Habitat Suitability Modeling for Tiger (*Panthera tigris*) in the Hukaung Valley Tiger Reserve, Northern Myanmar

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Göttingen, 2012

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A dissertation to obtain the degree

"Doctor of Philosophy" (Ph.D.)

at the Faculty of Forest Science and Forest Ecology of

Georg-August-Universität Göttingen

by

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Born in Dawei, Myanmar

Göttingen, im September 2012

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Date of oral examination: September 5, 2012

This book is dedicated to:

- My parents and parents-in-law
- My teachers
- My only brother who unfortunately passed away 13 years ago
- My three elder sisters and brothers-in-law
- My beloved husband

ACKNOWLEDGEMENTS

Firstly, I feel indebted to the Forest Department, Ministry of Environmental Conservation and Forestry of Union of Myanmar for being admitted to apply for this PhD study. I am also deeply indebted to DAAD-Deutscher Akademischer Austausch Dienst (German Academic Exchange Service) for financial support for my study.

I express my heartfelt gratitude to my professor Dr. Christoph Kleinn, director of the chair of Forest Inventory and Remote Sensing, for accepting me to study under his direction and for his valuable suggestion. Particular thanks go to Dr. Axel Buschmann who gave me the main guidelines for conceptual framework development and technical realization as well as ceaseless help throughout my study. I have no words to express my thanks to both of them.

I also deeply thank to Prof. Dr. Niko Balkenhol, professor of Wildlife Management to take a role of a co-referee and reviewed the draft and guided me in completing my thesis. Special thanks also go to the Prof. Dr. Dirk Hölscher (director of the chair of Tropical Silviculture and Forest Ecology) who takes a responsibility as an examiner. And I am grateful to Prof. Dr. Ralph Mitloehner for advising me to get a chance of this study and his kind encouragement throughout this study. I also thank my friend Henning Aberle (PhD candidate) who kindly provided advice in GIS and all my colleagues from Chair of Forest Inventory and Remote Sensing who were always ready to help me.

I would next like to extend my sincere gratitude to Wildlife Conservation Society (Myanmar Programme) for providing me GIS data sources. Special thanks are also according to Nature and Wildlife Conservation Division (NWCD), Park Warden and the staff of the Hukaung Wildlife Office, Tanai Township for their essential assistance during my field work and data collection in Hukaung Valley Tiger Reserve. And my thanks also go to my friends and my country mates for their moral support while I lived in Germany.

I deeply extend my deepest thanks to my beloved parents as well as my respectful parents-in-law, my three sisters, my brother-in-laws, my sister-in-laws and my lovely niece who gave me love, prayer and encouragement to accomplish this study. Finally, it is impossible without love, understanding, tolerance and patience of my husband, U Moe Aung (Staff Officer, Planning and Statistics Division, Forest Department) who have always encouraged me to complete this study successfully.

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List of Abbreviations and Acronyms

ASEAN-	Association of South-East Asian Nations
CBNRM-	Community Based Natural Resource Management
CI-	Conservation International
CITES-	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DEM-	Digital Elevation Model
EGVs-	Ecogeographical Variables
ENFA-	Ecological Niche Factor Analysis
FAO-	Food and Agriculture Organization
FRA-	Forest Resource Assessment
GAM-	Generalized Additive Model
GEF-	Global Environmental Facility
GLM-	Generalized Linear Model
GloVis-	Global Visualization Viewer
GIS-	Geographic Information System
GOs-	Governmental Organizations
GPS-	Global Positioning System
GTF-	Global Tiger Forum
GTI-	Global Tiger Initiative
HSM-	Habitat Suitability Modeling
HVTR-	Hukaung Valley Tiger Reserve
INGOs-	International Non Governmental Organizations
IUCN-	International Union for Conservation of Nature and Natural Resources
MCE-	Multi Criteria Evaluation
MFD-	Myanmar Forest Department
NCEA-	National Commission for Environmental Affairs
NGOs-	Non Governmental Organizations
NWCD-	Nature and Wildlife Conservation Division
NTAP-	National Tiger Action Plan
PAS-	Protected Area System
RS-	Remote Sensing
SI-	Smithsonian Institution
TRAFFIC-	Trade Records Analysis of Flora and Fauna in Commerce
USA-	United States of America
USGS-	United States Geological Survey
WCS-	Wildlife Conservation Society
WWF-	World Wildlife Fund

1 INTRODUCTION

1.1 General Background and Problem Statement

Biodiversity depletion over the past two decades has increased awareness of the conservation of endangered species and their habitats. The conservation and management of biodiversity is closely linked to the need of habitat quality estimation and prognosis of wildlife spatial distribution. Numerous international and national agreements have supported the conservation strategies of tiger by enhancing their natural habitat conservation. Scientists have been exploring the most appropriate ways to measure habitat selection of fauna and flora under a large range of areas to assess important habitat features. Identification of the suitable habitat areas for wildlife by reducing the human interferences in those areas is an effective wildlife conservation method. Wildlife habitat planners need to collect detailed information regarding with the populations and spatial distribution of species to formulate management plans (Singh *et al.*, 2009). Habitat suitability mapping for wildlife is currently gaining interest in wildlife conservation and ecosystem management to tackle the problem of habitat competition between human activities and wildlife. To define habitat suitability of large areas, multivariate models are applied in combination with remote sensing (RS) and geographic information system (GIS). RS is an invaluable source of information and GIS is an excellent tool for creating land cover and habitat factor maps required for habitat modeling. RS has been used to produce land cover maps since the 1970s (Bradley & Fleishman, 2008).

A large area of continuous habitat (3,000-15,000 km^2) is the main requirement for the tiger (*Panthera tigris*) for long-term survival (Lynam, 2003). They prefer extensive areas with adequate prey densities to maintain viable populations. Among the important habitat requirements of the tiger are a sufficient supply of large prey, enough cover for stalking and access to water (Sunquist and Sunquist, 2002). Due to the various pressures, exposed to the species for several decades, its present range is much smaller than its historical one. The fragmentation and loss of natural wildlife habitats are crucial issues in the long term conservation of the tiger and its prey species. The conservation of the tiger and its prey species is linked to the conservation of their natural habitats. But the lack of reliable and up to date information related to their habitat suitability mapping is the main obstacle for future conservation of this species. The tiger’s landscape has been converted dramatically into other land use types over the last century. Furthermore, these changes have continued and are ceaseless, increasing concern for the future existence of the tiger (Sunquist *et al.*, 1999). Myanmar, one of the 25 biodiversity hotspots of the world (Myers *et al*., 2000), is also one of 13 countries in Asia where there are still tiger populations today. It has a large proportion of the tiger habitat range and so it is a priority country in terms of conservation of the tiger and its prey species.

Table 1: Forest cover changes in Myanmar in sq. miles (FAO, FRA, 2010).

Year	Closed forest	Open forest	Other wood land	Others	Total Land	% of total
1990	28114.7	9755.8	10405.8	19381.6	67657.9	56%
2000	25841.0	9426.9	11435.3	20954.7	67657.9	52%
2005	25516.6	9970.5	11950.0	21741.3	67657.9	52%
2010	15391.0	16413.0	22722.0	13131.9	67657.9	47%

