)	0.67 (0.48–0.87)
Burmese hare	0.17 (0.03–0.29)	0.37 (0.19–0.47)	0.39 (0.20–0.55)	0.09 (0.04–0.16)	0.43 (0.24–0.56)	0.46 (0.26–0.65)
Irrawaddy squirrel			0.76 (0.62–0.86)			0.79 (0.68–0.94)

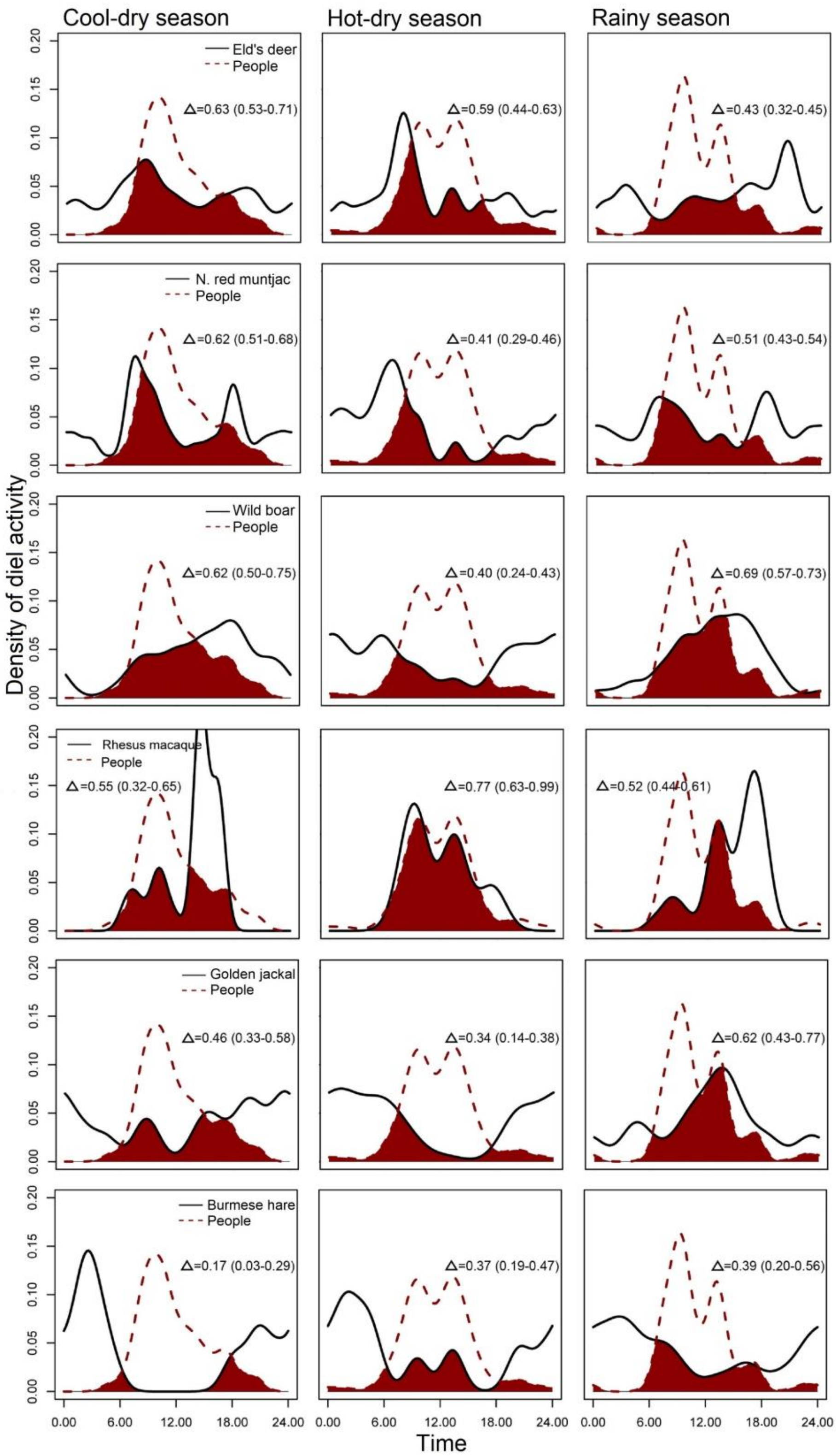

Figure 16. The diel activity (Table 5.2) of six mammal species compared to that of people in the three seasons (cool-dry, hot-dry, rainy) in Shwesettaw Wildlife Sanctuary, Myanmar. The shaded area shows the value of overlap (Δ), and its coefficient (with 95% CI).

