Ministry of Natural Resources and Environmental Conservation

Forest Department

Assessing Habitat Suitability of Tanintharyi Nature Reserve to Effectively Conserve the Key Mammal Species of Myanmar

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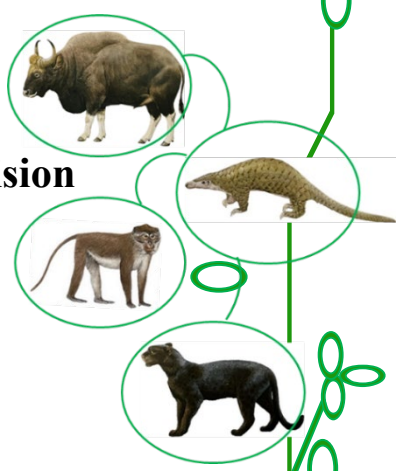

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Executive Summary

Tanintharyi Nature Reserve (TNR) with an area of 1700 km^2 is well known for its biodiversity and has the great potential to serve as National Model for Myanmar Wildlife and Ecosystem Conservation. In addition, TNR is the only established terrestrial Protected Area in Tanintharyi Region of Myanmar where the global iconic mammal species such as tiger (*Panthera tigris*), Malayan tapir (T*apirus indicus*), leopard (*Panther pardus*), Asian elephant (*Elephas maximus*) and Sunda pangolin (*Manis javanica*) can occur. TNR is regarded as one of the key conservation area of Myanmar; however, only six mammal research study have been conducted in TNR since its establishment in 2005. Most studies conducted in the TNR provide only baseline information and species specific; thus, it is crucial to undertake more comprehensive research in TNR to effectively conserve its globally iconic mammal species. The main objective of this research is to identify the key mammal species of TNR and suitable habitat area for those key mammal species with the goal of informing effective conservation strategies through a comprehensive understanding of species-habitat relationships. This study applied Maximum Entropy (MaxEnt) modeling to evaluate habitat suitability and to quantify the relative influence of bioclimatic and environmental variables on species distributions.

The modeling results showed substantial variability in suitable habitat availability among species. Across all species, the mean suitable habitat coverage was 17.23% of the reserve's total area, ranging from 10.35% for the Malayan tapir to 26.90% for the Asian elephant. The leopard occupied 317.76 km² (19.80%), contrasting with much lower values for the tiger (181.77 km², 11.32%), clouded leopard *Neofelis nebulosa* (173.13 km², 10.79%), and dhole *Cuon alpinus* (188.99 km², 11.77%). The marbled cat (*Pardofelis marmorata*) was a notable outlier among carnivores, with a high predicted habitat extent of 425.48 km² (26.51%). Omnivorous species such as the Asiatic black bear *Ursus thibetanus* (299.35 km², 18.65%) and Malayan sun bear *Helarctos malayanus* (321.32 km², 20.02%) had intermediate values, indicating moderately broad habitat tolerances. Primates exhibited a mid-range of habitat suitability. The stump-tailed macaque (*Macaca arctoides*) and northern pig-tailed macaque (*Macaca leonina*) occupied 344.09 km² (21.44%) and 331.68 km² (20.66%), respectively, whereas the Tenasserim langur and

common long-tailed macaque (*Macaca fascicularis*) were more restricted, with suitable areas of 243.43 km² (15.17%) and 237.73 km² (14.81%), respectively.

Environmental predictors influencing habitat suitability varied markedly across species groups. Water sources and precipitation emerged as key habitat determinants for the herbivore species such as Asian Elephant, Malayan tapir, Sambar, Gaur (Bos gaurus) and Sunda pangolin (*Manis javanica*). Elevation played a strong role for certain ungulate sepcies like Sambar (*Rusa unicolor*) and Gaur. while anthropogenic disturbaces such as proximity to villages and human footprint were notable predictors for Tenasserim langur (*Trachypithecus barbei)* and Chinese serow (*Capricornis milneedwardsii*).

For carnivores, prey distribution was the primary factor shaping habitat suitability, emphasizing the importance of healthy prey populations and intact food webs for supporting apex predators. Human footprint had strong negative impacts on leopard and dhole, signaling the increasing pressures from land conversion, infrastructure expansion, and encroachment around TNR's boundary.

Local Operating Unit (LoU) analysis identified the southern portions of TNR, particularly Thetkalkwet and Heinze, as strongholds that support high suitability for multiple mammal species. These areas should be prioritized for strict protection, anti-poaching enforcement, and long-term monitoring. Meanwhile, fragmented habitats in central and northern LoUs present opportunities for connectivity enhancement and forest restoration measures aimed at ensuring long-term species movement.

This study provides critical scientific evidence for adaptive conservation management in TNR. By identifying where key habitats are located, how species differ in their ecological requirements, and which areas support multi-species conservation potential, the results directly support protected area planning not only in TNR but also in Myanmar. Implementing the recommendations developed through this assessment will strengthen biodiversity conservation outcomes, sustain ecosystem functioning, and ensure the long-term survival of mammal species that contribute to the global ecological significance of Tanintharyi's forests.

Assessing Habitat Suitability of Tanintharyi Nature Reserve to Effectively Conserve the Key Mammal Species of Myanmar

1. Introduction

Mammals are pivotal in ecosystems by influencing nutrient cycling, energy flow, habitat modification and providing services like pollination and pest control (Lacher et al., 2019). Mammals represent an exceptionally diverse group of vertebrates, 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). However, 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). As per the International Union for Conservation of Nature (IUCN), 22.6% of global mammalian species are classified as threatened species, indicating that nearly one in four mammal species is currently at risk of extinction.

Myanmar supports a rich diversity of mammalian fauna (365 species: 33 marine and 332 terrestrial), belonging to 173 genera, 49 families and 13 orders which represents about one third of mammal species recorded in Indomalayan realm and about 5.6% of the global mammalian species (Thu et al., 2024). Among the 365 mammal species of Myanmar, 63 (8 Critically Endangered, 27 Endangered and 28 Vulnerable) which represents 17 % of Myanmar' mammals are classified as globally threatened mammal 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.

One third (36.9%) of Myanmar's area has been converted to anthropogenic

ecosystems over the last two centuries, leaving nearly half of Myanmar's ecosystems threatened (Murray et al., 2020). Habitat loss in Myanmar significantly impacts local biodiversity, particularly in regions like the Tanintharyi, which is part of the Indo-Burma biodiversity hotspot (Aung et al., 2017). 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 (Butti et al., 2022). These findings highlight the urgent need for comprehensive strategies to combat habitat loss and to identify suitable habitats for the effective conservation of mammal populations (Brodie et al., 2021).

Protected areas play a crucial role in preserving species and ecosystems as these designated areas serve as a vital mechanism for safeguarding biodiversity, maintaining ecosystem balance, and providing numerous benefits to both wildlife and humans (Pyke, 2007). The Kunming-Montreal Global Biodiversity Framework (KM-GBF) has established four goals and 23 targets including a challenging flagship target of '30 × 30' of protecting 30% of land, freshwater, coastal, and high-sea in a representative way by 2030, which will require both new mechanisms and funding streams to enact effectively (Hughes, 2023). As of 2024, a total of 293,696 Protected Areas (PAs) had been established globally, covering 16.1% of the total land area (UNEP-WCMC). However, there has been limited assessment on whether these established PAs continue to effectively support their original conservation objectives, especially given the environmental changes in the recent decades (Song et al., 2018). Li et al. (2023) stated that the long-established PAs do not always match the current distributions of target species under changing environmental conditions. Thus, it is crucial to examine how much area of an established PAs can effectively conserve the suitable habitats of its key biodiversity.

2. The gap in our knowledge

Myanmar is endowed with diverse ecosystems and precious biodversity which are being conserved by the establishment of Protected Areas (PAs). By 2024, Myanmar had established 62 PAs, covering 6.43 % of the country's area (NWCD, 2025). However, ongoing climate change, socio-economic development, urbanization and increasing human population negatively impacts the diverse biodiversity of Myanmar. In addition,

except for a few large PAs in northern Myanmar (e.g., Hukaung Valley Wildlife Sanctuary 17,373 km^2 and Hkakaborazi National Park 3,812 km^2), most PAs are too small to effectively conserve biodiversity and many are highly degraded to be included within the PA system (Rao, 2002). Therefore, it is crucial to assess the effectiveness of PAs in the conservation of its biodiversity.

Tanintharyi Region of Myanmar is home to the largest remaining areas of biologically rich Sundaic lowland forest in mainland Southeast Asia. This region supports a unique assemblage of globally threatened wildlife, including significant populations of tigers, Malayan tapir and the endangered Gurney's pitta, which is endemic to Tanintharyi. Despite its rich biodiversity, the region faces threats from deforestation, hunting, and land-use changes, particularly due to the expansion of oil palm plantations and other agricultural activities (Nomura et al., 2019). These challenges necessitate a balanced approach to development and conservation efforts.

Tanintharyi Nature Reserve (TNR) with an area of 1700 km^2 is well known for its biodiversity and has the great potential to serve as National Model for Myanmar Wildlife and Ecosystem Conservation. In addition, TNR is the only established PAs in Tanintharyi Region of Myanmar where the global iconic mammal species such as tiger (*Panthera tigris*), Malayan tapir (T*apirus indicus*), leopard (*Panther pardus*), Asian elephant (*Elephas maximus*) and Sunda pangolin (*Manis javanica*) can occur. TNR is regarded as one of the key conservation area of Myanmar; however, only the following mammal research study have been conducted in TNR since its establishment in 2005:

(1) *Report on mammals survey in Taninthayi Nature Reserve* that conducted in 2008 by using the questionnaire, track/sign and camera trap survey methods. A total of 69 mammal species were reported in this study.

(2) A report on Malayan Tapir (*Tapirus indicus*) surveyed in Tanintharyi Nature Reserve in 2011.

(3) Evaluating the status of tigers (*Panthera tigris*) and their prey in Tanintharyi Nature Reserve in 2011.

(4) A study on wild elephant density, distribution, its correlated ecological factors and threats in Tanintharyi Nature Reserve in 2011.

(5) Tanintharyi langur (*Trachypithecus barbei*) survey in Tanintharyi Nature Reserve in 2016.

(6) Large mammals surveyed in Tanintharyi Nature Reserve in 2016.

Most studies conducted in the TNR provide only baseline information. However, a large mammal survey conducted in 2016 identified the occupancy and distribution patterns of some large mammal species within TNR. Therefore, it is crucial to undertake more comprehensive research in TNR to effectively conserve its globally iconic mammal species. Due to increasing deforestation rates (Bhagwat et al., 2017), conversion of forested areas to agricultural land, concessions for oil palm and rubber plantations since 1970 (Normura et al., 2019, Donald et al., 2015), and mining activities in the Tanintharyi Region, forest dependent species will experience a decrease in the total amount of habitat available and have barriers to movements between suitable habitats in the future (Feeley et al., 2012). With the combined impacts of deforestation and climate change, understanding species distribution patterns, identifying suitable habitat areas are becoming critical for the conservation and management efforts (Zhang et al ., 2012). In addition, different mammal species have unique habitat requirements and thus, by assessing habitat suitability can ensure that the environment provides the necessary resources for the conservation of those mammal species.

3. Research Objectives

The main objective of this research is to assess the habitat suitability for key mammal species in TNR, with the goal of informing effective conservation strategies through a comprehensive understanding of species-habitat relationships. The detailed research objectives are as follows:

(1) To identify the key mammal species and suitable habitat area for those key mammal species in TNR.

This research study will assess and map the suitable habitat area in TNR to effectively conserve the key mammal species of Myanmar by identifying areas of suitable and unsuitable habitats.

(2) To determine the key factors such as geographic, biotic, abiotic, bioclimatic and anthropogenic factors that influence the habitat suitability for each

mammal species.

This research will investigate which geographic, biotic, abiotic, bioclimatic (e.g., temperature, precipitation) and human-related (e.g., proximity to settlements, human footprint) factors most strongly influence habitat suitability for each target species.

(3) To provide conservation recommendations for the effective protection of mammal species in TNR.

This study will develop practical, data-driven recommendations for conservation strategies that prioritize and protect key habitats, contributing to effective, long-term conservation of mammal species in the TNR.

4. Literature Review

4.1. Mammal Species Diversity of Tanintharyi Nature Reserve

Baseline assessments of mammal diversity in Tanintharyi Nature Reserve (TNR) have been undertaken over the past two decades to inform conservation planning. The first comprehensive survey, conducted from January to July 2008, employed a combination of questionnaire surveys, track-and-sign surveys, and camera trapping (Ye Htut, Sein Aung Min, & Tin Mya Soe, 2008). This study reported 67 mammal species based on track-and-sign and interview data, although no camera-trap photographs were obtained due to the limited deployment period.