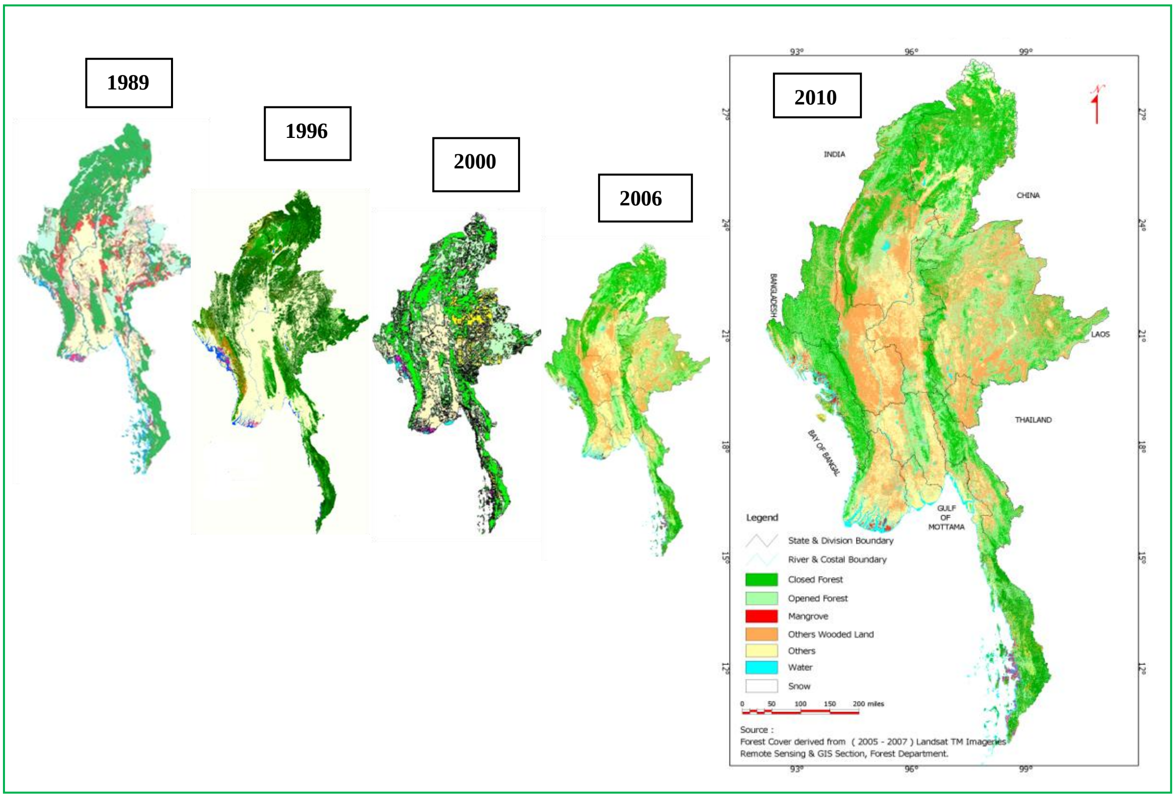


Figure 1: Forest cover changes in Myanmar between 1989 and 2010 (FAO, FRA 2010)

In contrast to its neighbors, Myanmar has large area of forest cover of 47% of the total country area, providing a unique opportunity to conserve natural habitats. From the far northern snow-capped mountains to the southern Mergui Archipelagos, Myanmar is a shelter for a wide range of biodiversity and wildlife. Various parts of the country are a home for a mix of species from north Asia, south Asia and Southeast Asia. In mainland Southeast Asia or Indochina Peninsular, Myanmar is the largest country by geographical area (Travel World, 2012). Although rich in biodiversity, loss of biodiversity due primarily to socioeconomic pressure is also unavoidable in a developing country like Myanmar. The forest cover decreased due to human pressure and forest cover changes between 1990 and 2010, as shown in Table 1 and Figure 1. The consequence is that the country's biodiversity is becoming under increasing pressure.

The general trend of wild animal population appears to be negative compared with their relative abundance over the past 20 or 30 years (NCEA Myanmar, 2009). Due to habitat destruction, the population of the tiger is not large enough to reproduce a viable population. The downward trend is evident with large mammals such as tigers and elephants because of degradation and fragmentation of their home ranges by human activities.

Practical conservation of Myanmar tigers still remains undeveloped due to poaching and illegal hunting. Lack of mainstreaming biodiversity conservation into land-use practices, and a missing clear-cut national land-use policy and its implementation, are further important major factors that threaten the tiger habitat. Weakness of awareness and obedience of national legislations is leading to illegal activities, which causes wildlife populations to become endangered. Myanmar Forest Department (MFD) and Wildlife Conservation Society (WCS) have implemented projects to improve the status of wildlife and its habitat. But there is still limited reliable information on the tiger's habitat. Hence, habitat suitability modeling (HSM) is urgently needed as one input for the development and implementation of conservation and protection measures for tigers and their habitat sooner than later before they disappear.

1.2 The Relevance of Habitat Suitability Modeling for Biodiversity Conservation

Biodiversity is the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are a part of; this includes diversity within species, between species and of ecosystems. Biodiversity is the foundation of life on Earth. It is crucial for the functioning of ecosystems which provide us with products and services without which we couldn't live (IUCN, 2012).

Habitat is more than just vegetation, so brief descriptions of the geology and topography, soils, weather and climate, cultural features, history of the land and general indices of site quality are useful for describing habitats (Krausman, 2002). Carrying capacity refers to the maximum density of animals that a habitat can support (Krebs, 1994; Morris and Davidson, 2000). One main assumption made in this context is that the measure of habitat suitability is directly proportional to the carrying capacity.

Today, every country all over the world has to deal with both biodiversity degradation and conservation. When attempting to conserve biodiversity, rare, threatened and endangered species are often used as focal species or as special-interest species. Habitat is a very important component of biodiversity. Preserving habitats is essential to preserving biodiversity. Hence, biodiversity and species habitats go hand in hand. Thinking about conservation of any species is difficult without considering its habitat. The basic objectives of most biodiversity conservation are to maintain habitats for species as they exist in undisturbed ecosystems or provide habitats where they have been depleted. So, habitat is essential for healthy biological diversity and species' populations. Habitats that are most frequently used by species have to be identified to help in defining environmental features (abiotic and biotic) required to maintain a favorable conservation status (Canadas *et al*., 2005).

Effective conservation of wild species populations requires an understanding of the relationship between populations and their habitats. Scientists have developed multivariate explicit models for conservation ecology, covering many aspects of population viability analysis, biogeography, conservation biology, climate change research, biodiversity loss risk assessment, landscape management for endangered species, ecosystem restoration and habitat or species management. Habitat Suitability Models (HSM) of plants and animals have also come into vague consideration for biodiversity conservation.

In the last two decades, HSM have been extensively used as a tool to predict the range of habitat variability that will sustain a particular species, and through that prediction the potential impact of habitat alteration (Turner *et al*., 1995; Kliskey *et al*., 1999; Marzluff *et* *al*., 2002). It is one of the most frequently used methods based on the concept of habitat and carrying capacity (Schamberger and O'Neil, 1986). In the meantime, HSM are gaining interest as tools to predict the geographic distribution of species (Boyce and McDonald, 1999; Guisan and Zimmermann, 2000; Manly *et al.*, 2002; Pearce and Boyce, 2006).

To build HSM, the comprehensive knowledge of potential factors affecting habitat choice of species coupled with their geographical distribution is critical to produce meaningful mapping outputs. As a tool for wildlife managers, the application of HSM becomes more essential day by day not only for effective recovery of wildlife but for predicting potential areas of high habitat quality for a given species to be conserved.

1.3 Protection Status of Tigers and Biodiversity in Myanmar

Myanmar is trying to conserve the habitats of wildlife species through the establishment of protected areas. Protected Areas (PAs) play a crucial role in conserving the country's biodiversity and species richness. Information on species' habitat preferences is very important for the long term functioning of PAs. PA's system management is not new to Myanmar and dates back to the period of Myanmar Kings through the establishment of a game sanctuary in the Mandalay Royal City in the 19th century. The trend of PAs is given in Fig. 2. A total of 35 protected areas cover 5.56% of the country, while eight forested areas have been proposed for gazettement as protected areas (see Figure 3).

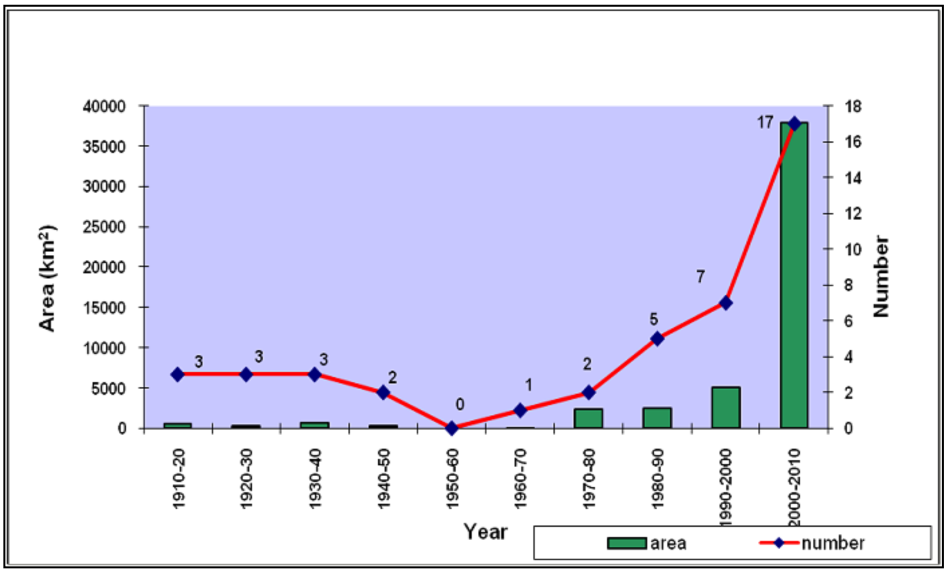


Figure 2: Establishment of Protected Area Systems in Myanmar (MFD, 2008).

Under the guidance of the government, laws related to biodiversity conservation are promulgated by all biodiversity related sectors (see Table 2). To protect the wild fauna and flora, the Protection of Wildlife, and Wild Plants and Conservation of Natural Areas Law was enacted in 1994. The law specifies the establishment scientific reserves, national parks, marine parks, nature reserves, wildlife sanctuaries, national heritage sites, etc., in order to conserve wildlife, wild plants, scenic beauties and natural areas of geo-physical or cultural significance for prosperity (NCEA, Myanmar, 2009).