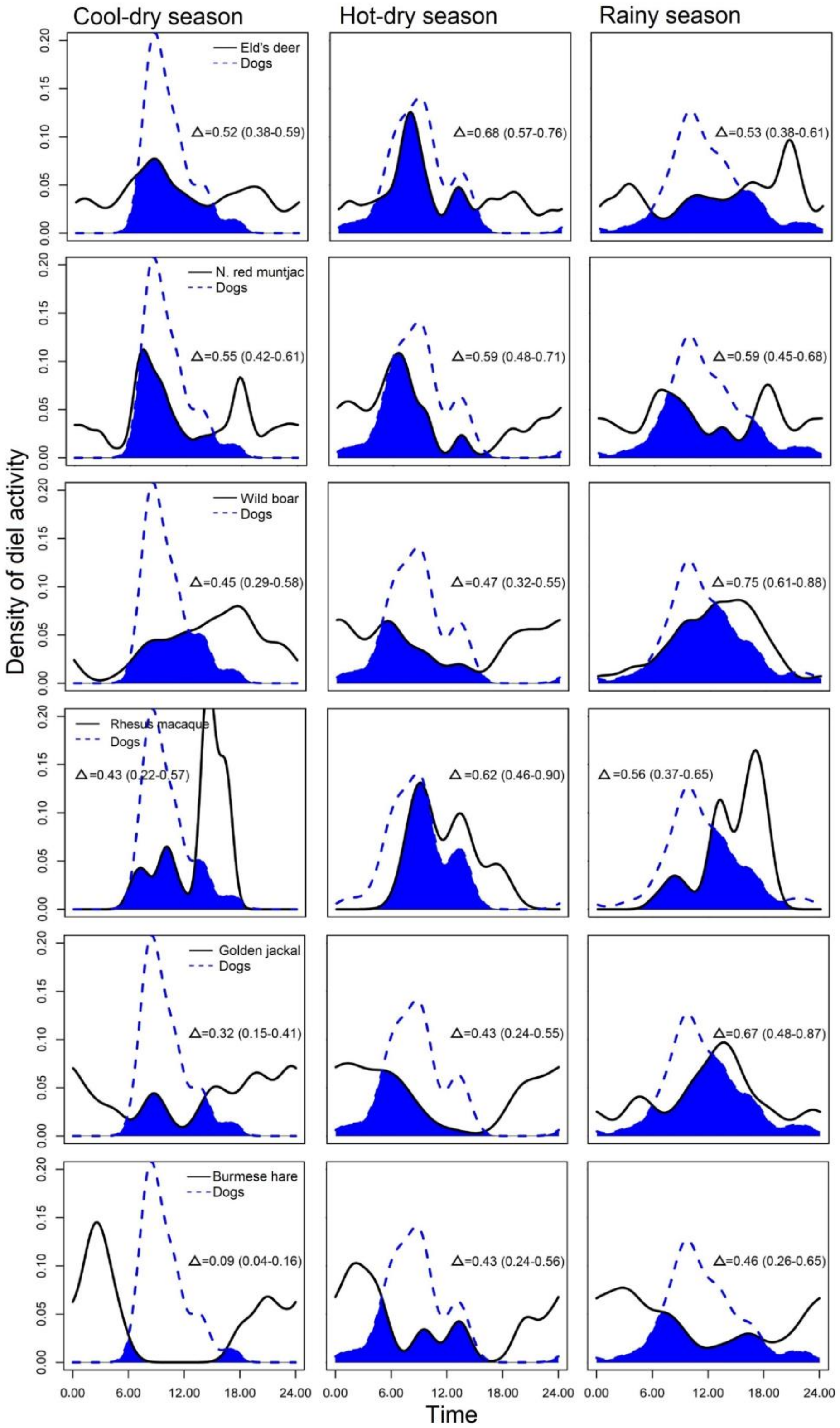

Figure 17. The diel activity (Table 5.2) of six mammal species compared to that of dogs in the three seasons (cool-dry, hot-dry, rainy) in Shwesettaw Wildlife Sanctuary, Myanmar. The shaded area shows the value of overlap (Δ), and its coefficient (with 95% CI)

5. Discussion

5.1 Mammal Species Diversity, Distribution and Conservation Status

This is the first attempt to compile a comprehensive list of the mammals of Myanmar since Tun Yin (1993) and We found that Myanmar supports a rich diversity of mammalian fauna (365 species: 33 marine and 332 terrestrial), belonging to 173 genera, 49 families and 13 orders. It represents about one third of the 954 mammal species recorded in Indomalayan realm and about 5.6% of the 6,596 global mammalian species (Mammal Diversity Database, 2022). Compared to the previous publication "Wild Mammals of Myanmar (Tun Yin 1993)" and "Wild Animals of Burma (1967)", we can add 113 species to the mammals of Myanmar particularly for the rodents, bats and marine mammals.