To strengthen this baseline, TNR staff conducted a series of camera-trap monitoring surveys in 2013, 2017, 2018, 2019, and 2020. These surveys deployed 15, 60, 60, 18, and 100 camera traps, respectively, across accessible Local Operating Units (LoUs). Collectively, they recorded 45 mammal species within TNR. However, uncertainties in taxonomy and identification prevented confirmation of several species, including the large-spotted civet (*Viverra megaspila*), Eurasian otter (*Lutra lutra*), and southern serow (*Capricornis sumatraensis*). The species recorded during these monitoring efforts are listed in Table 1, along with their conservation status under the IUCN Red List (2025), Myanmar National Red List (2020), and legal protection status under the Conservation of Biodiversity and Protected Areas Law (2018).

In addition to these baseline monitoring surveys, Friends of Wildlife (FoW)

conducted a research-oriented large mammal survey in the Yebone LoU from November 2015 to April 2016 (FoW, 2016). This study aimed to document species richness, occupancy patterns, and ecological attributes of large mammals, as well as to establish a framework for long-term population monitoring. Using 37 camera traps deployed across 25 grid cells (3,327 trap nights) combined with track-and-sign and interview surveys, the study recorded 30 medium- to large-sized mammal species. A total of 1,338 independent photographs were obtained, with 67% representing non-carnivores and 33% carnivores. Frequently photographed species included stump-tailed macaque (*Macaca arctoides*), wild boar (*Sus scrofa*), Northern red muntjac (*Muntiacus vaginalis*), Fea's muntjac (*Muntiacus feae*), Chinese serow (*Capricornis milneedwardsii*), and Asiatic black bear (*Ursus thibetanus*), whereas marbled cat (*Pardofelis marmorata*) and gaur (*Bos gaurus*) were rarely detected. Notably, no tigers (*Panthera tigris*) or leopards (*Panthera pardus*) were recorded, suggesting extremely low or non-viable populations within the Yebone LoU.

Table 1. Mammal species of Tanintharyi Nature Reserve (TNR), Myanmar, with their IUCN Red List (2025) status, Myanmar National Red List (2020) status (CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient; NE = Not Evaluated), and legal protection status under the Conservation of Biodiversity and Protected Areas Law (2018) (CP = Completely Protected; NP = Normally Protected; SP = Seasonally Protected; NE = Not Evaluated).

No	Species	IUCN Status	National Red List Status	Protection Status	Remark
Order Proboscidea, Family Elephantidae					
1.	Asian elephant *Elephas maximus*	EN	EN	CP	
Order Primates, Family Cercopithecidae					
2.	Tenasserim Langur *Trachypithecus barbei*	VU	VU	CP	
3.	Common long-tailed macaque *Macaca fascicularis*	EN	VU	CP	
4.	Stump-tailed macaque *Macaca arctoides*	VU	NE	CP	
5.	Northern pig-tailed macaque *Macaca leonina*	VU	NE	CP	
6.	Rhesus macaque *Macaca mulatta*	LC	VU	NP	

No	Species	IUCN Status	National Red List Status	Protection Status	Remark
Order Rodentia, Family Sciuridae					
7.	Black giant squirrel *Ratufa bicolor*	NT	NE	NP	
8.	Red-cheeked flying squirrel *Hylopetes spadiceus*	LC	NE	NP	
9.	Pallas's squirrel *Callosciurus erythraeus*	LC	NE	NP	
Family Hystricidae					
10.	Asiatic brush-tailed porcupine *Atherurus macrourus*	LC	NE	NP	
11.	Malayan porcupine *Hystrix brachyura*	LC	NE	NP	
Order Pholidota, Family Manidae					
12.	Sunda pangolin *Manis javanica*	CR	NE	CP	
Order Carnivora, Family Felidae					
13.	Leopard *Panthera pardus*	CR	EN	CP	
14.	Tiger *Panthera tigris*	EN	CR	CP	
15.	Clouded leopard *Neofelis nebulosa*	VU	EN	CP	
16.	Asian Golden Cat *Catopuma temminckii*	NT	VU	CP	
17.	Marbled cat *Pardofelis marmorata*	NT	EN	CP	
18.	Leopard cat *Prionailurus bengalensis*	LC	NT	NP	
Family Prionodontidae					
19.	Banded Linsang *Prionodon linsang*	LC	NE	NP	
Family Viverridae					
20.	Binturong Arctictis binturong	VU		CP	
21.	Small-toothed palm civet *Arctogalidia trivirgata*	LC	NE	CP	
22.	Masked palm civet *Paguma larvata*	LC	NE	CP	
23.	Common palm civet/ Sumatran palm civet *Paradoxurus musangus*	LC	NE	NP	
24.	Large-spotted civet *Viverra megaspila*	EN	NE	CP	Distribution Uncertain
25.	Large Indian civet *Viverra zibetha*	LC	NE	CP	
26.	Small Indian civet *Viverricula indica*	LC	NE	NP	
Family Herpestidae					
27.	Crab-eating mongoose *Urva urva*	LC	NE	NP	
Family Canidae					
28.	Dhole *Cuon alpinus*	EN	NE	CP	
Family Ursidae					
29.	Asiatic Black Bear *Ursus thibetanus*	VU	VU	CP	

No	Species	IUCN Status	National Red List Status	Protection Status	Remark
30.	Sun Bear *Helarctos malayanus*	VU	VU	CP	
Family Mustelidae					
31.	Eurasian otter *Lutra lutra*	NT	NE	CP	Distribution Uncertain
32.	Greater hog badger *Arctonyx collaris*	VU	NE	CP	
33.	Large-toothed ferret badger *Melogale personata*	LC	NE	NP	
34.	Small-toothed ferret badger *Melogale moschata*	LC	NE	NP	
35.	Yellow-throated marten Martes flavigula	LC	NE	NP	
Order Perissodactyla, Family Tapiridae					
36.	Malayan tapir *Tapirus indicus*	EN	EN	CP	
	Family Suidae				
37.	Eurasian wild pig/Wild boar *Sus scrofa*	LC	NE	NE	
Family Tragulidae					
38.	Lesser Indo-Malayan Chevrotain/ Lesser mouse-deer *Tragulus kanchil*	LC	NT	CP	
39.	Greater Indo-Malayan Chevrotain/ Greater mouse-deer *Tragulus napu*	LC	NE	CP	
Order Artiodactyla, Family Cervidae					
40.	Fea's muntjac *Muntiacus feae*	DD	NE	CP	
41.	Northern red muntjac *Muntiacus vaginalis*	LC	NE	SP	
42.	Sambar *Rusa unicolor*	VU	NE	NP	
Order Artiodactyla, Family Bovidae					
43.	Gaur *Bos gaurus*	VU	NE	CP	
44.	Chinese Serow *Capricornis milneedwardsi*	VU	NE	CP	
45.	Southern serow Capricornis sumatraensis		NE	CP	Taxonomy Uncertain

(*Source: Data obtained from five camera-trap surveys conducted in 2013, 2017, 2018, 2019, and 2020 by the Tanintharyi Nature Reserve Project.*)

4.2. Research on Key Species

In parallel with general diversity assessments, several studies have focused on key mammal species in TNR. In 2011, three research studies were undertaken in

Tanintharyi Nature Reserve (TNR) focusing on key mammal species: (i) the Malayan tapir (*Tapirus indicus*), (ii) tigers (*Panthera tigris*) and their prey, and (iii) wild elephant density, distribution, ecological correlates, and threats (Nay Myo Shwe, 2011; Myint Maung, 2011; Hla Myo Aung, 2011). In addition, a population survey of the Tanintharyi langur (*Trachypithecus barbei*) was conducted by Friends of Wildlife (FoW) in 2016.

The study on Malayan tapir (Nay Myo Shwe, 2011) reported three individuals recorded by camera traps at two sites within TNR. Hunting and habitat degradation were identified as major threats to the species in and around the reserve. The author recommended the implementation of awareness programs, additional biological surveys, and the development of a national “Myanmar Tapir Conservation and Action Plan” to guide the effective conservation of this declining population.

Recognized as a critical habitat for tigers, TNR was the focus of a comprehensive survey in 2011 to document tiger distribution and recommend urgent management interventions for population recovery and enhanced protection (Myint Maung, 2011). Although no individual tigers were captured on camera traps due to extremely low density and detectability, a plaster cast of a tiger footprint was collected upstream of Meke. Several prey species, including gaur, sambar, barking deer (northern red muntjac), Chinese serow, wild pig, and porcupine (Hystrix spp.) were recorded.

Research on wild elephants was carried out to estimate population density, distribution, and ecological requirements using questionnaire surveys and established methods (Dawson, 1991; Rabinowitz, 1997) (Hla Myo Aung, 2011). The study estimated a population of 45-64 individuals within 1,601.30 km² (94.19%) of TNR and documented 35 plant species consumed by elephants as forage.

In 2016, Friends of Wildlife (FoW) conducted a study on the Tanintharyi langur (*Trachypithecus barbei*) to assess its abundance, distribution, and ecology. The species was recorded in nine Local Operating Units (LoUs) of TNR. Population density was estimated at 1.35 groups/km² using Distance Software v6.2, corresponding to a total of 423 groups in the Yebone area. Group sizes ranged from 8 to 30 individuals, occurring between 377 m and 1,001 m above sea level. Dietary observations recorded consumption of fruits and leaves from 12 plant species, including Taung-Thayaet

Swintonia floribunda, *Taw-Kyetmauk* Nephelium lappaceum, Ye-Thapan *Ficus glomerata*, Nyaung-thabye *Ficus obtusifolia*, Ngwe-Pan *Globba coronarium*, and Taung-Peinne *Artocarpus chaplasha* (Friends of Wildlife, 2016).

The general diversity surveys and species-specific studies demonstrated the high conservation value of TNR as a stronghold for globally threatened mammals such as the Malayan tapir, tiger, Asian elephant, and Tanintharyi langur. While baseline diversity assessments have provided a broad inventory of species presence, focused research has shed light on population densities, distribution patterns, ecological requirements, and key threats. Collectively, these studies highlight urgent conservation challenges including hunting, habitat loss, and low population densities as well as opportunities for targeted interventions through enhanced patrolling, community engagement, and species-specific action plans.

5. Materials and Methods

5.1. Study Area

Tanintharyi Nature Reserve is located between Ye-Dewai road in the west along with the Andaman Sea and Myanmar-Thailand international border line in the east. TNR is administratively located in Yebyu and Dewai Townships of Dewai District in the northern part of Tanintharyi Region. TNR area (Figure 1) is geographically situated between the latitudinal range of N 14°20´50″ to 14°57´55″ and the longitudinal range of E 98° 5´10″ to 98° 31´32″ . TNR was notified as a Nature Reserve in 2005 with a total area of 1700 km^2 (about 169,998.7 ha). It consists of three forest reserves, viz., the eastern parts of Kaleinaung Reserve and Heinze Reserve (about 85,764 ha), and Luwaing Reserve (about 84,307 ha) .These reserves were classified as Reserve Forests in 1885, 1902 and 1932 respectively, being some of the very oldest preserved tropical rain forests in Myanmar.

The climate in the study area is seasonal influenced by tropical monsoon, usually with high rainfall. Annual rainfall is 5,000 mm with 145 rainy days from May to October. Average temperature range is 25-28 °C with the hottest in March and the coldest in January (Meteorological Department of Dewai District). The predominant vegetation is tropical rain forest growing in high elevation of mountains, but associated with the

deciduous hardwood and bamboo forest in the lowlands.