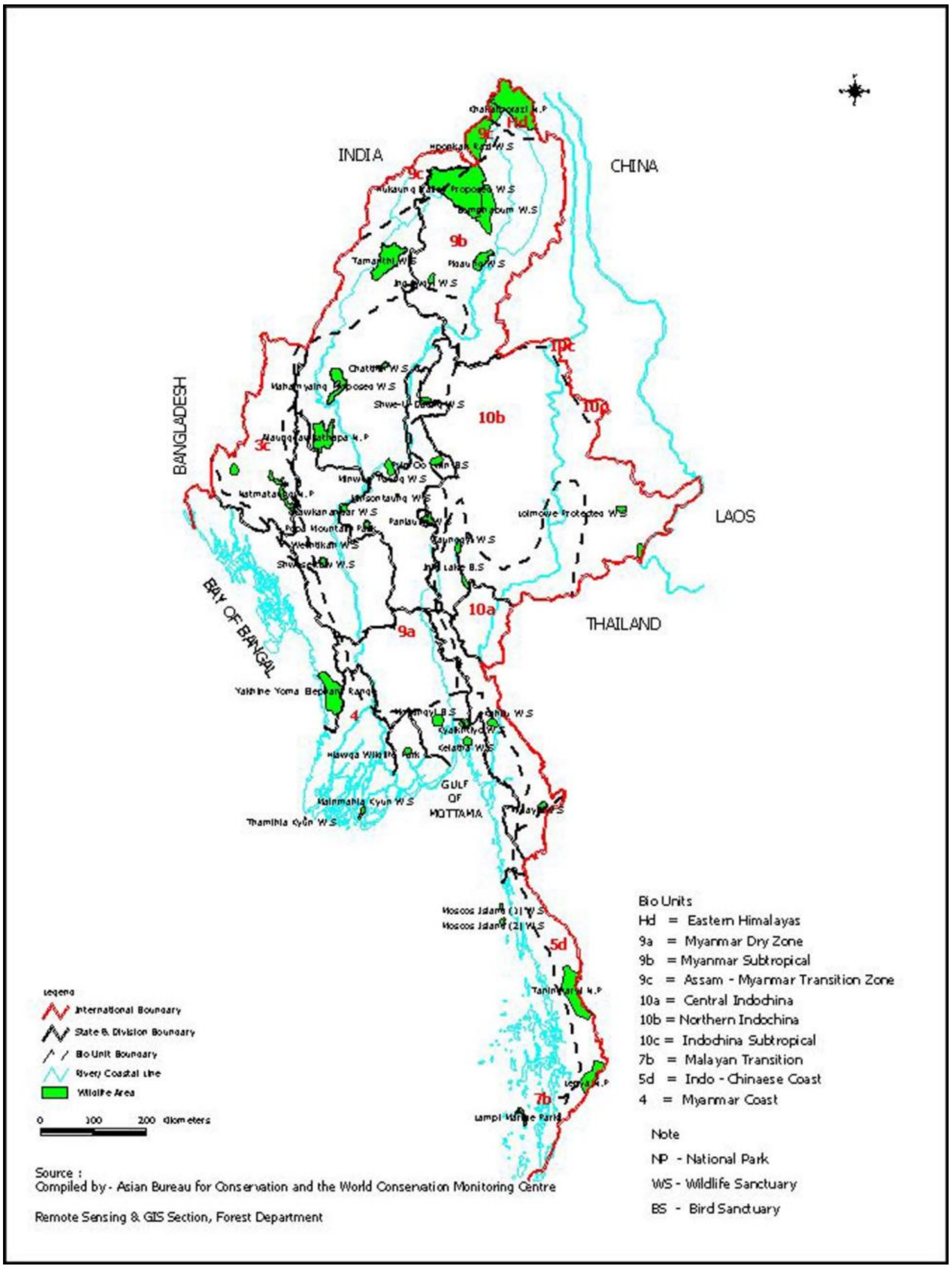


Figure 3: Map showing national biodiversity conservation areas of Myanmar (Provided by FD, Myanmar, 2010)

In Myanmar, the tiger (*Panthera tigris*) is legally protected under the Protection of Wildlife, Wild Plants and Conservation of Natural Areas Law (1994) and, as such, it should not be killed or captured. The penalty for killing, hunting and illegal possession of the tiger and its parts can be a sentence of up to 7 years imprisonment or 50000 kyats fine, or both. The use and export of the tiger or its parts is banned under the provisions of the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES). Myanmar acceded to CITES in 1997 (see Table 3). The habitat of the tiger is legally protected under the Forest Law (1992). Myanmar is now promoting international cooperation to conserve and manage biodiversity. Table 3 shows agreements and commitments under international conventions.

Table 2: Laws relating to biodiversity conservation in Myanmar (NCEA, Myanmar, 2009).

Law/Act	**Year**	**Major Aims**
Wild Elephant Protection Act	1879	To safeguard the population of wild elephants vital in timber operations
Forest Act	1902	Responsible for wildlife management empowered to Forest Management
Wildlife Protection Act	1936	Provides designation of protected areas and protected species
Forest Law	1992	Can designate Reserved Forests for environmental and biodiversity conservation
Protection of Wildlife, Wild Plant and Conservation of Natural Areas Law	1994	To implement policies on protecting wild flora and fauna and natural areas, to fulfill international convention obligations, to enable research to be conducted
Forest Rules	1994	Provide articles to protect biodiversity
Forest Policy	1995	Provide basic fundamentals to preserve biodiversity
Protection of Wildlife and Wild Plant and Conservation of Natural Areas Rules	2002	To conserve natural ecosystems and protect wildlife species

Table 3: Myanmar's commitment to biodiversity-related agreements/conventions.

No.	International Agreements/Conventions	Status
1.	Plant Protection Agreement for Southeast Asia and the Pacific Region	1959 (R)
2.	United Nations Framework Convention on Climate Change	1994 (R)
3.	Convention on Biological Diversity	1994 (R)
4.	Convention on Conservation of World's Cultural Heritage	1994 (R)
5.	International Tropical Timber Agreement, Geneva (1994)	1996 (R)
6.	United Nations Convention on the Law of the Sea	1996 (R)
7.	Convention on International Trade in Endangered Species of Wild Fauna and Flora	1997 (A)
8.	United Nations Conventions to Combat Desertification	1997 (A)
9.	ASEAN Agreement on the Conservation of Nature and Natural Resources, 1985	1997 (S)
10.	ASEAN Agreement on Transboundary Haze and Pollution	2003 (R)
11.	ASEAN Declaration on Heritage Parks and Reserves	2003 (S)
12.	Convention on Wetlands of International Importance especially as Waterfowl , 1971, as amended in 1982 and 1987	2004 (A)
13.	International Treaty on Plant Genetic Resources for Food and Agriculture, 2001	2004 (R)
14.	Agreement on the Establishment of the ASEAN Centre for Biodiversity	2005 (S)
15.	Cartegena Protocol on Biosafety	2008 (R)

R-Ratified; S-Signed; A-Assessed/Accepted/Adhered (NCEA, Myanmar, 2009)

1.4 Important Issues Facing in the Hukaung Valley Tiger Reserve

The Hukaung Valley Tiger Reserve (HVTR) was first identified as a high priority site for Myanmar when the Myanmar Forest Department and the Wildlife Conservation Society, including local and international scientists, explored the area in 1999. Their survey identified tigers, Asian elephants, clouded leopards and other rare large mammal species. HVTR is the world's largest tiger reserve, situated in northern Myanmar, adjoining the 'Namdapha Tiger Reserve' in India. Thus it is still one of the tiger refuges for a transboundary population where the Indochina sub-species *cobetti* meets with the Bengal tiger subspecies *tigris*. This area is also possessing significant conservation values in terms of globally harbouring threatened species and habitats, and distinct cultures.

Access to the area has been essentially facilitated by the construction of the Ledo Road in late colonial times at the end of World War II. It is connected to the town of Ledo in north-east India and with Myintkyina in Kachin State and was completed in 1945. People have been attracted by available forest lands. Human settlements and subsequent land cultivation have basically been spreading out along the historical Ledo Road. Ledo Road crosses through the area of the Reserve, from north-west to south-east, thus dividing the reserve into two major parts (see in Figure 4).