In addition, we found that Myanmar is home to at least nine endemic mammal species. Anthony's pipistrelle Hypsugo anthonyi and Joffre's pipistrelle Hypsugo joffrei were previously listed as the endemic species of Myanmar, however, recent studies showed that H. anthonyi as the junior subjective synonym of H. joffrei and distributed in the westward geographic range beyond Myanmar (Saikia et al., 2017). House-dwelling leaf-nosed Bat Hipposideros einnaythu was previously regarded as endemic to Myanmar; however, Wongwaiyut et al. (2023) confirm the presence of this species in Thailand.

Although a total of 131 species are legally protected under The Conservation of Biodiversity and Protected Areas Law 2018 of Myanmar, two endangered species: Pomona leaf-nosed bat Hipposideros pomona and greater marmoset rat Hapalomys longicaudatus, two vulnerable rodent species: Vordermann's flying squirrel Petinomys vordermanni and whitehead's sundaic spiny rat Maxomys whiteheadi, one near threatened Indo-Pacific bottlenose dolphin Tursiops aduncus, and nine near threatened bat species: East Asian tailess leaf-nosed bat Coelops frithii, hog-nosed bat Craseonycteris thonglongyai, great evening bat Ia io, pained woolly bat Kerivoula picta, Malayan slit-faced bat Nycteris tragata, variable flying fox Pteropus hypomelanus, large flying fox Pteropus vampyrus, trefoil horseshoe bat Rhinolophus trifoliatus and Leschenault's rousette Rousettus leschenaultia are still needed for legal protection in Myanmar.

Number of recorded species were highest ($\geqslant$ 100 mammal species) in the northern (Kachin State and Sagaing Region) and the southern (Tanintharyi Region) Myanmar (Figure 2.2). Our results highlight that the eastern and western area (Shan, Chin and Rakhine States) need to conduct more biological inventories to better describe mammal diversity of Myanmar. In addition, our camera trap survey in Tanintharyi Region highlighted that even small and degraded forest blocks (190 km2) still serve as a potential refuge for locally rare species, as well as globally threatened species by contributing our knowledge of the current distribution of banded civet in Southeast Asia.

5.2 The Ecological Impacts of Anthropogenic Disturbances on Spatio-Temporal Responses of Mammals

This study refines our understanding of how different anthropogenic disturbances can impact wildlife spatiotemporal habitat use and raises concerns about the potential ecological impacts of dogs in Southeast Asia, particularly in Myanmar. We found that human settlements and a highway road had important effects on the occupancy and detection probability of 10 wildlife species, whereas dogs had negative impacts on their activity patterns. Among the different forms of disturbance analyzed, human settlements had strong negative impacts on wildlife detection probability, except for golden jackal (positive effect) and Eld's deer (no effect; Table 2), which reflects animals' elusiveness in proximity of a direct and permanent source of human disturbance. Urbanized areas represent long-term and spatially constant sources of disturbance (Ordeñana et al., 2010), which wildlife may avoid because of the associated noise, light, and the risk of poaching or preying by domestic carnivores (Yen et al., 2019). Contrary to our expectation, the detection and occupancy of five species (northern red muntjac, wild boar, common palm civet and small Indian civet) increased near the highway road. Food resources along roads bisecting forest ecosystems can attract wildlife, sometimes acting as ecological traps (e.g., Yamamoto-Ebina et al. 2016). In the case of Shwesettaw Wildlife Sanctuary, the 'highway' is actually a mere asphalt road with low traffic density and wildlife roadkill has not been reported to be a common problem.

The hierarchical nature of occupancy models (Kéry, 2008) allowed us to identify that, in some cases, a type of disturbance had opposite effects on a species' occupancy and detection probability. For example, northern red muntjac's occupancy increased near settlements, while detection probability decreased (Table 2), likely because muntjacs show a stronger response to food availability than to human disturbance (Rahman et al., 2017). This is concordant with their reduction in detectability with increasing human presence, as muntjacs might be afraid of humans and hence need to behave more elusively in their presence. Similarly, golden jackal's detection probability was higher close to settlements and roads, but occupancy was lower near roads. Golden jackals are versatile predators and opportunistic feeders (Lange et al., 2021) with broad diets that include from small mammals and rodents (Lanszki et al., 2010) to poultry and cattle (Raichev et al., 2013). Given their human-tolerance, they seemed to avoid human disturbance adopting more elusive or foraging habits (Suraci et al., 2019).