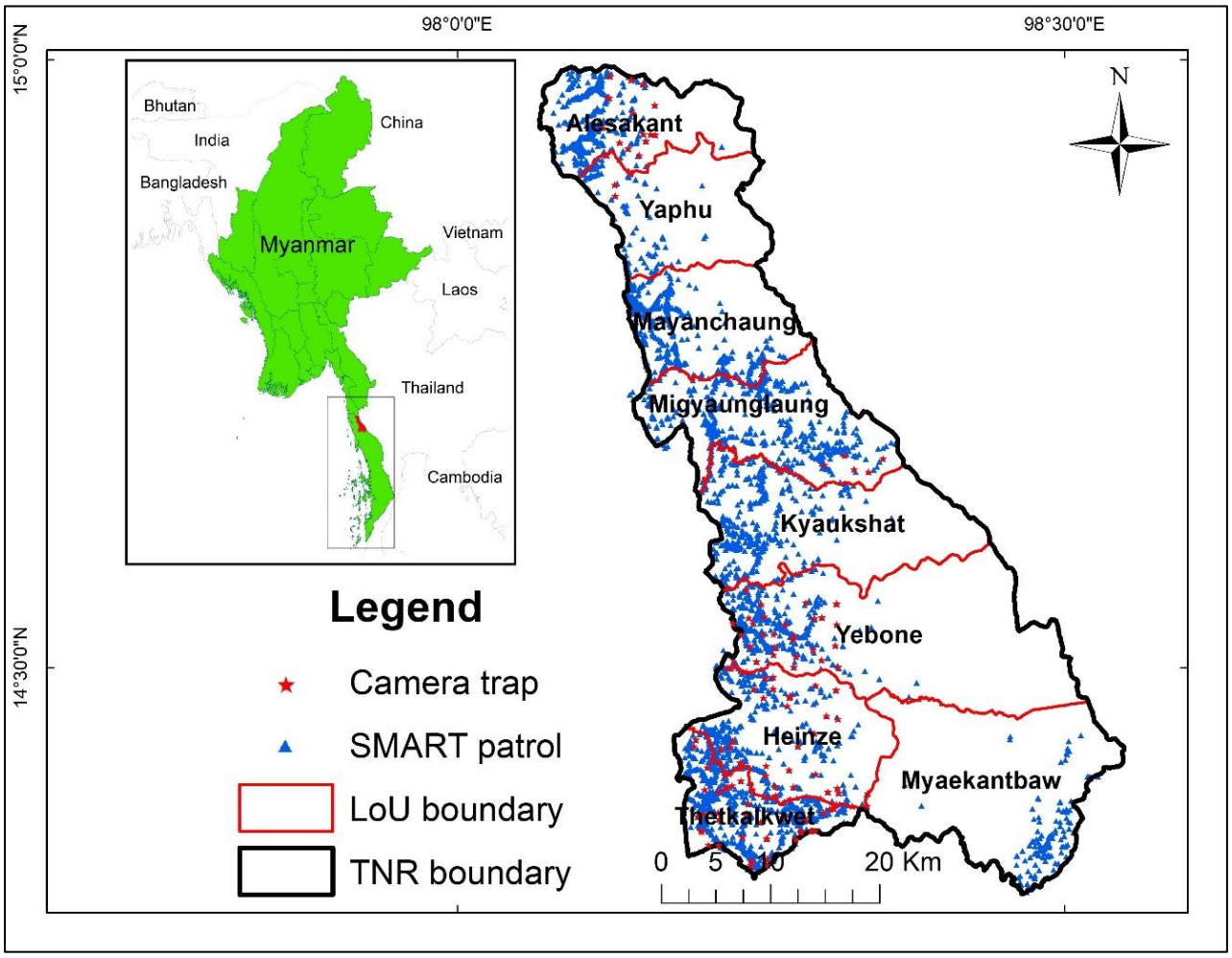

Figure 1. Location of Tanintharyi Nature Reserve (TNR), Local operating Unit (LoU) and occurrence records of mammals from camera trap and SMART patrol in TNR, Myanmar.

5.2. Climate and other environmental variables

A total of 18 environmental variables that could potentially influence the distribution of mammal species were initially considered for modelling. Variables with a correlation coefficient greater than 0.7 were excluded to reduce multicollinearity, resulting in a final selection of seven environmental variables, including mean annual precipitation as the primary bioclimatic variable. The bioclimatic variable was obtained from the WorldClim database at a spatial resolution of 30 arc seconds (approximately 1 km) for the current climate (average for 1969-1990).

Other environmental variables used to develop the distribution models for key mammal species included: land cover of Myanmar (15 classes) (Remote Sensing and GIS Section, Forest Department, 2024); Euclidean distance to villages; distance to the

nearest water sources (both obtained from the Myanmar Information Management Unit [MIMU]); the global human footprint (percentage metric indicating anthropogenic impacts on the environment) (Branco et al., 2023); soil pH (accessed February 2024); and elevation (meters) (Table 2).

All variables were resampled to a uniform spatial resolution of 30 meters. Pearson's correlation test was applied to assess multicollinearity among the final set of variables. The environmental variables used for the MaxEnt analysis and their respective data sources are listed in Table 2, while Pearson's correlation coefficients are presented in Table 3.

Since the order Carnivora includes two distinct dietary groups: (1) obligate carnivores such as tiger, dhole, and clouded leopard, and (2) ecological omnivores such as Asiatic black bear and Malayan sun bear, whose diet consists primarily of plant material, small mammals, and carrion, two separate prey species distribution maps were generated: one for obligate carnivores (Greenspan et al., 2020; Tananantayot et al., 2022) and one for omnivores.

Table 2. Bioclimatic and environmental variables used in the habitat suitability modeling of the key mammal species in Tanintharyi Nature Reserve, Myanmar.

No.	Environmental variables	Original spatial resolution	Year	Source
1.	Annual precipitation (Bio12)	~1 km	1901-2016	http://www.worldclim.org
2.	Elevation			
3.	Soil pH	~ 250 m	1990-2020	https://soilgrids.org
4.	Land cover (15 classes)	30 m	2023	Remote Sensing and GIS Section, Forest Department, 2024
5.	Euclidean distance to water sources	30 m	2024	http://geonode.themimu.info/
6.	Euclidean distance to villages	30 m	2024	http://geonode.themimu.info/
7.	Global human footprint	~ 1 km	1990-2020	Branco et al., 2023
8.	Distribution of prey species (for true carnivores)	~ 30 m	2025	Appendix Figure (modeling from MaxEnt)
9.	Distribution of prey species (for bear species)	~ 30 m	2025	Appendix Figure (modeling from MaxEnt)

Table 3. Pair-wise Pearson's correlation coefficients of environmental variables.

	Mean Annual Precpitation	Elevation	Human footprint	Soil pH	Distance to water sources	Distance to villages	Land use/ cover
Mean Annual Precpitation	1	-0.567	0.536	0.376	-0.693	-0.647	0.223
Elevation	-0.567	1	-0.058	-0.504	0.43	0.416	-0.245
Human footprint	0.536	-0.058	1	0.098	-0.498	-0.307	0.069
Soil pH	0.376	-0.504	0.098	1	-0.339	-0.261	0.260
Distance to water sources	-0.693	0.430	-0.498	-0.339	1	0.631	-0.190
Distance to villages	-0.647	0.416	-0.307	-0.261	0.631	1	-0.193
Land use/ cover	0.223	-0.245	0.069	0.260	-0.190	-0.193	1

5.3. Species Occurrence Data

Mammal species occurrence data were obtained from camera trap surveys and SMART patrolling records collected in the Tanintharyi Nature Reserve (TNR) over a five-year period (2018-2024). A total of 22,815 occurrence records were documented for 42 mammal species inhabiting TNR.

For this study, habitat suitability modelling was conducted for 19 key mammal species listed in Table 2. After removing duplicate records, 1,913 unique occurrence points were retained for these species (Figure 1; Table 2).

Table 4. Number of occurrence points of 19 key mammal species for species distribution modeling after meticulous data cleaning and the exclusion of duplicate points

No	Species	IUCN Status	Number of Occurrence points
	Order Proboscidea, Family Elephantidae		
1.	Asian elephant *Elephas maximus*	EN	32
	Order Primates, Family Cercopithecidae		
2.	Tenasserim Langur *Trachypithecus barbei*	VU	23
3.	Common long-tailed macaque *Macaca fascicularis*	EN	19
4.	Stump-tailed macaque *Macaca arctoides*	VU	170
5.	Northern pig-tailed macaque *Macaca leonina*	VU	134
	Order Pholidota, Family Manidae		
6.	Sunda pangolin *Manis javanica*	CR	33
	Order Carnivora, Family Felidae		
7.	Leopard *Panthera pardus*	CR	12
8.	Tiger *Panthera tigris*	EN	53
9.	Clouded leopard *Neofelis nebulosa*	VU	219
10.	Asian Golden Cat *Catopuma temminckii*	NT	53
11.	Marbled cat *Pardofelis marmorata*	NT	108
	Family Viverridae		
12.	Binturong Arctictis binturong	VU	65
	Family Canidae		
13.	Dhole *Cuon alpinus*	EN	75
	Family Ursidae		
14.	Asiatic Black Bear *Ursus thibetanus*	VU	132
15.	Sun Bear *Helarctos malayanus*	VU	232
	Order Perissodactyla, Family Tapiridae		
16.	Malayan tapir *Tapirus indicus*	EN	20
	Order Artiodactyla, Family Cervidae		
17.	Sambar *Rusa unicolor*	VU	287
	Order Artiodactyla, Family Bovidae		
18.	Gaur *Bos gaurus*	VU	57
19.	Chinese Serow *Capricornis milneedwardsi*	VU	189
	Total		**1913**

5.4. Species distribution model

Species distribution models (SDMs) are widely used in biogeography, ecology, and conservation to assess biodiversity patterns, explore species-environment relationships (Than, 2020), project future distributions under land-use and climate change scenarios (Trisurat et al., 2015), identify priority conservation areas (Hughes et al., 2017), and evaluate potential range shifts due to climate change (Thang et al., 2020).

In this study, I used the Maximum Entropy model (MaxEnt) version 3.4.3 (Phillips et al., 2006), which has been shown to outperform other modelling methods in terms of higher Area Under the Receiver Operating Characteristic Curve (AUC) values, reduced overfitting of suitable ranges (Peterson et al., 2007), and superior predictive performance for carnivore species (Elith et al., 2006; Jones et al., 2016). MaxEnt also performs well with small sample sizes (<25 occurrence points) (Pearson et al., 2007).

Models were trained using 75% of the occurrence data and evaluated with the remaining 25%. Default settings were applied with a maximum of 10,000 background points. Each model was run with ten replicates using the cross-validation method. Model performance was assessed using AUC, with values >0.8 indicating good predictive accuracy, >0.9 considered excellent (Wang & Tabeta, 2023), and <0.65 indicating inadequate predictive performance (Çorbacıoğlu & Aksel, 2023).

The jackknife test was used to determine the relative importance of environmental variables for each of the 19 key mammal species. Final model outputs included the average habitat suitability maps and evaluation metrics. Habitat suitability was classified into two categories: 0 = unsuitable habitat and 1 = suitable habitat, using the 10-percentile training presence threshold, following methods used in similar studies (Trisurat et al., 2012; Greenspan et al., 2020). The total areas of suitable and unsuitable habitats within TNR were calculated for all 19 species. Analyses were conducted in R (version 2023.12.1) using the ENMTools, raster, and corrplot packages, and in ArcGIS 10.7.

As a biotic predictor for obligate carnivores (tiger, dhole and clouded leopard), a prey distribution map was generated using 4,126 occurrence points from potential prey species such as muntjac, gaur, serow, sambar and wild boar. For ecological omnivores (Asiatic black bear and Malayan sun bear), a prey distribution map was created using

807 occurrence points of small mammals such as mouse deer, porcupines, and squirrels. Both prey species models were developed using the same MaxEnt approach described above. The resulting prey habitat suitability maps are shown in Appendix Figure 1.

In addition to individual habitat suitability maps for each of the 19 focal mammal species, composite maps were generated to identify spatial overlap in suitable habitat for ecologically related species groups within Tanintharyi Nature Reserve (TNR). This was achieved by overlaying individual MaxEnt-derived suitability maps for species within the same functional guild and extracting the intersecting areas above the suitability threshold. I defined five functional guild/group as follows;

(1) Large herbivores in the order Artiodactyla, the predicted suitable habitats of sambar, gaur, and Chinese serow were combined to delineate areas of concurrent suitability, highlighting key zones for multi-species ungulate conservation.

(2) Primate map was produced by overlapping the suitable habitat distributions of the four macaque species: stump-tailed macaque, northern pig-tailed macaque, common long-tailed macaque, and Tenasserim langur.

(3) Large carnivores, the suitable habitats of tiger, leopard, dhole, and clouded leopard were intersected to identify shared core areas.

(4) Medium carnivores were similarly analyzed by overlapping the distributions of Asian golden cat, marbled cat, and binturong.

(5) Omnivore group was represented by overlapping suitable habitats of the Asiatic black bear and Malayan sun bear.

6. Results

Maximum Entropy (MaxEnt) modeling was conducted for 19 key mammal species within the Tanintharyi Nature Reserve, Myanmar, to evaluate habitat suitability and to quantify the relative influence of bioclimatic and environmental variables on species distributions. The performance of the models, as assessed by the area under the receiver operating characteristic curve (AUC), indicated generally high predictive accuracy for herbivorous species (AUC range: 0.83-0.897) and moderate-to-high accuracy for carnivorous species (AUC range: 0.678-0.868) (Table 5 and 6).

Among the ten herbivorous species modeled, Malayan tapir achieved the highest AUC (0.897), followed closely by gaur (0.890) and Tenasserim langur (0.893). The nine carnivorous species exhibited lower AUC values on average compared to herbivores, with Binturong (0.868) and Asian Golden Cat (0.840) showing the highest predictive performance, while leopard had the lowest AUC (0.678), indicating that the model's prediction for this species is less reliable (Tables 5 and 6).

Table 5. The area under the receiver operating characteristic curves (AUCs) from Maximum Entropy modeling and the relative contribution of bioclimatic and environmental variables to the distribution of 10 key herbivorous mammal species.

Variable names / Species	AUC	Annual Precipitation	Elevation	Soil pH	Land cover	Euclidean distance to water sources	Euclidean distance to villages	Human footprint
	Percent Contribution (%)							
Asian Elephant	0.836	1.2	22.8	0.5	14.2	36.1	23.3	1.9
Sunda Pangolin	0.831	51.7	7.7	0.4	8.3	11.3	3.2	17.4
Malayan Tapir	0.897	0	18.4	9.7	5.6	40.7	18.1	7.5
Sambar	0.880	32.6	46.2	4.5	2.8	10.3	2.4	1.2
Gaur	0.890	39	34.1	4.1	1.8	2.4	5	13.6
Chinese Serow	0.858	11.7	21	1.9	9.3	3.4	24.8	27.9
Common Long-tailed Macaque	0.880	64	4.2	2	12.8	12.2	4.8	0
Tenasserim Langur	0.893	1.7	5.6	14.3	15.6	16.2	44.9	1.6
Stump-tailed Macaque	0.831	30.7	20.6	0.4	14.9	1.6	6.7	25.2
Northern pig-tailed Macaque	0.868	45.9	18.4	1.5	2.9	5.2	8.7	17.4

Table 6. The area under the receiver operating characteristic curves (AUCs) from Maximum Entropy modeling and the relative contribution of bioclimatic and environmental variables to the distribution of 9 key carnivorous mammal species.