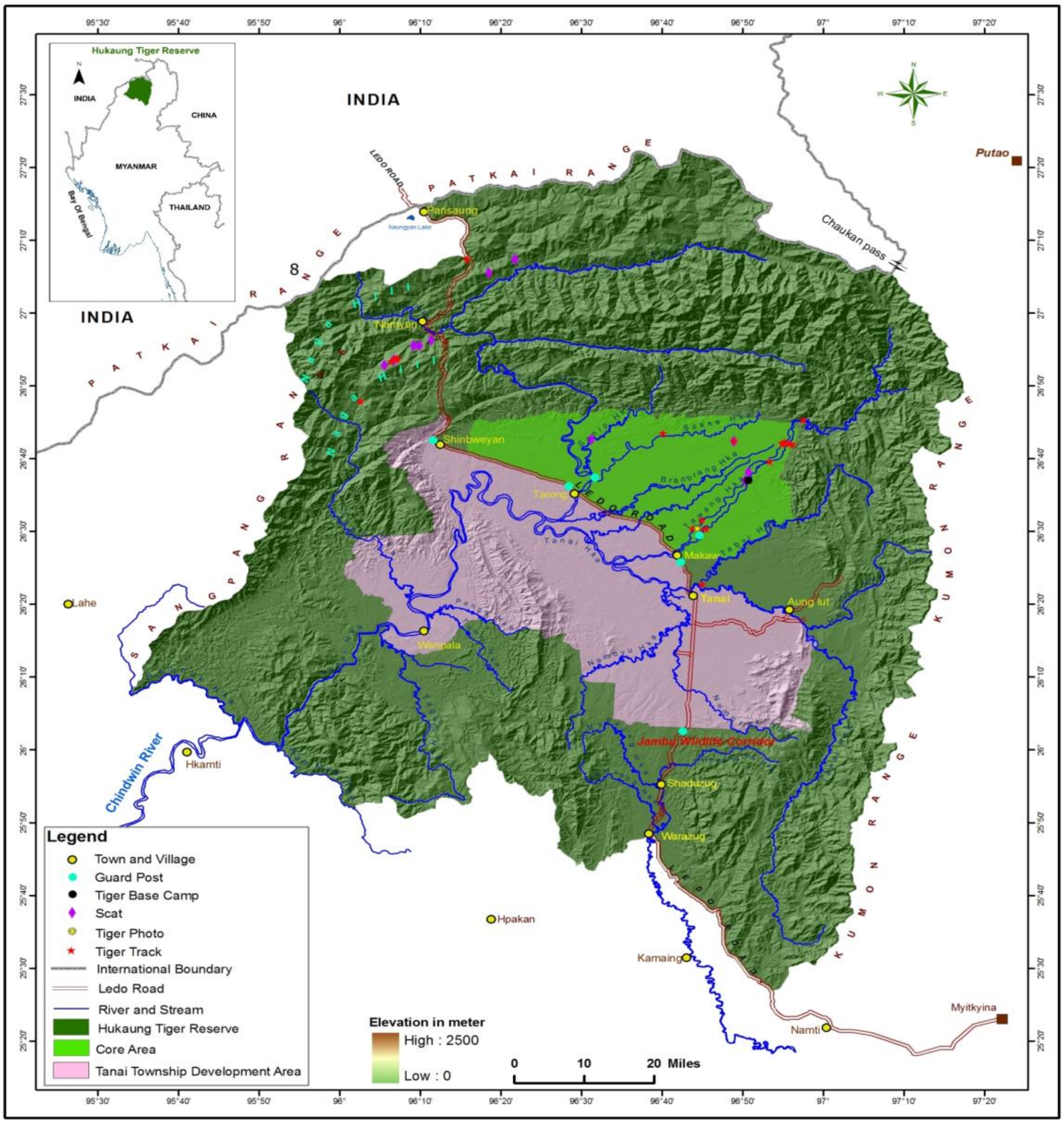


Figure 4: Hukaung Valley Tiger Reserve (provided by WCS Myanmar Programme, 2011)

Uncontrolled human intrusion, together with the expansion of current land use practices, is threatening the HVTR and its conservation goals. As human settlement close to the forest has increased, wildlife habitats and their natural environments have been disturbed. Five major ethnic groups have been using the natural resources of Hukaung Valley for many years: the Kachin, the Naga in the northern part of the valley along the border with India, the Lisu people from the north, the Shan and the Myanmar people from the central dry zone of the country. These groups are engaging in forest-based commercial activities such as permanent and shifting cultivation, rattan production, fishing, timber extraction and gold-mining as well. These activities are also critical for the Reserve's flagship species, the tiger, and its prey, especially since they are always accompanied by illegal hunting.

Tigers seem to be confined to the remote areas now, especially the mountainous northern part. In spite of some hints during interviews, no recent findings have been confirmed in the south and south-west part, which tigers may already evade. Tigers evidently avoid crossing the Ledo Road barrier with its villages and adjacent fields except in the north-west of the Reserve where higher mountains provide better shelter.

Myanmar culture and livelihoods are based on the use of forest resources for subsistence and as a source of cash income. Non-timber forest products (NTFPs) still remain crucial because there is no immediate alternative to NTFP use in the rural economy (Latt, 2011). People in the Reserve directly or indirectly depend on the forest for their daily requirements of timber, fuel wood and for other livelihood. Demand for fuel wood is also exceedingly high. People living on the reserve, without access to gas resources and electricity for energy, depend heavily upon the use of wood for cooking and other domestic uses. Thus, collection of forest products occurs everywhere on the Reserve, often contributing substantially to the villagers' incomes. Most of the forest destruction on the Reserve is caused by shifting cultivation. It comprises all forms of agriculture in which the forests are cleared, usually by fire and cultivated for shorter periods; then the lands are left fallow (Kywe, 2006).

Hukaung Valley is also abundant in mineral resources, mainly gold, where it is accessible for mining in the area. Mining causes water runoff and sedimentation. Consequently, it reduces the quality of water in rivers and streams. Due to the gold-mining activities, the rates of timber extraction and fuel wood consumption have increased. The mining areas have also fragmented forest habitats and favored the dominance of economically useless areas such as bush land and grassland. Moreover, the soil is severely depleted, and it will be difficult to rehabilitate.

Altogether, the tiger population is most likely declining due to a combination of habitat loss, human interferences and loss of prey. Human presence in the HVTR is frequent and abundant, disturbing wildlife by fishing, illegal hunting and trapping of wild animals. Forests and grasslands have been lost, degraded and fragmented, and ungulate populations have declined precipitously, both in abundance and distribution ranges. Nowadays, tiger’s numbers have also declined, and almost all remaining subpopulations are now small and isolated. Hence, it has become critical for the survival of the species to develop landscapes, where possible to become more suitable habitat.

The tiger (*Panthera tigris*) is extremely endangered in Myanmar. Based on historical records, the tigers were widely distributed almost all over the country. Currently, the tiger surveys showed that there is no evidence of tigers except for the 4 sites such as the Hukaung Valley Tiger Reserve, Htamanthi Wildlife Sanctuary, Myinmoletkat Area and Taninthayi Nature Reserve (Lynam, 2003).

Since 1996, human intrusion into the HVTR has increased. Almost all places except the core zone are confronted with the issue of human impacts due to various land use practices. Today’s challenge of the HVTR is to fulfil the demands of a growing population and the management of natural resources. Although local subsistence of natural resources did not affect the reserve, the impact of commercial extraction caused declines of habitat quality and diversity of wildlife species in Hukaung. The concern of the reserve managers is increasing so as to control and manage the area in a proper way.

Many conservation activities are now conducted to protect the reserve, including zoning village development, extension service for local communities and people participation in the conservation programme. Effective conservation of the tiger requires exploring the suitable habitat type. Identification of potential habitats becomes critical for effective recovery of tiger numbers. For this reason, this study was formalized with the research questions as shown in the next section.

1.5 Research Questions

With the aim to contribute to the effective conservation of suitable habitat in the core zone, the following research questions were of interest:

Research question 1: Has there been any previous analysis which is suitable for building a habitat suitability model for the tiger in case of small number of presence points/missing absence data? Has a selected model been proven to be a suitable approach for tiger habitat suitability analysis?

Indicators: Review habitat suitability models based on only presence data.

Research question 2: What are the habitat preferences of tigers regarding vegetation features? Are there any habitats which are favoured by tigers in the study area?

Indicators: Tiger presence in/close to vegetation types (closed evergreen forest, open evergreen open forest, Kaing grass, bamboo, rattan, etc.)

Research question 3: Are there any ecological relationships between topographical variables and the tiger's habitat preferences?

Indicators: Tiger presence at different slopes, elevations and aspects (flat/ north/ east/ south/ west).

Research question 4: Have there been any human disturbances to the tiger's habitat in the core zone?

Indicators: Amount/ distance of different human interferences to tiger presence in the core zone (dynamite fishing, settlement, gold-mining, logging, etc.)

1.6 Objectives

Based on the research questions, the overall objective of this study is:

- to improve the basic understanding of tiger ecology for providing the basic information for the successful implementation of a management plan for HVTR in order to concentrate the critical areas and minimize threats
- to support tiger population's conservation

Technical objectives are:

- to assess the impacts on habitat disturbances caused by human interferences
- to draw a tiger habitat suitability map in order to identify the potential tiger areas of high habitat quality (i.e. prognosis of tiger spatial distribution).