Where wildlife species are unable to avoid humans in space, they may avoid them in time instead (Carter et al., 2012; Gaynor et al., 2018). Against our expectations, humans' presence in the forest had a positive effect on Eld's deer detection (Table 2). This could reflect an overlap in preferred habitats, which the deer could compensate by avoiding humans in time. In fact, our results show that Eld's deer shifted their active time to nocturnal during the rainy season, when human presence in the wildlife sanctuary increases (Figure 16). Similarly, Hainan Eld's deer changed more nocturnal behaviour when being translocated to a human-inhabited area (Pan et al., 2011). Although the presence of dogs did not show any effect on Eld's deer occupancy, it showed strong negative effect on the detection probability (Table 2). This suggests that Eld's deer increased their elusive behavior in the presence of dogs. This is consistent with the reduced activity level of Eld's deer that we found in the cool-dry season, when dogs' activity increased (Figure 17).

We observed wild boars to be highly human-tolerant, as their detection was positively affected by human presence and they did not avoid humans temporally, showing intermediate activity overlaps with humans (Table 2, Figure 16). Wild boars' activity, thus, seems to depend on location and seasonal conditions and to have considerable plasticity (Johann et al., 2020). Although macaques are also considered highly tolerant to people and known to thrive even in densely populated urban areas (e.g., Priston and McLennan, 2013), we found higher detection of rhesus macaque with increasing distance from settlements. Moreover, macaques exhibited low temporal overlap with both humans and dogs (Figure 16 and 17), suggesting an avoidance strategy.

Being nocturnal, the occupancy and detection probability of common palm civets and small Indian civets were not affected by the presence of humans and dogs (Table 2). These civets, however, avoided dogs temporally (Yen et al., 2019), showing no overlap particularly in the cool-dry season when the activiy of dogs was higher. Burmese hares avoided humans temporally rather than in space, since hares are mainly nocturnal (Rehnus, 2014). The presence of dogs can alter the distribution, occupancy, and activity patterns of native wildlife in protected areas (Zapata-Ríos and Branch, 2016; Yen et al., 2019 and this study). Our results showed that wildlife negative responses (i.e., avoidance in space and/or time) were stronger towards dogs than towards humans, suggesting that they perceived dogs as a greater risk than humans. In Shwesettaw Wildlife Sanctuary, we detected dogs in a substantial number of locations (43.4% of the cameras), representing 2.4% of the all the independent captures. Though the current population size of dogs in Myanmar and its protected areas is unknown, the dog population is believed to be increasing, since human and dog population sizes are strongly correlated (Hughes and Macdonald, 2013).

Our results also stress the need for better management practices regarding dog control and their presence in protected areas, since they have been reported to pose a threat to 188 threatened species worldwide (Doherty et al., 2017). Due to people's perceptions of dogs as working members of households (e.g., herding, guarding, and hunting) in rural communities, at least in Myanmar, it is difficult to completely prohibit their presence within protected areas. In order to facilitate local communities' support to dog population management, we suggest developing socially-sensitive campaigns of awareness on wildlife conservation and dogs' potential negative impacts.

6. Conclusion

This research underscores the rich mammalian biodiversity of Myanmar and how to mitigate the anthropogenic disturbances impact on spatio-temporal habitat use of mammals. We recommend the comprehensive mammals surveys, inside and outside PAs of Myanmar undoubtedly yield additional species in the future. Due to the limited molecular based taxonomic study, the taxonomic status of many rodents is still in a state of flux. Hence, systematic taxonomic study is crucial in Myanmar to explore the species new to science as well as valid species currently treated as synonyms. Our study also highlights a list of mammal species which are needed to manage for legal protection and conservation in Myanmar. It is likely that the number of species will be revised in the future with increasing surveys and taxonomic revisions, particularly among small mammals. We found that vertebrates in a protected area of Myanmar altered their temporal and spatial patterns of habitat use in response to human disturbances, including the presence of dogs. Follow up studies are necessary to better understand how these changes in the spatio-temporal patterns of habitat use translate into population dynamics, particularly of threatened species such as Eld's deer. Based on our findings, we highly recommend initiating a management program to control dog presence in protected areas and creating a new regulation for managing and controlling domestic animals in buffer zones surrounding protected areas in Myanmar and other Southeast Asian countries.

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