Variable names / Species	AUC	Prey Distrib-ution	Annual Preci-pitation	Elevation	Soil pH	Land cover	Euclidean distance to water sources	Euclidean distance to villages	Human footprint
	Percent Contribution (%)								
Leopard	0.678	1	2.4	1.8	8.7	43	0.1	41.3	1.8
Tiger	0.707	31.8	0	43	0.2	13.7	0	10.9	0.4
Clouded Leopard	0.831	52.3	8.4	12.6	2.6	4.7	4.1	0.7	14.5
Asian Golden Cat	0.840	58.7	2.3	21.1	1.2	6.1	3.4	3.8	3.4
Marbled Cat	0.818	74.7	8	6.5	2	0.4	2.3	5.2	0.9
Binturong	0.868	44.2	0.9	41.3	0.4	5.7	1.7	0.6	5.1
Dhole	0.770	38.4	4.7	29.4	1	7.9	0.2	5.1	13.3
Asiatic black bear	0.841	60.2	1.1	13.2	1.6	2.3	12.5	1.8	7.4
Malayan Sun bear	0.841	66.5	3.2	11.3	2.7	1.9	8.9	2	3.5

6.1. Factors affecting on habitat suitability of Key Mammal Species in Tanintharyi Nature Reserve

Variable contributions varied markedly between species. The jackknife test was also run to determine the importance of environmental variables for the distribution of 19 key mammals in TNR. I found that Euclidean distance to water sources emerged as the most influential predictor for the Asian elephant (36.1%), Malayan tapir (40.7%), and Sambar (10.3%) (Table 5, Figure 2). Annual precipitation was the dominant predictor for the Sunda pangolin (51.7%), gaur (39%), and sambar (32.6%) (Table 5, Figure 2). Elevation had a strong influence for sambar (46.2%) and gaur (34.1%) while proximity to villages and human footprint were notable predictors for Tenasserim langur (44.9%) and Chinese serow (27.9%) (Table 5, Figure 2).

For carnivorous mammals, prey distribution was the primary driver for five species, most strongly for marbled cat (74.7%), Malayan sun bear (66.5%), Asiatic black bear (60.2%), Asian golden cat (58.7%), and clouded leopard (52.3%) (Table 6, Figure 2).

Elevation contributed heavily to tiger (43%) and binturong (41.3%) models whole land cover was particularly important for leopard (43%) and human footprint was a strong negative driver for leopard (41.3%) and dhole (13.3%) (Table 6, Figure 2).

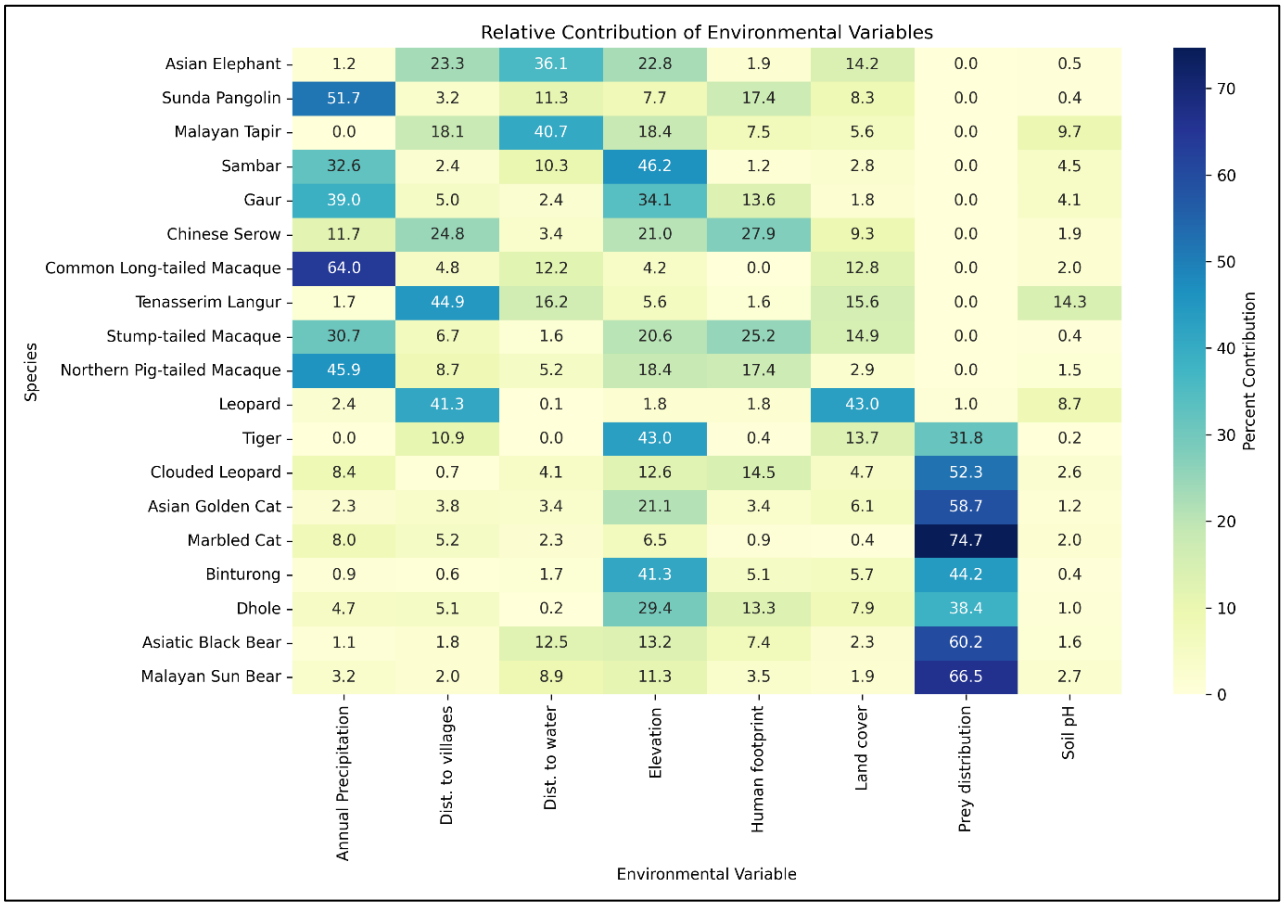

Figure 2. Relative Contribution of Environmental Variables to MaxEnt Habitat Models for 19 Key Mammal Species in Tanintharyi Nature Reserve, Myanmar.

6.2. Predicted Habitat Suitability and Overlap Patterns for Key Mammal Species in Tanintharyi Nature Reserve

MaxEnt modelling predicted heterogeneous distributions of suitable habitat for the 19 focal mammal species within TNR, Myanmar (Figure 3 to 10). Across all species, the mean suitable habitat coverage was 17.23% (±5.21 SD) of the reserve's total area, ranging from 10.35% for the Malayan tapir (Table 7, Figure 4) to 26.90% for the Asian elephant (Table 7, Figure 3).

When species were grouped by functional guild, herbivores (n = 6) exhibited the highest mean proportion of suitable habitat (19.36% ± 5.81), followed by omnivores (n = 4; 18.40% ± 3.41) and carnivores (n = 9; 15.58% ± 5.07). Among herbivores, the Asian

elephant (431.76 km², 26.90%) and Chinese serow (352.24 km², 21.94%) occupied the largest extents of predicted suitable habitat, while the Malayan tapir was the most restricted (166.07 km², 10.35%).

Carnivores displayed substantial variation. The leopard occupied 317.76 km² (19.80%), contrasting with much lower values for the tiger (181.77 km², 11.32%), clouded leopard (173.13 km², 10.79%), and dhole (188.99 km², 11.77%) (Table 7 and Figure 8). The marbled cat was a notable outlier among carnivores, with a high predicted habitat extent of 425.48 km² (26.51%) (Table 7 and Figure 8). Omnivorous species such as the Asiatic black bear (299.35 km², 18.65%) and Malayan sun bear (321.32 km², 20.02%) had intermediate values, indicating moderately broad habitat tolerances (Table 7 and Figure 10) .

Primates exhibited a mid-range of habitat suitability. The stump-tailed macaque and northern pig-tailed macaque occupied 344.09 km² (21.44%) and 331.68 km² (20.66%), respectively, whereas the Tenasserim langur and common long-tailed macaque were more restricted, with suitable areas of 243.43 km² (15.17%) and 237.73 km² (14.81%), respectively (Table 7 and Figure 7).

The extent of habitat overlap varied considerably among the mammal guilds within Tanintharyi Nature Reserve (Table 8, Figure 6-10). Omnivores, represented by the Asiatic black bear and Malayan sun bear, exhibited the largest area of overlapping suitable habitats, covering 271.99 km² or 16.94% of the reserve. Medium-sized carnivores (Asian golden cat, marbled cat, and binturong) showed the second highest overlap, with 157.38 km² (9.80%). In contrast, primates (long-tailed macaque, Tenasserim langur, stump-tailed macaque, and northern pig-tailed macaque) and large carnivores (tiger, leopard, dhole, and clouded leopard) exhibited more restricted overlap, occupying 78.14 km² (5.16%) and 67.48 km² (4.20%), respectively. The lowest overlap was recorded for the artiodactyl herbivores (sambar, gaur, and Chinese serow), with only 4.94 km² (0.33%).

Composite overlap analysis revealed that the shared suitable habitat for the three Artiodactyla species represented key multi-species conservation zones within TNR, concentrated mainly in Mayangchaung and Migyaunglaung LoUs (Figure 6). Similarly, the overlap among the four primate species identified core areas of concurrent suitability

primarily in Kyaukshat, Yebone, Heinze and Thetkalkyat LoUs (Figure 7), while large carnivore overlap indicated limited shared habitat patches due to their narrower distribution (Figure 8). Medium carnivore and omnivore overlaps were comparatively more extensive, suggesting greater tolerance to varied habitat conditions (Figure 9 and 10).

Table 7. Suitable and unsuitable habitats area (km^2) and percentage in Tanintharyi Nature Reserve, Myanmar for 19 key mammal species.

No	Species	Suitable Habitat		Unsuitable Habitat	
		Area (Km^2)	Percentage	Area (Km^2)	Percentage
1.	Asian Elephant	431.76	26.90	1173.40	73.10
2.	Common Long-tailed Macaque	237.73	14.81	1367.43	85.19
3.	Tenasserim Langur	243.43	15.17	1361.74	84.83
4.	Stump-tailed Macaque	344.09	21.44	1261.07	78.56
5.	Northern pig-tailed Macaque	331.68	20.66	1273.48	79.34
6.	Sunda Pangolin	247.64	15.43	1357.52	84.57
7.	Leopard	317.76	19.80	1287.40	80.20
8.	Tiger	181.77	11.32	1423.40	88.68
9.	Clouded Leopard	173.13	10.79	1432.04	89.21
10.	Asian Golden Cat	282.91	17.62	1322.26	82.38
11.	Marbled Cat	425.48	26.51	1179.69	73.49
12.	Binturong	261.69	16.30	1343.47	83.70
13.	Dhole	188.99	11.77	1416.17	88.23
14.	Asiatic black bear	299.35	18.65	1305.81	81.35
15.	Malayan Sun bear	321.32	20.02	1283.84	79.98
16.	Malayan Tapir	166.07	10.35	1439.09	89.65
17.	Sambar	283.06	17.63	1322.10	82.37
18.	Gaur	173.82	10.83	1431.34	89.17
19.	Chinese Serow	352.24	21.94	1252.92	78.06

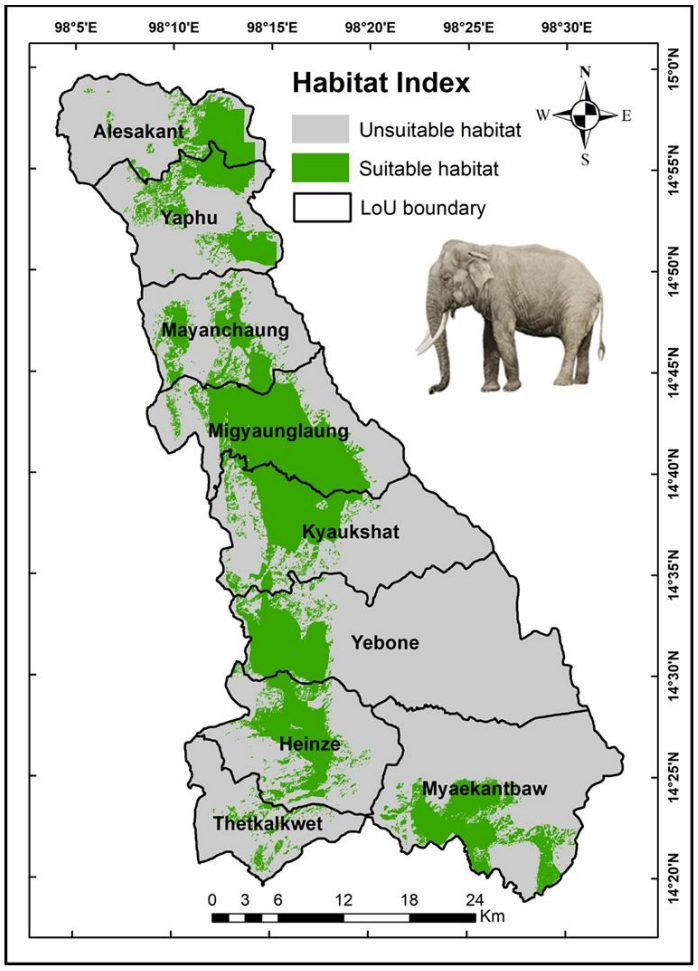

Figure 3. Distribution of suitable habitat area of Asian Elephant (*Elephas maximus*) in Tanintharyi Nature Reserve, Myanmar.