2 LITERATURE REVIEW

2.1 Tiger Ecology

Ernst Haeckel (1866) defined ecology as the comprehensive science of the relationship of an organism to the environment. The understanding of tiger ecology is necessary for modeling habitat suitability. Knowledge of the ecology and habitat preferences of species of interest is crucial for identifying their key habitats. George Schaller (1967) pioneered the scientific studies of tigers and then the Smithsonian Tiger Ecology Project made further scientific advances in 1973-1985 by means of radio telemetry studies in Nepal. Karanth *et al.* (1990), Chundawat *et al*. (1999) and Seidensticker *et al.* (1999) started long-term ecological studies of tigers by employing radio telemetry, camera trapping, diet analyses and prey density estimation. Their studies provided a basis for examining the habitat selection of the tiger and its prey species.

2.1.1 Species description

The tiger, *Panthera tigris*, is a member of the Felidae family, one of the largest of the 'big cats' in the genus Panthera. They are a recognisable and emotive animal, often requiring large contiguous areas for long term survival. It is one of the most threatened species on the earth. The tiger is admired, feared and respected by humans for its beauty, grace, strength, ruthlessness and other natural and supernatural attributes (Tamang, 1993). Because of the uniqueness of the tiger, it is often considered a species well worth conserving.

Figure 5: Camera trap pictures of tigers in HVTR (Provided by WCS, Myanmar Programm).

There are nine different subspecies of the tiger. Three subspecies were extinct in the latter part of the 20th century, including the Bali (*P. t. balica*), Javan (*P. t. sondaica*) and Caspian tigers (*P. t. virgata*). The remaining subspeciesare the Siberian (*P. t. altaica*), South China (*P. t. amoyensis*), Sumatran (*P. t. sumatrae*), Indochinese (*P. t. corbetti*), Malayan (*P. t. jacksoni*) and Bengal tigers (*P. t. tigris*). Until 2004, the Malayan tiger (*Panthera tigris jacksoni*) which is found in the southern part of the Malay Peninsula, was not considered a subspecies. After a study by Luo *et al.* (2004) from the Laboratory of Genomic Diversity Study, the Malayan tiger species was recognized as distinct sub-species (IUCN, 2011).

The colour of the Malyan tiger is distinct: reddish-orange to yellow fur with vertical dark stripes which can easily be distinguished from other large mammals. The characteristic stripe pattern is unique and covers one side of the tiger's body to the other (Macdonald, 2001). In the forest habitat, the tigers camouflage themselves by their dark stripes of the tawny fur. The total length of adults can generally reach up to 10 feet; females are smaller. They have heavily-muscled forelimbs and large, curved and retractable claws (Mazák, 1981). Their weight ranges from 250 -300 kilograms (Hewett, 1938; Baudy, 1968). Their body size, fur colour and markings may vary with different subspecies. In the wild, extreme colour varieties are occur occasionally (Macdonald, 2001). A tiger of whitish-grey with chocolate stripes is the result of gene combination (Maruska 1987; Macdonald, 2001). Karanth (2006) observed that the tigers mate year-round in tropical areas. Moreover, the breeding activity of radio-collared tigers depends on the climatic conditions of the regions. The gestation period is rather short, 103 days (Sunquist *et al.*, 1999). Tigresses select a secluded spot under fallen logs, in rocky crevices or in thick cover to take a birth (Karanth, 2006). The litter size is normally three (Sunquist *et al.*, 1999). But, according to a study by Karanth (2006), they can give birth to up to 7 cubs. Their inter-birth interval is short (7-8months) in the case when entire litters were lost (Sunquist *et al.*, 1999). Only daughters prefer to stay near the mothers and sons move away at larger distances from their mothers. During the first month of birth, tigresses were never more than 1.4 km away from their cubs (David Smith in Karanth, 2006, p.60). After two months, the cubs began accompanying their mother. The male tigers do not take part in raising their offspring.Tigers become independent at the age of 2 years and can establish their residency (WWF, 2012). The male attains sexually maturity at the age of 3-4 years, whereas the female becomes sexually mature at about 3 years (Sankhala, 1967; Smith, 1984; Smith and McDougal, 1991; Christie and Walter, 2000; Sunquist and Sunquist, 2002: Kerley *et al.*, 2003).

Tigers seem to use the aspect of mountain slopes to avoid extreme weather conditions. Tigers are not adaptable to direct sun for long periods in hot weather. In their habitat, they prefer to be active during the cooler parts of the day. They tend to lie under dense shade during the times of extremely hot weather. Wherever undisturbed rivers or pools are available, they lie down in the water to cool off during the hottest parts of the day (Karanth, 2006, p.43).

The tigers establish their own territory independently. To demarcate their territory as well as to attract the opposite sex, the tigers spray urine on the ground or a branch or leaves or bark of a tree to leave a particular scent. As an array of communication methods, tigers apply a variety of vocalization, scent deposits or other signs (Karanth, 2006). When in contact with this scent by other tigers, they know that the territory is occupied (Corbett Fun Resort, 2012). The range of male tigers can coexist with that of several females. They find the prospective mates by loud moaning calls. Their roar carries as far as 5 km through the forest in the silence of the night. Such long-distance roars are used by female tigers in estrus and males searching for them. Females also use roars when they try to stay in touch with their cubs (Karanth, 2006).

2.1.2 Hunting behaviour

Tigers use fairly thick cover to hunt (Karanth, 2006). They usually hunt larger prey which can provide enough food for many days. In undisturbed areas, tigers can hunt at any time of the day or night. But, in many parts of the tigers' ranges, they are more nocturnal in response to human interferences (Baker, 2006). A study by Karanth (2006) showed that the radio-tracked tigers in Nagarahole were more nocturnal. They were most active between 6:00pm and 9:00am: they preferred to rest between 9:00am and 3:00pm. Based on studies of prey selection in Nagarhole, India, Karanth and Sunquist(1995) suggested that the structure of the prey community is an indicator for determining ecological densities of tigers and other predators. A function of prey densities appears to determine densities of tigers (Schaller, 1967; Sunquist, 1981; Seidensticker and McDougal, 1993; Karanth and

Sunquist, 1995; Karanth and Nichols, 1998; Chundawat *et al*., 1999; Sunquist *et al.*, 1999). A male tiger needs to kill 40-50 large prey animals per year just to survive whereas a tigress needs as many as 60-70 to raise cubs (Karanth, 2001). Tigers can see better and detect activities under lower light levels than their ungulates prey. Increasing darkness helps tigers to more effectively attack their prey suddenly (Karanth, 2006).

Tigers are well adapted for hunting animals of medium and large size. They mainly feed on mammals such as wild boar (*Sus scrofa*), gaur (*Bos gurus*), Sambar deer (*Cervus unicolar*), barking deer (*Muntiacus muntjak*) and buffalo. Ungulates-hoofed animals are the essential prey for them. At one time, a tiger can eat as much meat as 88 pounds (WWF, 2012). It has also been shown that they prey on crocodiles, small elephants, fish, rhino calves, birds, reptiles and even their competitors: leopards (WWF, 2012). The tiger is able to drag something 5 times more than its own weight (Tigers in Crisis, 2012).

In a study by Sunquist and Sunquist (2002), the tiger was found to make a stealthy approach using every available tree, rock or bush as cover to get as close as possible to its target. For hunting, tigers use their sight and hearing rather than smell. They stalk and hunt their prey alone; once a prey is close, a tiger attacks from the side and then kills its prey by biting the neck or the back of the head. After eating its fill, they use grass or debris to cover the remaining meals for the next days (WWF, 2012).

2.1.3 Dispersal capabilities

Tigers are territorial and generally solitary animals, requiring large contiguous areas of habitat that support their prey requirements (Mazák, 1965). While hunting, they move around within their usual home ranges. The tiger's movement is usually related to hunting or to social communication with other tigers. In the forest, tigers use trails, roads and game paths to move quickly between areas where they try to hunt. Especially through fragmented landscapes, little is known about how tigers move (Karanth, 2006). Tigers' movements depend mainly on food availability. They travel 7-32 km per night (Schaller, 1967; Sunquist, 1981). But, according to a study by Karanth (2006), the range of the daily movement of radio-tracked tigers in Chitwan and Nigarahole was found to be 2 to 11km. In Chitwan , Smith (1993) found that the average dispersal distance for males was 33-65 km, while that of females was slightly less than 10- 33km, meaning that tigers can disperse over great distances. Karanth's study in 2006 also found that tigers usually look for their prey in areas intensively used by prey. Most of the tiger habitats were at sites with abundance of forage and water where the ungulate prey favoured to concentrate. Smith (1993) also found that tigers did not disperse across open cultivated areas of 10 to 20 km wide, but they travelled through degraded forest habitat. They are capable of swimming and they can cross water bodies as wide as 5 miles (8km) (Karanth, 2006). Prior to Smith's study, there was evidence to suggest that a sub-adult male from Chitwan travelled 150 km to the Trijuga-Koshi-Tappu in eastern Nepal (Sunquist, 1981). Griffiths (1996) estimated tigresses' home range sizes to be 137-190 km^2 in the mountainous terrain above 600m in Gunung Leuser National Park, Sumatra (Sunquist *et al.,* 1999). The probability of their encountering prey is the most important factor to determine dispersal capability of a hunting tiger (Karanth, 2006). For instance, the size of female home ranges in productive South Asian forests and grasslands is 10-20 km^2, whereas in the Russian Far East it is as large as 200-400 km^2 (Sunquist, 1981; Karanth and Sunquist, 2000).