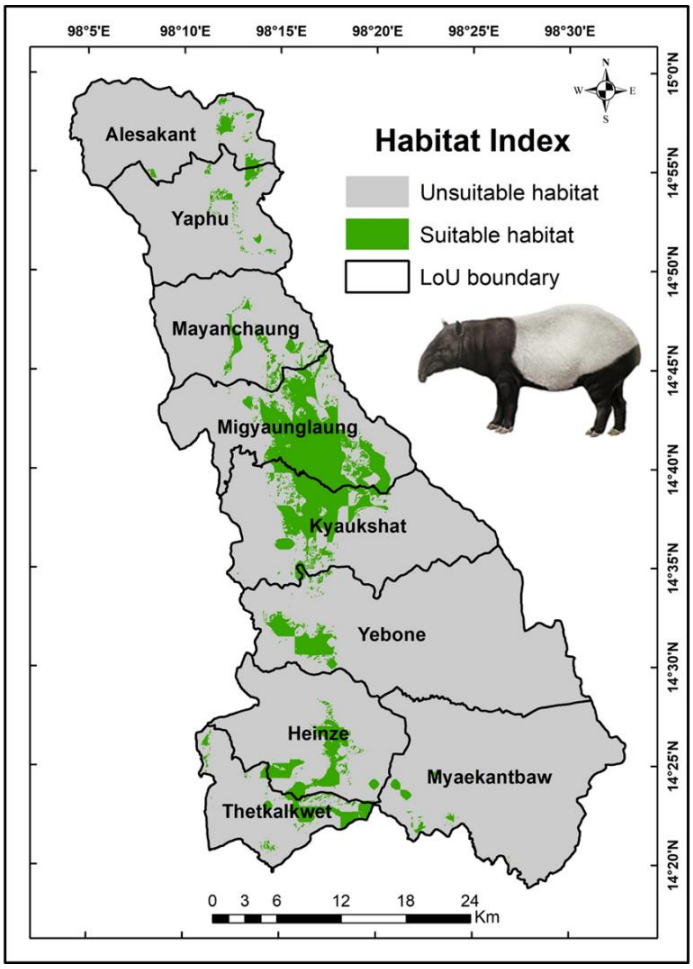

Figure 4. Distribution of suitable habitat area of Malayan Tapir (*Tapir indicus*) in Tanintharyi Nature Reserve, Myanmar.

Table 8. Overlap of predicted suitable habitats among mammal guilds in Tanintharyi Nature Reserve, Myanmar.

Guild/Group	Species Included	Overlap Area (km²)	Overlap (% of TNR)
Artiodactyla	Sambar, Gaur, Chinese Serow	4.94	0.33
Primates	Common Long-tailed Macaque, Tenasserim Langur, Stump-tailed Macaque, Northern Pig-tailed Macaque	78.14	5.16
Large Carnivores	Tiger, Leopard, Dhole, Clouded Leopard	67.48	4.2
Medium Carnivores	Asian Golden Cat, Marbled Cat, Binturong	157.38	9.8
Omnivores	Asiatic Black Bear, Malayan Sun Bear	271.99	16.94

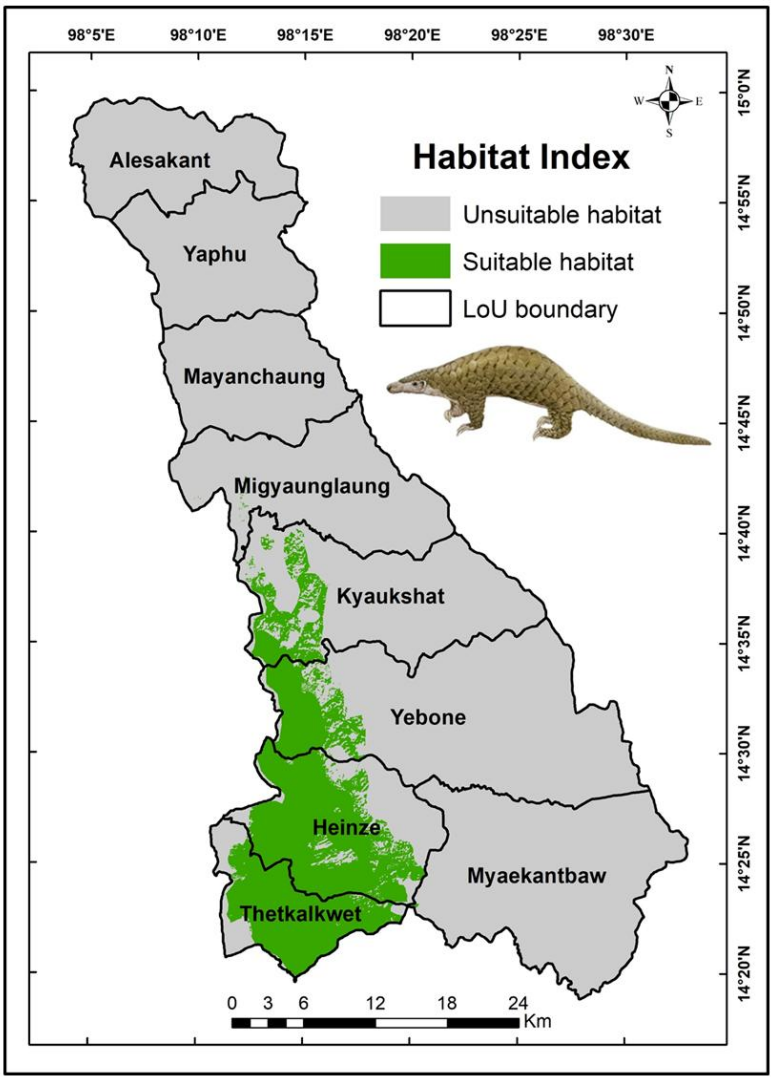

Figure 5. Predicted habitat suitability maps of Sunda pangolin (*Manis javanica*) in Tanintharyi Nature Reserve, Myanmar.

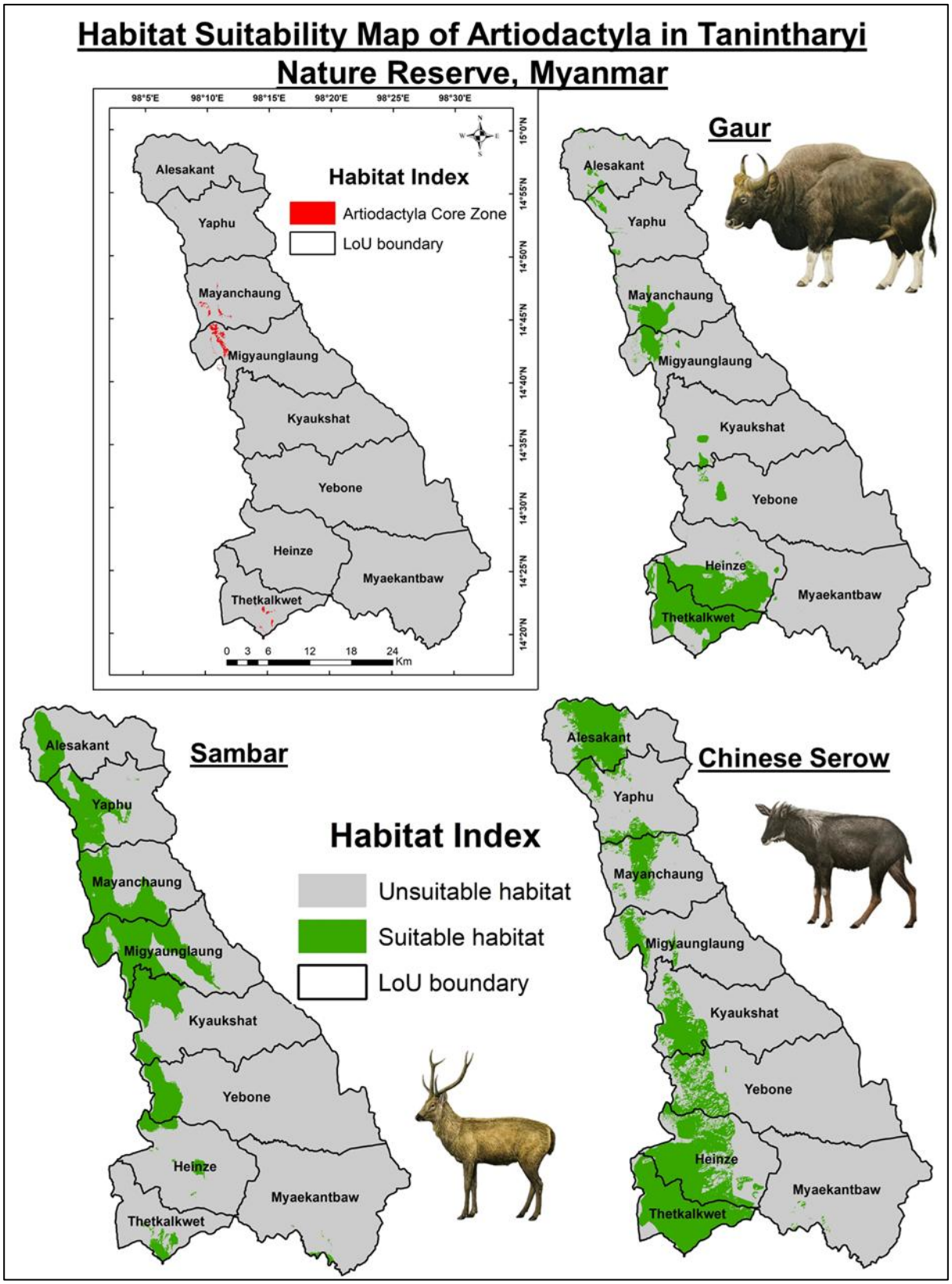

Figure 6. Predicted habitat suitability maps for sambar (*Rusa unicolor*), gaur (*Bos gaurus*), and Chinese serow (*Capricornis milneedwardsii*), with overlapped areas indicating zones of concurrent suitability for all three species in Tanintharyi Nature Reserve, Myanmar.

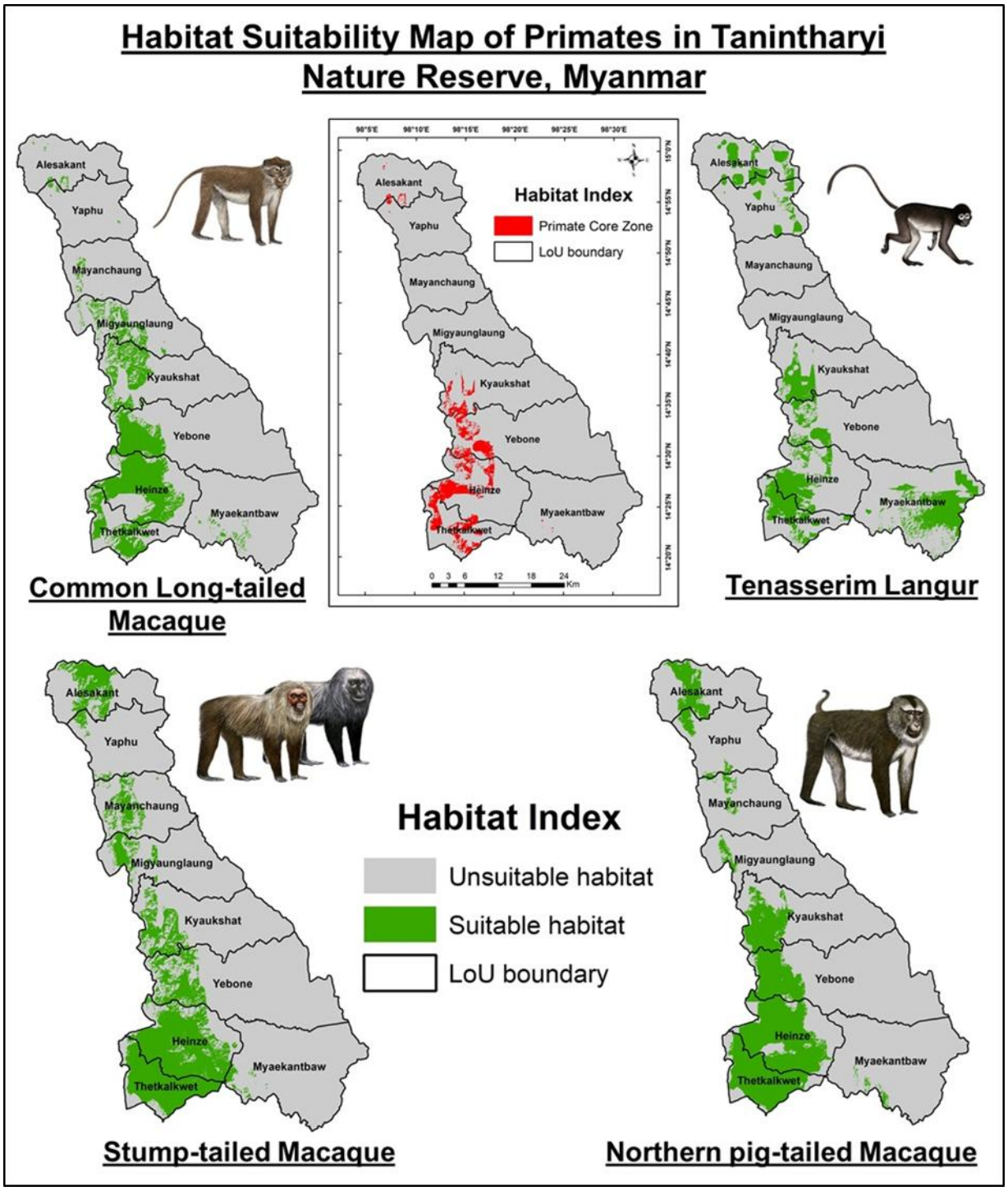

Figure 7. Predicted habitat suitability maps for common long-tailed macaque (*Macaca fascicularis*), Tenasserim langur (*Trachypithecus germaini*), stump-tailed macaque (*Macaca arctoides*), and northern pig-tailed macaque (*Macaca leonina*), with overlapped areas indicating zones of concurrent suitability for all four species of primates in Tanintharyi Nature Reserve, Myanmar.

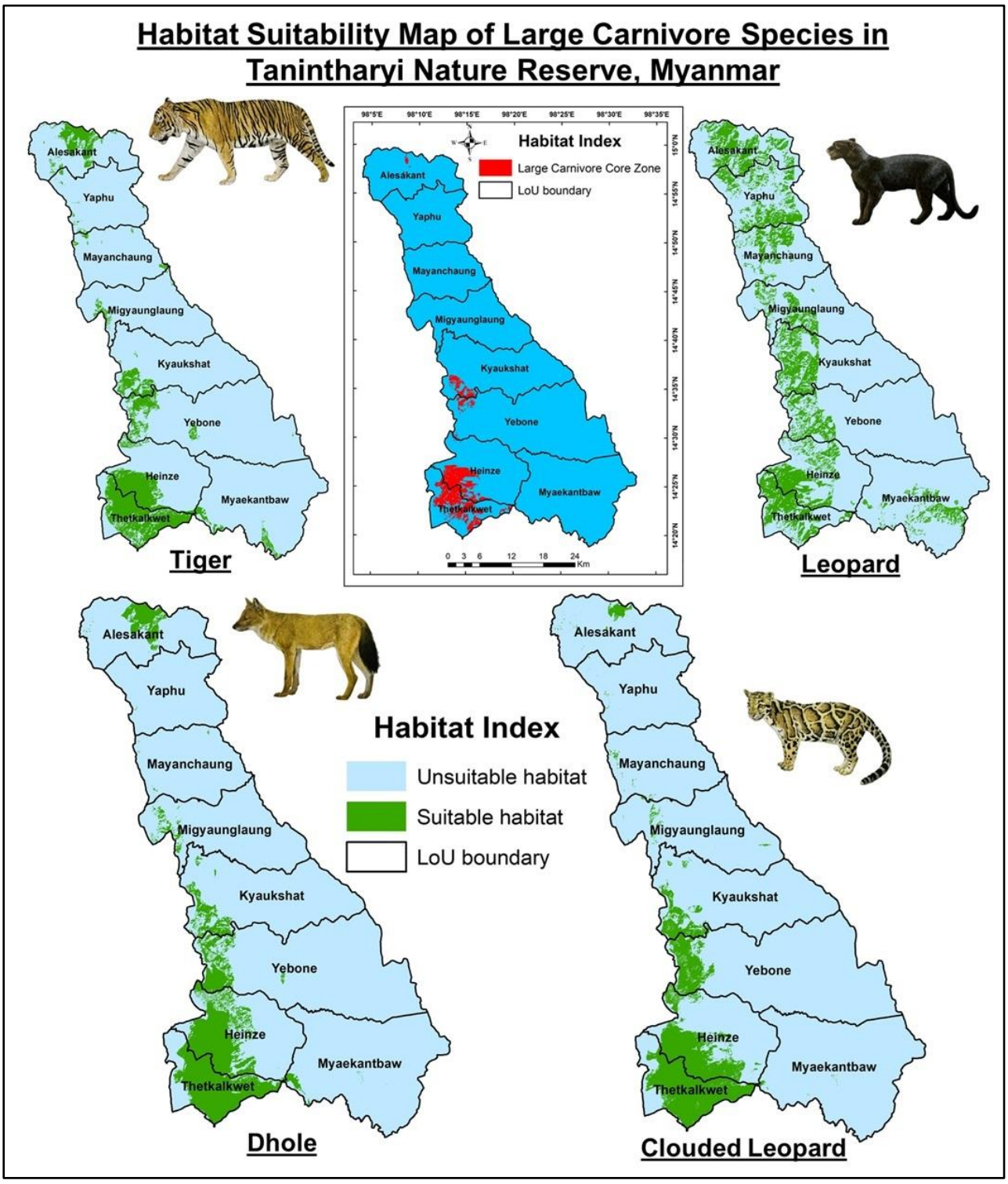

Figure 8. Predicted habitat suitability maps for tiger (*Panthera tigris*), leopard (*Panthera pardus*), dhole (*Cuon alpinus*) and clouded leopard (*Neofelis nebulosa*), with overlapped areas indicating zones of concurrent suitability for all four species of large carnivores in Tanintharyi Nature Reserve, Myanmar.

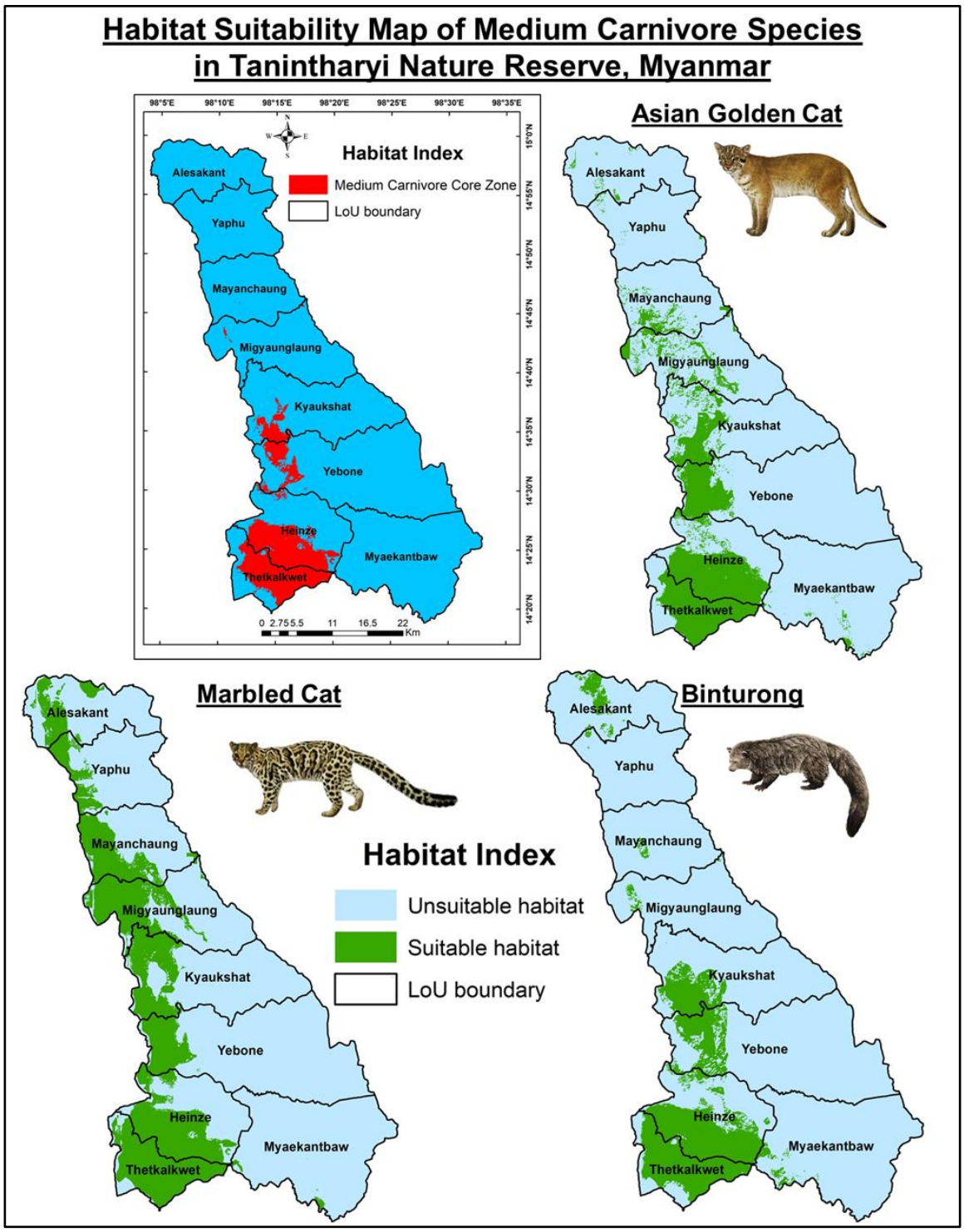

Figure 9. Predicted habitat suitability maps for Asian golden cat (*Catopuma temminckii*), marbled cat (*Paradofelis marmorata*) and binturong (*Arctictis binturong*), with overlapped areas indicating zones of concurrent suitability for all three species of medium carnivores in Tanintharyi Nature Reserve, Myanmar.

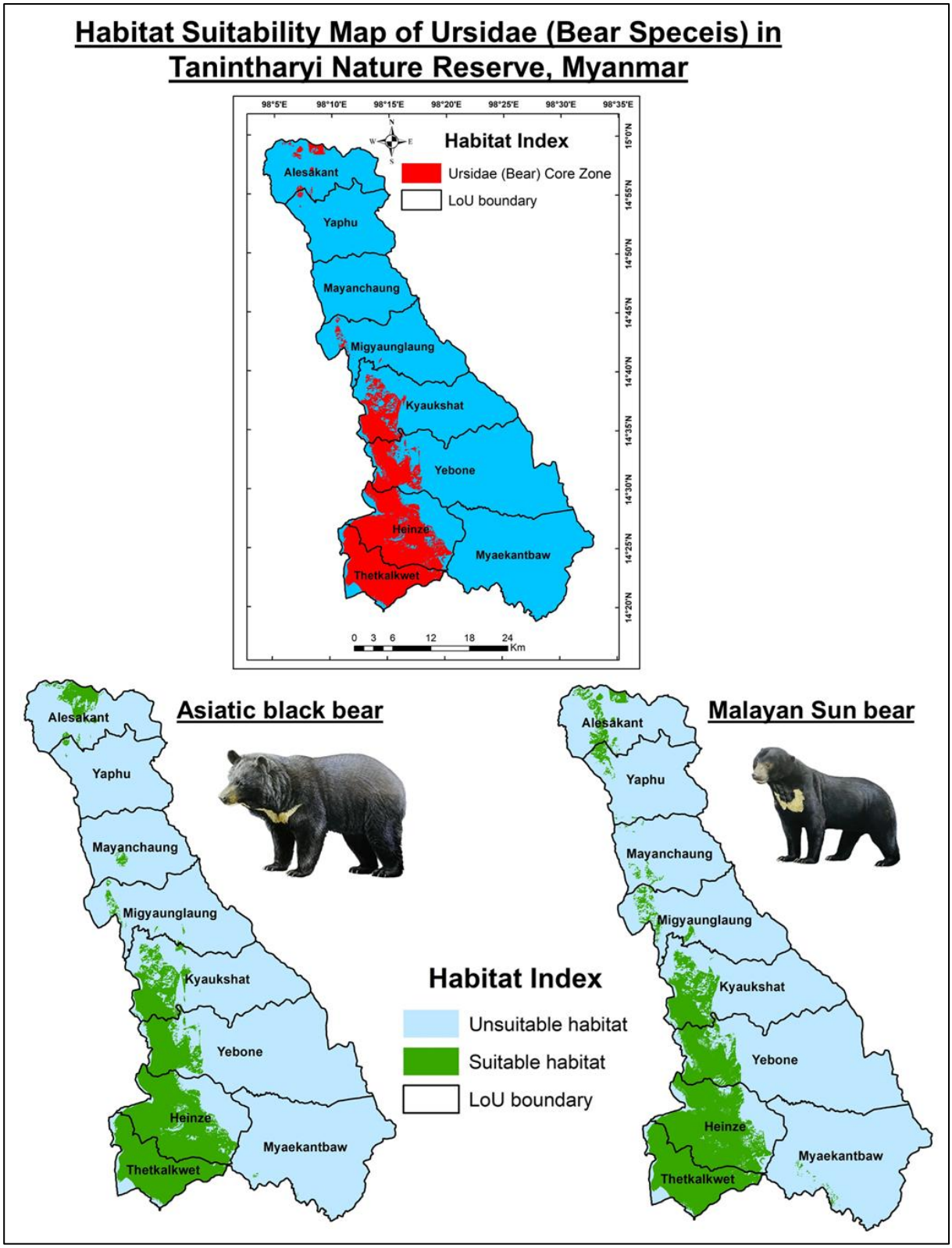

Figure 10. Predicted habitat suitability maps for Asiatic black bear (*Ursus thibetanus*) and Malayan sun bear (*Helarctos malayanus*), with overlapped areas indicating zones of concurrent suitability for these two species of omnivores in Tanintharyi Nature Reserve, Myanmar.