2.1.4 Natural habitat of tiger

Animals normally are found in areas where their needs for food and shelter are met (Cody, 1985). The required habitats are not the same for each species. Some animals have different seasonal or annual habitat needs, whereas others require different habitats for feeding and nesting during the same season. Because of their adaptability, tigers occupy a wide variety or biomes and habitats: from tropical evergreen and deciduous forests of southern Asia to the coniferous, scrub oak and birch woodlands of Siberia. They also inhabit in the mangrove swamps of the Sundarbans, dry thorn forests of north-western India and the tall grass jungles at the foot of the Himalayas (Wildlife Sanctuary, 2012). In recent years, however, the tiger has been found as high as 4,000 m altitude in the Himalayas (BBC News, 2010). Prater (1971) reported the tracks of a tiger in winter snow at 3, 000 m.a.s.l in the Himalayas. Prater (1971) identifies three factors that are essential for the tiger:

1) The proximity of large animals upon which they can prey,

2) Ample shade for resting, and

3) Water

They tolerate temperatures as low as -31°F (-35°C) in the Russian Far East as well as the heat of 118°F (48°C) in northern India. Tigers are found in the dry forests where the annual rainfall is a mere 24 inches (600mm), and in tropical evergreen forests where it may reach 395 inches (10,000mm). In South and Southeast Asia, tigers are found in tropical wet evergreen forests, semi-evergreen forests, subtropical forests, peat forests, moist deciduous forests, dry deciduous forests and dry thorn forests. They also occur in the grasslands and mangrove forests of major river deltas (Karanth, 2006). The Bengal tiger, or Royal Bengal tiger, roams a wide range of habitats including high altitudes, tropical and subtropical rainforests, mangroves and grasslands. It is primarily found in parts of India, Nepal, Bhutan, Bangladesh and Myanmar.

A study by Johnsingh (1983) also found that tigers prefer dense vegetation (more than 70%). The findings of Karanth and Sunquist (2000) showed that tigers attacked their prey more in slightly dense cover than leopards. They also found that 55% of tigers' attacks were in moist deciduous forest which was less open. Khan (2004) also examined tigers' preferences of habitat of good cover. A collaborative project conducted by WWF, WCS, Northeast Normal University, KORA, and the University of Montana in 2010 showed that tigers preferred a larger pure deciduous forest more frequently. A study by Johnsingh (1983) was doubted by Khan *et al.* (2007). They studied tigers' preferences based on signs of the tiger in the Sundarban East Wildlife Sancturay in Bangladesh and most of the sightings of tigers were in open habitats such as sea beaches, grasslands and transitional areas rather than in mangrove woodlands. Furthermore, a study by Reza *et al*. (2001) also found that just 6% of tiger tracks were located in the forest of Katka-Kochikhali area (20 km^2). The findings of Karanth and Sunquist (2000) also showed that tigers rarely attacked potential dangerous prey like adult guar in dense cover.

The tiger was historically widespread in Myanmar (see Figure 6). It is the pride of the fauna in Myanmar. In general, the Indochinese or Corbett's Tiger (*Panthera tigris corbetti*) can be found in Myanmar. This species is even found in China, Laos, Thailand, Cambodia and Vietnam. Records show that a number of Bengal tigers are also found in Myanmar. These two subspecies are very similar but the Corbetti's tiger is smaller and darker in appearance. The Bengal tiger *Panthera tigris tigris* inhabitats India which is very near to the HVTR, indicating that tigers in the HVTR also belong to this subspecies. According to the subspecies distribution map created by Wentzel *et.al*. (1999), the tigers in the HVTR are truly a trans-boundary population, not only between the two countries, India and Myanmar, but also between the two subspecies. HVTR may be home to these two subspecies, but this question has never been until now even though the two subspecies are considerably different in anatomy, size and fur pattern (Thant, 2006).

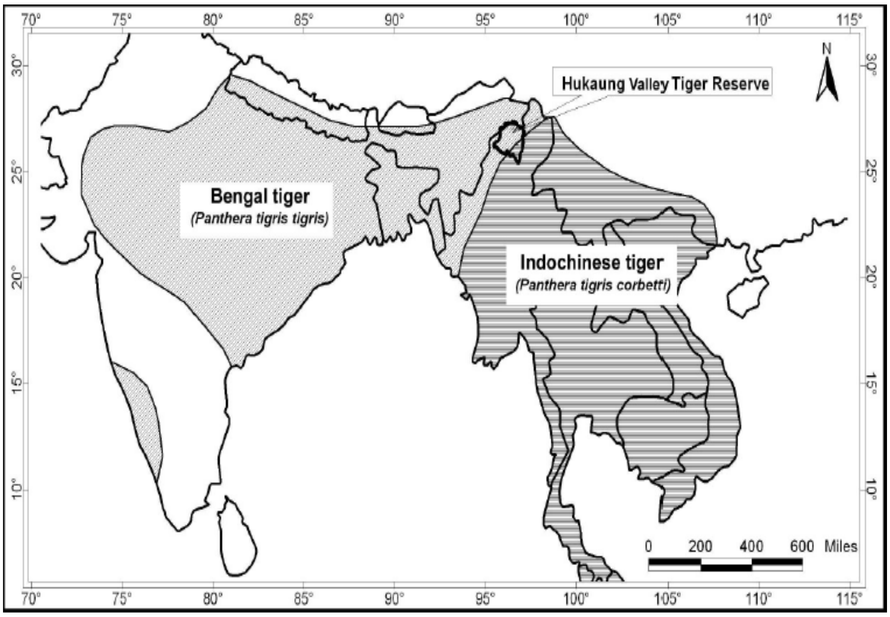


Figure 6: Distribution of tiger subspecies in India and South-East Asia (Thant, 2006)

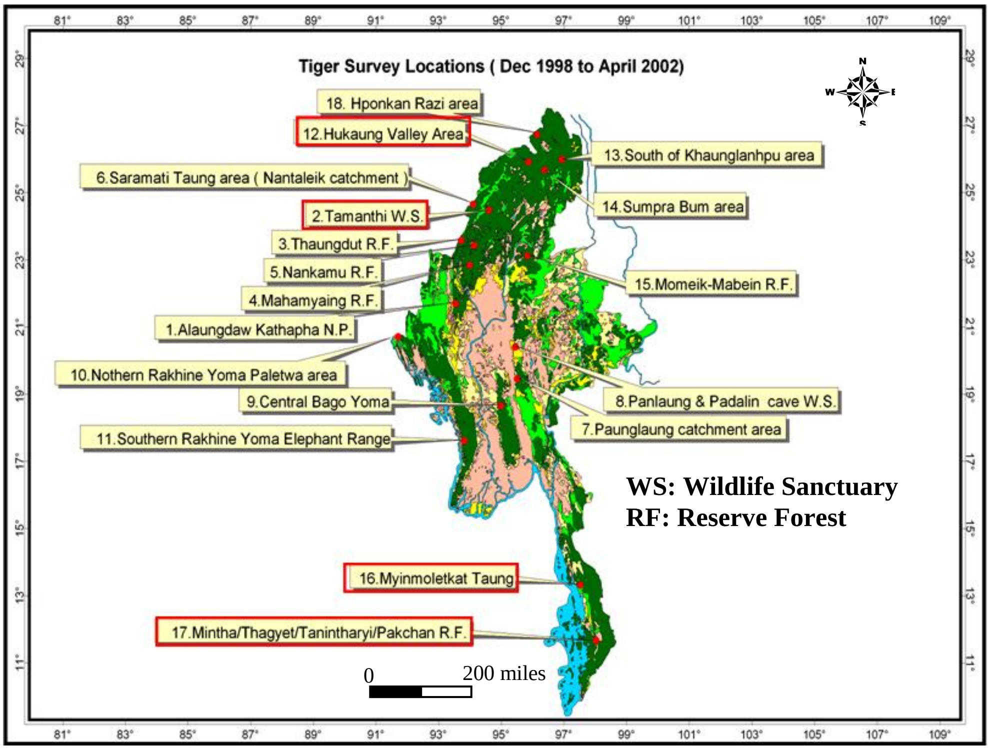


Figure 7: 17 Direct Tiger Survey Sites in Myanmar from December 1998 to April 2002. Tiger's presence was confirmed by camera trapping at 4 sites, indicated by red boxes (NWCD, MFD, 2011).