6.3. Predicted Habitat Suitability of Key Mammal Species across Local Opearating Units (LoUs) in Tanintharyi Nature Reserve

Habitat suitability analysis was conducted for 19 priority mammal species across nine Local Operating Units (LoUs) in the Tanintharyi Nature Reserve. A species-by-LoU habitat suitability table and a LoU-based habitat suitability heatmap were generated to summarize spatial variation in conservation value across the landscape (Table 9 and Figure 11).

Habitat suitability significantly varied across the study area. Thetkalkwet and Heinze, located in the southern zone of the reserve, exhibited the highest overall suitability values, supporting predominantly Core (≥50%) or High (40–49%) suitability habitat for multiple large carnivores (e.g., tiger, clouded leopard, Asian golden cat, dhole), bears (Asiatic black bear and Malayan sun bear), and herbivores (sambar, gaur, and Chinese serow). Kyaukshat and Yebone provided moderately suitable habitat for these species, although suitability was generally more fragmented. Primates and Sunda pangolin exhibited narrower suitable area distributions than carnivores and ungulates. Several species, including leopard and northern pig-tailed macaque, did not achieve core suitability in any LoU, indicating elevated conservation concern under current habitat conditions.

Table 9. Habitat suitability (%) of nineteen key mammal species across nine Local operating Units (LoUs) in Tanintharyi Nature Reserve, Myanmar.

LoUs / Species	Thetkalkwet	Heinze	Kyaukshat	Yebone	Migyaunglaung	Alesakant	Mayanchuang	Yaphu	Myaekantbaw
Asian Elephant	10	35	25	10	50	10	25	20	30
Long-tailed Macaque	35	40	20	25	15	3	5	3	5
Tenasserim Langur	30	40	20	15	0	10	0	10	40
Stump-tailed Macaque	70	70	35	35	20	20	20	5	5
Northern Pig-tailed Macaque	70	60	35	35	5	20	5	5	5
Sunda Pangolin	60	60	25	30	0	0	0	0	0

LoUs / Species	Thet kal kwet	Heinze	Kyauk shat	Yebone	Mi gyaung laung	Alesa kant	Mayan chuang	Yaphu	Myaek ant baw
Leopard	35	35	35	15	30	30	30	25	15
Tiger	55	50	15	15	5	10	5	5	5
Clouded Leopard	50	45	15	20	5	5	3	3	3
Asian Golden Cat	55	45	25	30	15	5	10	3	3
Marbled Cat	60	50	35	35	35	15	25	15	5
Binturong	60	45	35	25	25	10	5	5	5
Dhole	60	45	10	20	20	15	5	5	5
Asiatic Black Bear	60	50	35	35	20	15	5	5	3
Malayan Sun Bear	65	60	35	35	10	15	5	5	5
Malayan Tapir	15	15	30	5	50	5	10	5	5
Sambar	10	10	20	20	45	15	35	30	5
Gaur	45	45	8	8	10	5	10	5	3
Chinese Serow	65	50	35	30	25	40	25	10	5

(Note: Leopard suitability values should be interpreted cautiously given lower model reliability.)

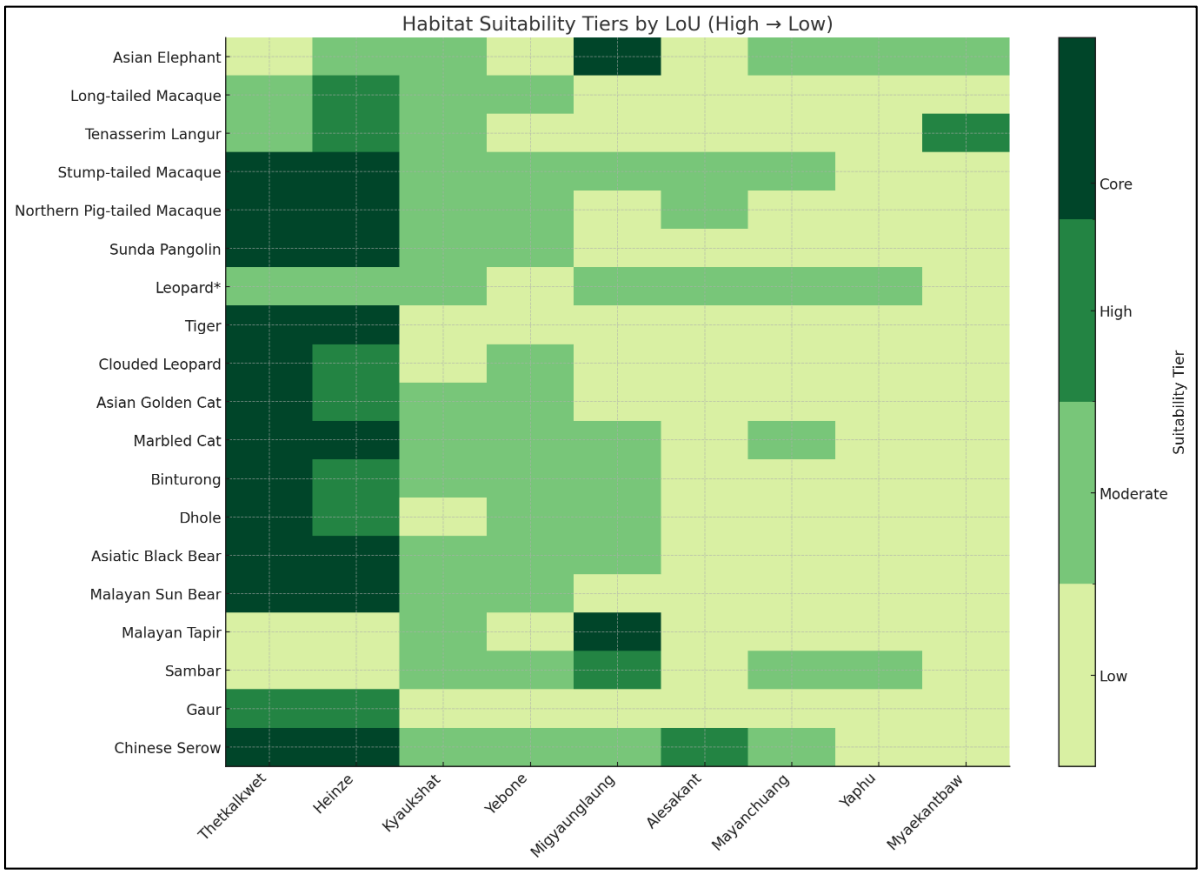

Figure 11. LoU-based habitat suitability heatmap showing conservation priority gradients in Tanintharyi Nature Reserve. (Note: Core ≥50%; High 40–49%; Moderate 20–39%; Low <20% suitability. LoUs are ordered from highest to lowest overall suitability. Leopard suitability values should be interpreted cautiously given lower model reliability.

7. Discussion

This study provides the first comprehensive application of Maximum Entropy (MaxEnt) modeling for multiple key mammal species in the Tanintharyi Nature Reserve (TNR), Myanmar. The results revealed strong predictive performance for most herbivores and moderate-to-high performance for carnivores, identified species-specific environmental drivers of habitat suitability, and demonstrated variable levels of habitat overlap across mammalian guilds. Together, these findings underscore both the conservation value of TNR and the complexity of managing its diverse mammal assemblages.

7.1. Model Performance and Reliability

Herbivores achieved consistently higher AUC scores (0.83–0.897) compared to carnivores (0.678–0.868), suggesting that their distributions are more readily captured by

environmental and climatic predictors. This pattern aligns with prior research indicating that herbivore distributions are strongly tied to vegetation, water availability, and climatic gradients (Campos-Arceiz et al., 2012; Gray et al., 2018). In contrast, carnivores are often more difficult to model due to their wide-ranging movements, dependence on prey dynamics, and sensitivity to human disturbance (Srivathsa et al., 2014; Sunarto et al., 2012). The particularly low AUC for leopard (0.678) suggests that habitat suitability models for this species may be less reliable, possibly due to its low detectability by the camera trap and its generalist ecology and adaptability across varied landscapes (Jacobson et al., 2016).

7.2. Environmental and Anthropogenic Drivers of Habitat Suitability

Environmental variables influenced species distributions in distinct ways. Water availability was the dominant predictor for Asian elephant, Malayan tapir, and sambar, reflecting the central role of riparian habitats in supporting large herbivores (Fernando et al., 2008). Annual precipitation and elevation were especially important for gaur and Chinese serow, suggesting sensitivity to climatic variability and terrain complexity, consistent with studies from neighboring Thailand and Laos (Chutipong et al., 2015).

Carnivore distributions were primarily shaped by prey availability, particularly for marbled cat, Asiatic black bear, Malayan sun bear, and clouded leopard. This finding is consistent with ecological theory, where prey biomass is a key determinant of carnivore occupancy (Karanth et al., 2004; Ramesh et al., 2012). Elevation was an important factor for tiger and binturong, while leopard and dhole were negatively associated with human footprint, highlighting their vulnerability to human pressures. Similar patterns have been documented across Southeast Asia, where carnivore persistence is threatened by habitat loss and anthropogenic disturbance (Rayan & Linkie, 2016; Steinmetz et al., 2013).

7.3. Habitat Suitability and Guild-Level Overlap

Predicted habitat suitability varied widely among species. Large-bodied herbivores such as Asian elephants and Chinese serows occupied the broadest extents of suitable habitat, while the Malayan tapir was restricted to more fragmented areas. Carnivores displayed high variability, with marbled cats predicted to occupy large extents, while tiger and clouded leopard were more limited. These findings suggest that generalist species

with broader ecological niches are more resilient, whereas specialists face greater risks from habitat fragmentation.

Guild-level overlap analyses further highlighted ecological contrasts. Omnivores exhibited the highest overlap (16.94% of TNR), reflecting their dietary plasticity and adaptability, while artiodactyl herbivores exhibited minimal overlap (0.33%), indicating more specialized and spatially segregated habitat requirements. Large carnivores also showed limited overlap (4.2%), which may reflect territoriality and niche partitioning among sympatric predators (Steinmetz et al., 2013). Such patterns suggest that conservation strategies must balance the needs of generalists, which may withstand habitat changes, and specialists, which require targeted habitat protection.

7.4. Habitat Suitability Outcomes and Management Priorities Across Local Operating Units (LoUs)

This study provides a spatially explicit evaluation of habitat suitability for 19 mammal species across nine LoUs in the Tanintharyi Nature Reserve. When compared with the 2016 large mammal survey based on local interview data (Friends of Wildlife, 2016), several consistencies and notable shifts in species' LoU associations were evident.

Species such as Asian elephant, Malayan tapir, Chinese serow, and leopard retained similar distribution patterns to those reported in 2016, suggesting relatively stable occupancy despite ongoing anthropogenic pressures. Conversely, large carnivores such as tiger, clouded leopard, dholes, and bears (Asiatic black bear and Malayan sun bear) showed shifts toward a more southerly distribution than indicated by interview results. This is consistent with evidence that prey depletion and human disturbance constrain large carnivores across Southeast Asia, leading to range contraction into the most intact forest blocks (Wolf & Ripple 2016; Pliosungnoen, 2023). Several species did not exhibit Core habitat (≥50% suitability) in any LoU (e.g., Northern pig-tailed macaque, Common long-tailed macaque, and Leopard) highlighting their vulnerability to land-use change and forest edge exposure. For primates, fragmentation sensitivity and hunting are the primary threats in Tanintharyi (Roos et al., 2014).