Direct surveys for tigers were conducted at 17 sites in Myanmar. These sites were selected based on the places of the historical tiger range and the most recent available evidence from the reports of foresters and local people. Out of these 17 sites, the tiger's presence was confirmed by camera trapping at 4 sites such as the Hukaung Valley Tiger Reserve, Htamanthi Wildlife Sanctuary, Myinmoletkat Area and Taninthayi Nature Reserve (see Figure 7).

2.1.5 The decline of the tiger population

The tiger population is declining across its range (Seidensticker *et al*., 1999) due to the various reasons caused by high human populations, habitat loss, increasing demand for traditional medicines, poaching and illegal hunting. Although there are no accurate estimates of the world tiger population, numbers are thought to have fallen down from perhaps 100, 000 in the 20th century to the current estimate of possibly as few as 3, 200 individuals (IUCN, 2012). Scientists argue that the situation of the current number of 3,200 is critical, that the tiger will be facing with extinction in the wild by the time of the next Year of the Tiger in 2022. Law enforcement and monitoring of markets combined with improved domestic legislation could contribute to a reduction in the trade of tiger parts (Lynam, 2003).

According to Myanmar government and Wildlife Conservation Society estimates, tiger numbers in Myanmar have sharply declined from 3000 tigers in 1980-81 to 1000 in 1996. The reason is human encroachment on the tigers' habitats, conversion of forests to commercial plantations and illegal hunting for medicinal or consumption purposes. The current estimation of total tiger populations is around about 150 for all of Myanmar; 50- 80 in Hukaung, 30 in Htamanthi Wildlife Sanctuary and 50 in Tanintharyi Nature Reserve (Myanmar Times, 2011). But, the figure of the IUCN's global tiger population estimation of Myanmar shows only 35-70 (GTI, 2009) (see Figure 10).

2.1.6 Habitat loss, degradation and fragmentation

Tiger (*Panthera tigris*) were once found across Asia from eastern Turkey to the Russian Far East and south to the Indonesian archipelago (Nowell and Jackson, 1996). Myanmar is one of fourteen countries in mainland Asia where tigers persist today (Lynam, 2003) (see Figure 8). Over the past 100 years, tigers have disappeared from Southwest and central

Asia, from two Indonesian islands (Java and Bali) and from large areas of southeast and eastern Asia. A decade ago, tigers have lost 93% of their geographic range (Sanderson *et al*., 2006, Walston *et al.*, 2010) and they are currently found in thirteen Asian range states: Myanmar, China, India, Indonesia, Laos PDR, Malaysia, Bangladesh, Bhutan, Cambodia, Nepal, Russia, Thailand and Vietnam. Although there has been no recent confirmed evidence, they may still persist in North Korea (IUCN, 2011).

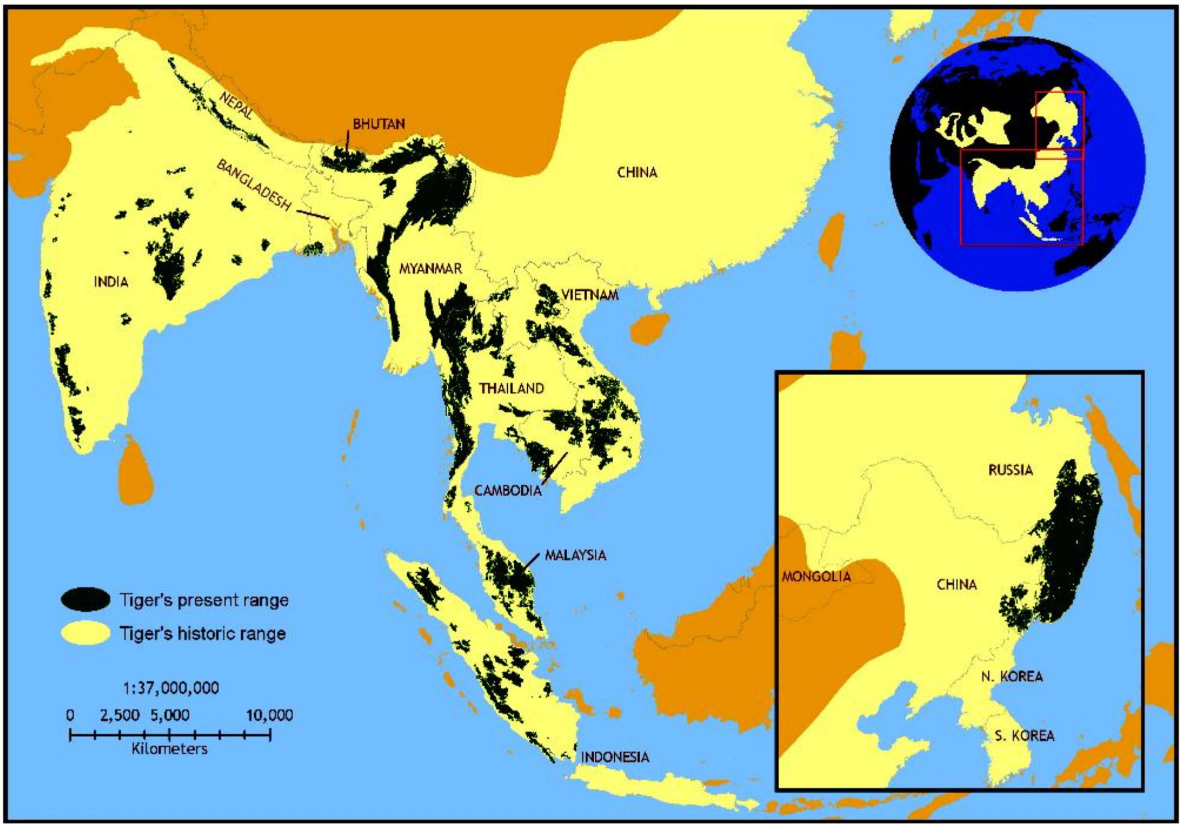


Figure 8: Map, current tiger range in relation to historic distribution (from Save the Tiger Fund, 2012).

The lack of prey bases and anthropogenic disturbances does not permit the existence of wild tigers in most of the forested areas (Karanth, 2001). The approximation of tiger habitats is now 40% less than that estimated in 1995 throughout India, Indochina and Southeast Asia (Sanderson *et al.*, 2010). Habitat loss and poaching are key threats to the survival of the tiger. Ecosystems around tigers are being eroded by human activities. Understanding and encouraging landscape patterns where tigers can persist are the challenges that one faces in preventing the tiger from extinction (Seidensticker *et al.*, 1999).

2.1.7 Human intervention

Negative ways: The influence of human activities such as direct persecution of tiger, infrastructure development, and conversion of tiger habitat to other land use changes and hunting of prey species play key roles for tiger distribution. Until the 1930s, tiger numbers declined due to sport hunting. Trophy hunting persisted as a major threat to tigers up to the early 1970s. Due to encroachment accelerated by human population growth, logging and conversion of forests to commercial plantations such as oil palm and pulpwood, the greatest threat to habitat took place between the 1940s and the late 1980s. In China, several thousand tigers were killed off under the progress and development programme during the Cultural Revolution. In the 1990s, hundreds of tigers were exterminated for traditional medicines, especially in China, Taiwan, and South Korea, but also in Japan and Southeast Asia. Their parts are exported illegally to ethnic Asian communities all over the world, including those in Australasia, Europe, the USA and Canada (WWF, 2002). The illegal demand from China for traditional medicine is still a strong reason for the poaching pressure on tiger populations over its range of distribution.

In Myanmar, the status of the tiger population was also uncertain for many years due to illegal hunting and poaching for the trade of traditional Chinese medicine, hunting of tiger prey species and forest clearance to meet human needs. The hunting of tigers has a long history in Myanmar (Pollok and Thom, 1900) because they were traditionally considered as pests. The government provided licenses and rewards for killing them until 1931. This induced depopulation on a large scale through sport hunting. Most of the tiger habitat areas are located in tribal areas and they were mostly hunted by various tribal groups with the purpose of supplying trade (Rabinowitz *et al.*, 1995), leading to their extirpation in some areas (Rabinowitz, 1998). The sale of tiger products was banned by CITES since 1975. The size of the trade is difficult to measure. Between 1970 and 1993, East Asian countries imported at least 10, 000 kg of tiger bone which represents 500 - 1, 000 tigers (Hemley and Mills, 1999). Direct hunting of tigers drives the Myanmar tiger population to extinction (NTAP of Myanmar, 2003). By the early part of the 20th century thousands of tigers had been reported to have been killed in Myanmar (Lynam, 2003). According to a study by Thant (2006), less than one third of the supposed previous tiger population has survived on less than 25% of the HVTR’s area. Continued depletion at this speed would lead to the tiger’s extinction in the next 2 decades. The first reason for the disastrous tiger decline in the HVTR is illegal hunting/poaching of tigers for profits. Intensive illegal hunting of prey species is an additional threat to the few remaining tigers. Plans to conserve the species are still required due to the limited knowledge about where tigers live and how they are threatened in their habitats (Lynam, 2003). The question of "how to conserve wild tigers" needs to be urgently answered by the scientific community. Habitat and prey play important roles for the long- term survival of tigers in the wild. But it is still illegal to trade tiger parts that may lead to extinction. Tiger parts are still sold on the Chinese markets despite legal protection, prohibition of international trade, anti-poaching efforts and millions spent by NGOs and governments over most of its range (Lapointe *et al.*, 2007)