The differential patterns between the 2016 interviews and habitat modeling results may also reflect methodological differences. Local ecological knowledge improves detection of cryptic species but can overestimate distributions due to spatial recall bias whereas, habitat models better depict current environmental suitability and pressures, particularly when integrating disturbance factors (Phillips et al., 2006).

From a conservation planning perspective, Thetkalkwet and Heinze represent irreplaceable multi-species strongholds, consistent with regional conservation prioritizations along the Tanintharyi mountain belt. Therefore, protection and enforcement efforts should be focused primarily in key habitats in the south while simultaneously implementing habitat restoration and corridor strengthening in central and northern LoUs. Sustaining connectivity will be essential for wide-ranging carnivores and elephants, which require landscape-scale mobility to maintain viable populations (Hilty et al., 2020; Merenlender et al., 2022).

8. Conclusion and Recommendations

This study represents the first multi-species habitat suitability assessment conducted in the Tanintharyi Nature Reserve (TNR), Myanmar, using MaxEnt modeling to evaluate the ecological and environmental drivers of 19 key mammal species. The findings highlight significant variations in habitat suitability, overlap, and the relative influence of environmental and anthropogenic factors, providing valuable insight into the ecological dynamics of the reserve. The research revealed that water availability, precipitation, and elevation are key determinants of herbivore distributions, while prey distribution and human footprint were dominant factors influencing carnivore and omnivore species. Herbivores generally exhibited broader suitable habitats compared to carnivores, reflecting the former’s dependency on stable vegetation and water resources.

Thetkalkwet and Heinze LoUs emerged as critical multi-species strongholds that support high habitat suitability for several mammal species, particularly wide-ranging carnivores and large herbivores. Protecting riparian corridors and perennial water sources is critical for sustaining elephants, tapirs, and other water-dependent species. Prey protection must be prioritized to maintain viable carnivore populations, particularly for tigers and clouded leopards. The strong negative effects of human footprint on leopard

and dhole underscore the urgency of mitigating human-wildlife conflict and preventing further habitat encroachment. The guild-level differences in habitat overlap suggest that TNR should adopt a dual conservation strategy: protecting core habitats for specialists while maintaining landscape connectivity to accommodate wide-ranging generalists. Establishing ecological corridors linking LoUs identified in this study may enhance connectivity, reduce fragmentation, and strengthen resilience against anthropogenic pressures.

Therefore, the following conservation actions are recommended for evidence-based conservation planning across the Tanintharyi landscape:

(a) Strengthen protection and law enforcement in Thetkalkwet and Heinze LoUs to safeguard the most critical habitats.

(b) Enhance ecological connectivity between southern and central LoUs through habitat restoration and forest corridor management.

(c) Implement long-term monitoring programs integrating camera traps and remote sensing to evaluate species responses to ongoing land-use changes.

(d) Promote community engagement programs to mitigate anthropogenic threats, especially hunting and agricultural expansion.

(e) Integrate MaxEnt-based outputs into spatial planning and adaptive management strategies for the Tanintharyi Nature Reserve.

9. Consevation Implications

The results demonstrate the conservation importance of Tanintharyi Nature Reserve as one of Myanmar's last refuges for Sundaic lowland forest fauna. Species with restricted habitats, such as the Malayan tapir and tiger, face heightened vulnerability due to fragmentation and human pressures. Therefore, maintaining landscape connectivity is vital to ensure genetic flow and population viability. The identification of key LoUs offers a spatially explicit framework for prioritizing conservation investment and management actions.

Integrating these findings into national conservation strategies and regional land-use planning will be crucial for achieving Myanmar's biodiversity targets under the

National Biodiversity Strategy and Action Plan (NBSAP). Furthermore, the spatially explicit results provide a decision-support tool for optimizing resource allocation and strengthening inter-agency coordination between the Forest Department, conservation NGOs, and local communities.

10. References

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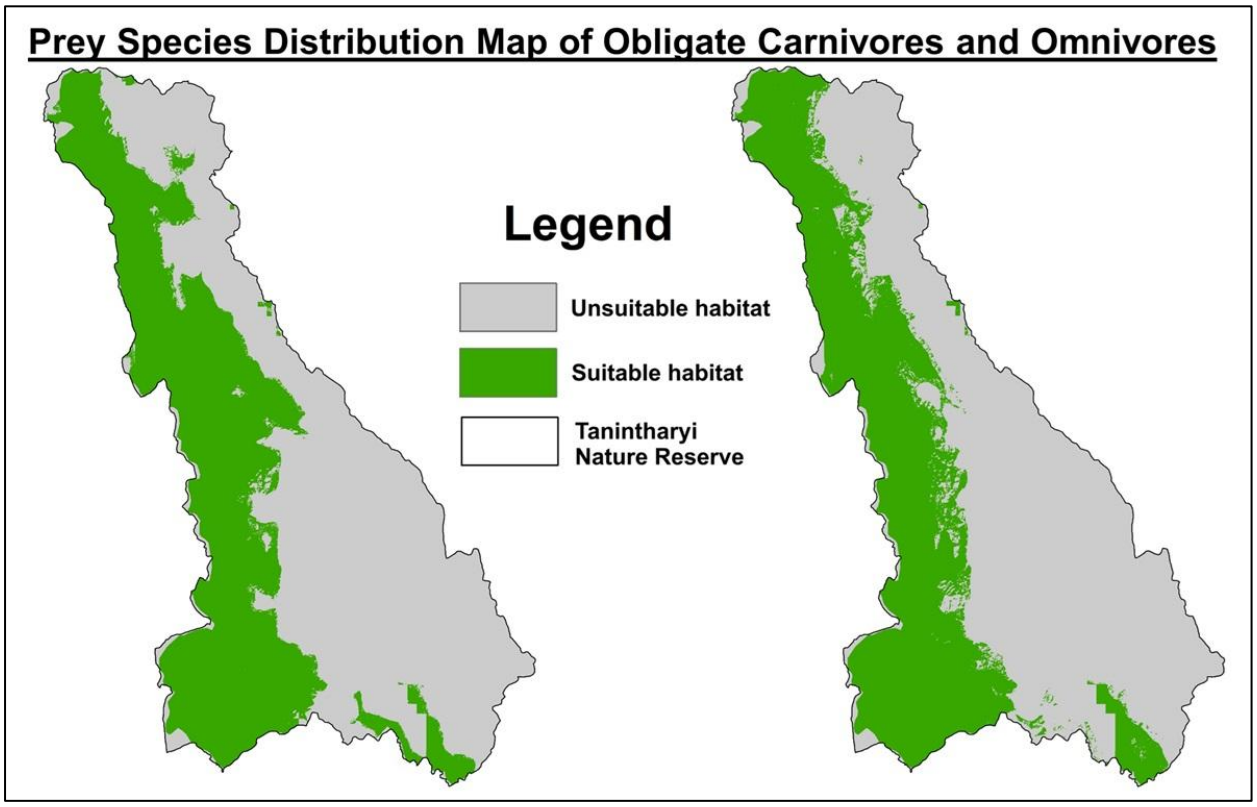
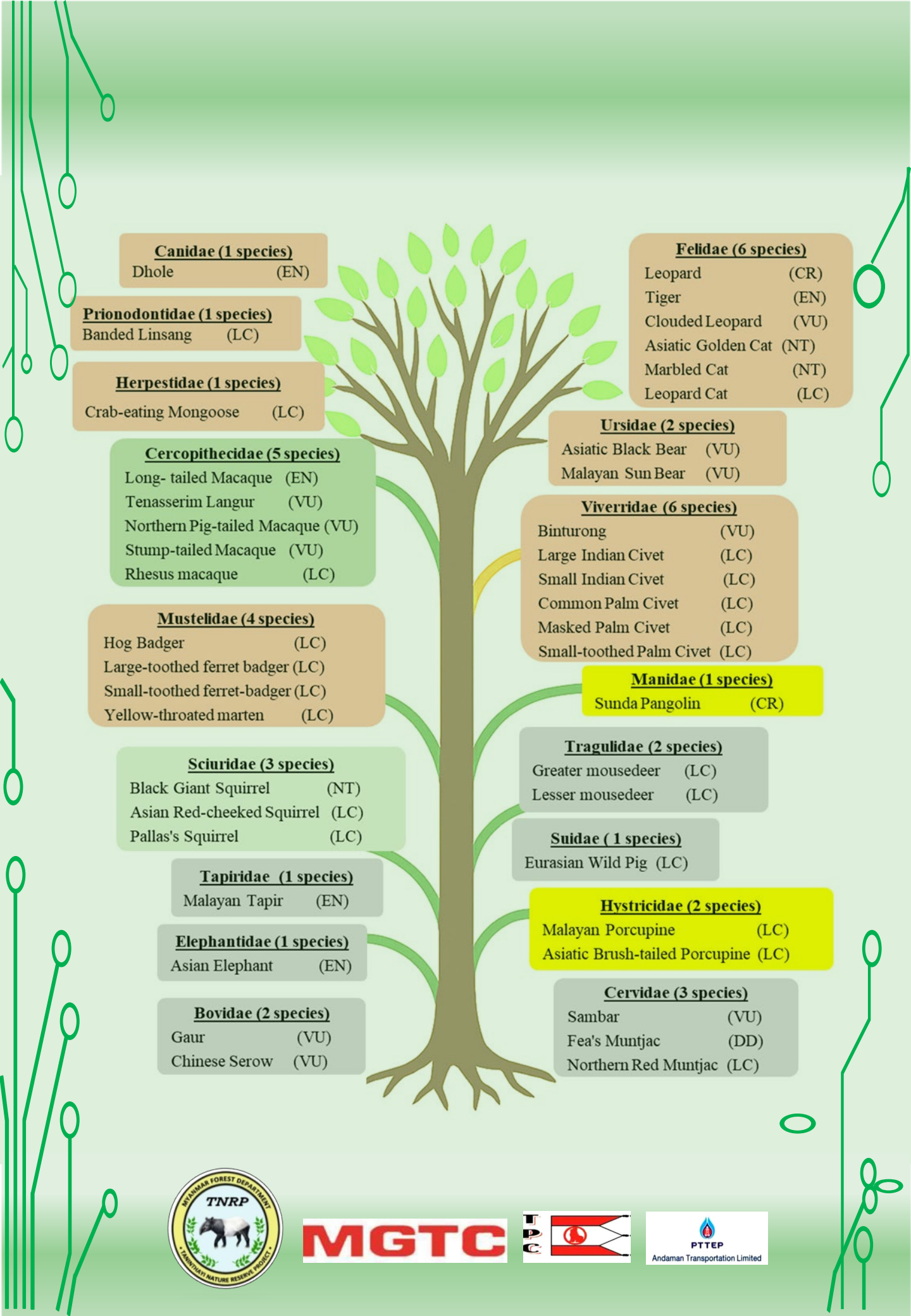
Appendix



Appendix Figure 1. Predicted habitat suitability maps of prey species for obligate carnivores and omnivores species in Tanintharyi Nature Reserve, Myanmar.


Canidae (1 species)
Dhole (EN)
Prionodontidae (1 species)
Banded Linsang (LC)
Herpestidae (1 species)
Crab-eating Mongoose (LC)
Cercopithecidae (5 species)
Long- tailed Macaque (EN)
Tenasserim Langur (VU)
Northern Pig-tailed Macaque (VU)
Stump-tailed Macaque (VU)
Rhesus macaque (LC)
Mustelidae (4 species)
Hog Badger (LC)
Large-toothed ferret badger (LC)
Small-toothed ferret-badger (LC)
Yellow-throated marten (LC)
Sciuridae (3 species)
Black Giant Squirrel (NT)
Asian Red-cheeked Squirrel (LC)
Pallas's Squirrel (LC)
Tapiridae (1 species)
Malayan Tapir (EN)
Elephantidae (1 species)
Asian Elephant (EN)
Bovidae (2 species)
Gaur (VU)
Chinese Serow (VU)
Felidae (6 species)
Leopard (CR)
Tiger (EN)
Clouded Leopard (VU)
Asiatic Golden Cat (NT)
Marbled Cat (NT)
Leopard Cat (LC)
Ursidae (2 species)
Asiatic Black Bear (VU)
Malayan Sun Bear (VU)
Viverridae (6 species)
Binturong (VU)
Large Indian Civet (LC)
Small Indian Civet (LC)
Common Palm Civet (LC)
Masked Palm Civet (LC)
Small-toothed Palm Civet (LC)
Manidae (1 species)
Sunda Pangolin (CR)
Tragulidae (2 species)
Greater mousedeer (LC)
Lesser mousedeer (LC)
Suidae (1 species)
Eurasian Wild Pig (LC)
Hystricidae (2 species)
Malayan Porcupine (LC)
Asiatic Brush-tailed Porcupine (LC)
Cervidae (3 species)
Sambar (VU)
Fea's Muntjac (DD)
Northern Red Muntjac (LC)
MYANMAR FOREST DEPARTMENT
TNRP
TANINTHARYI NATURE RESERVE PROJECT
MGTC
TPC
PTTEP
Andaman Transportation Limited