Positive ways: GOs and NGOs activities in the conservation of tigers: Tigers are a conservation dependent species. They require protection from killing, an adequate prey base and adequate habitat area (Sanderson *et al.,* 2006). Numerous international governmental organizations (GOs) and non-governmental organizations (NGOs) have supported conservation strategies to recover the tiger habitat and help to immediately begin the reverse of declining wild tiger populations (see Table 5). Globally, NGOs spent more than US $31 million in tiger conservation from 1998 to 2003 (Christie, 2006). The tiger is one of the priority species for the World Wildlife Fund (WWF), and it provides financial and technical support in most of the tiger range countries. The IUCN (International Union for Conservation of Nature) and the CITES (Convention on International Trade of Endangered Species of Wild Flora and Fauna) also support the conservation of tiger. The Global Tiger Initiative (GTI) was constituted in June 2008 by the World Bank, the Smithsonian Institution, GEF (Global Environmental Facility) and an alliance of governments and international organizations. The aim was to repopulate and recover the tiger's habitat towards sustainable population sizes. The GTF (Global Tiger Forum) is working with tiger range countries by using the convening power of the World Bank and is unionizing with international organizations such as WWF, WCS (Wildlife Conservation Society) and SI (Smithsonian Institution). GTI has started six themes to focus both on saving wild tigers and building foundations to sustain conservation efforts to other wild species, habitats, ecosystems and local people. These six themes are composed of wildlife enforcement and governance, capacity building, smart green infrastructure, demand management and consumer education, community incentives and innovative financing. The International Tiger Conservation Forum or The Tiger Summit was held in Russia on

November 21-24, 2010. Representatives from the 13 countries where tigers live today attended to this summit. The resulting commitment is based on:

- the establishment of new funding from governments to support tiger conservation programmes, and,
- the endorsement of 13 tiger range countries for the Global Tiger Recovery Programme by the next 5 years.

Figure 9: Twelve important landscapes for future tiger conservation (for the names see Table 4) (from WWF, Save Tigers Now, 2012).

WWF acted as the summit to encourage the world's political leaders for tiger conservation. The WWF also committed to spending US$50 million over the next 5 years on tiger conservation, and set the goal to increase this amount to US$85 million. The WWF seeks emergency measures to save the tiger, as well as a long-term foundation to secure the future of the tiger. WWF efforts are focused on:

- securing funds to prevent poaching in the most critical tiger landscapes
- securing political will and taking action to double wild tiger numbers by 2022
- protecting tiger habitats at an unprecedented scale, including clamping down hard on the illegal tiger trade (WWF, 2012). The 12 landscapes have been identified by the world's top

tiger expert. The orange coloured areas in figure 9 will be focused on as priority tiger conservation landscapes in future.

Table 4: 12 WWF Priority Tiger Landscapes (for map see Fig. 9) (WWF, Save Tigers Now, 2012).

No.	Name of Landscapes
1.	Amur-Heilong-China and Ruissa
2.	Terai Arc-India and Nepal
3.	Greater Manas-Bhutan and India
4.	Kaziranga-Karbi Anglong-India
5.	Satpuda-Maikal-India
6.	Sndarbans-Bangladesh and India
7.	Western Ghats-Nilgiris-India
8.	Dawna-Tennaserim-Myanmar and Thailand
9.	Forests of the Lower Mekong-Cambodia, Laos and Vietnam
10.	Banjaran Titiwangsa-Malaysia
11.	Central Sumatra-Indonesia
12.	Southern Sumatra-Indonesia

Table 5: Participants in the Tiger Conservation Programme (WWF, Save Tigers Now, 2012).

GOs	NGOs	
Bangladesh	Conservation International-CI	Wildlife Conservation Nepal
Bhutan	The Corbett Foundation	WCS
Cambodia	David Shepherd Wildlife	Wildlife Trust of India
China	FREELAND Foundation	World Association of Zoos and Aquariums
India	Global Tiger Patrol	World Bank
Indonesia	Humane Society International	WWF
Lao	International Fund for Animal Welfare	The Zoological Society of London
Malaysia	Save the Tiger Fund	ASEAN Wildlife Enforcement Network
Myanmar	Smithsonian Institution	Aaranyak
Nepal	Smithsonian's National Zoological Park	American College of Traditional Chinese Medicine
Russian	Species Survival Network	Animals Asia Foundation
Thailand	Tigris Foundation	Animal Welfare Institute
Vietnam	TRAFFIC	Association of Zoos and Aquariums
The above 13 countries where there are still tiger populations today.	21st Century Tiger	British and Irish Association of Zoos and Aquariums
	World Society for the Protection of Animals	Born Free
	WildAid	Council of Colleges of Acupuncture and Oriental Medicine
	Wildlife Alliance	Care for the Wild

2.1.8 Tiger conservation in Myanmar

In Myanmar, the Wildlife Conservation Society (WCS) has collaborated with the Myanmar Forest Department (MFD) in the Tiger Conservation Programme since 1994. However, no systematic efforts have been made so far to estimate the number of the Myanmar tiger populations. The Myanmar Forest Department formally proposed financial support to the WCS to promote and update the Tiger Conservation strategy in 1997. The Tiger Conservation Project started in 1998 with the goal of determining the status of the tiger populations all over the country. The conservation plan is being implemented by the MFD and WCS by reviewing and referring to the examples of successes and failures from other tiger range countries (Lynam *et al*., 2006). The following 9 elements were accepted to be implemented for the future conservation of Myanmar tiger populations:

"1". Suppress all killing of tigers and the illegal trade of tiger products

- amend the Protection of Wildlife and Natural Areas Law to be in line with implementation of CITES
- accelerate wildlife awareness training for local officials
- develop national wildlife enforcement and investigations units to suppress trade, wildlife crimes and habitat destruction.

"2". Reduce killing of tiger prey species and associated illegal trade

- deter wildlife offenders (conservation awareness lectures)
- upgrade the staff level, skilled labor and infrastructure
- upgrade the national protection status of large ungulates

"3". Improve forest management to stop the further loss of tiger habitat and restore degraded habitat

- reduce environmental damages by timber extraction methods
- ban hunting in forest harvest areas
- include forest harvest staff in conservation awareness training

"4". Improve forest management to reduce intrusion of people into tiger habitat and improve planning to avoid development in critical tiger areas

- close the mines close the wild meat market
- commence with vegetation rehabilitation programs in mined areas
- allow rights and privileges for local people for subsistence extraction of non-timber forest products except hunting

- avoid construction of man-made features in forest reserves (e.g. logging roads)

“5”. Establish protected areas, ecological corridors and priority management areas to protect wild tigers and their habitat

“6”. Improve international cooperation and establish trans-boundary protected areas to maintain connectivity of tiger habitats across international boundaries

“7”. Monitor the status of tiger and prey populations to assess the effectiveness of conservation efforts and provide guidance for improvement

“8”. Improve public awareness of the importance of tiger conservation to increase support from local people

“9”. Define roles and responsibilities of personal responsible for tiger conservation

Implementation of the above 9 elements is progressing in the three tiger range areas, namely Hukaung Valley, Tanintharyi Nature Reserve and Htamanthi Wildlife Sancturary. These areas are managed as tiger conservation landscapes by the MFD through designation as protected areas, law enforcement activities, capacity building and educational programmes, public awareness and cooperation research with relevant international and local organizations. Activities on tiger conservation are:

- Area protection through regular patrolling by field staff, police and local authorities
- Capacity building by recruiting and training more field rangers and staff in conservation, law enforcement and monitoring techniques in cooperation with international non-governmental organizations (INGOs)
- Raise awareness by environmental education through mini-talks, tiger drama and school children programmes at the villages, open dialogue at the national level on the importance of tiger conservation and exploration of opportunities to improve national policies which can support tiger conservation as well
- Community Based Natural Resource Management (CBNRM) through village use zone demarcation to get community participation in the reduction of illegal hunting as well as dynamite fishing
- Stakeholder relationship meetings which highlighting the role and responsibilities of local communities in tiger conservation

This study: habitat suitability analysis plays a potential role for establishing wildlife corridors and for identifying priority areas of high habitat quality for future protection of tigers and their habitats.

2.1.9 The wild tiger's status in the world

The tiger is listed as an endangered species (EN) by the U.S. Fish and Wildlife Service and the IUCN Red Book. It is an Appendix I species under CITES and completely protected in the National Legislation of Myanmar (Protection of Wildlife, Wild Plants and Conservation of Natural Areas Law, 1994). Figure 10 summarizes the national tiger population estimates from which also the IUCN's global population estimate was derived.

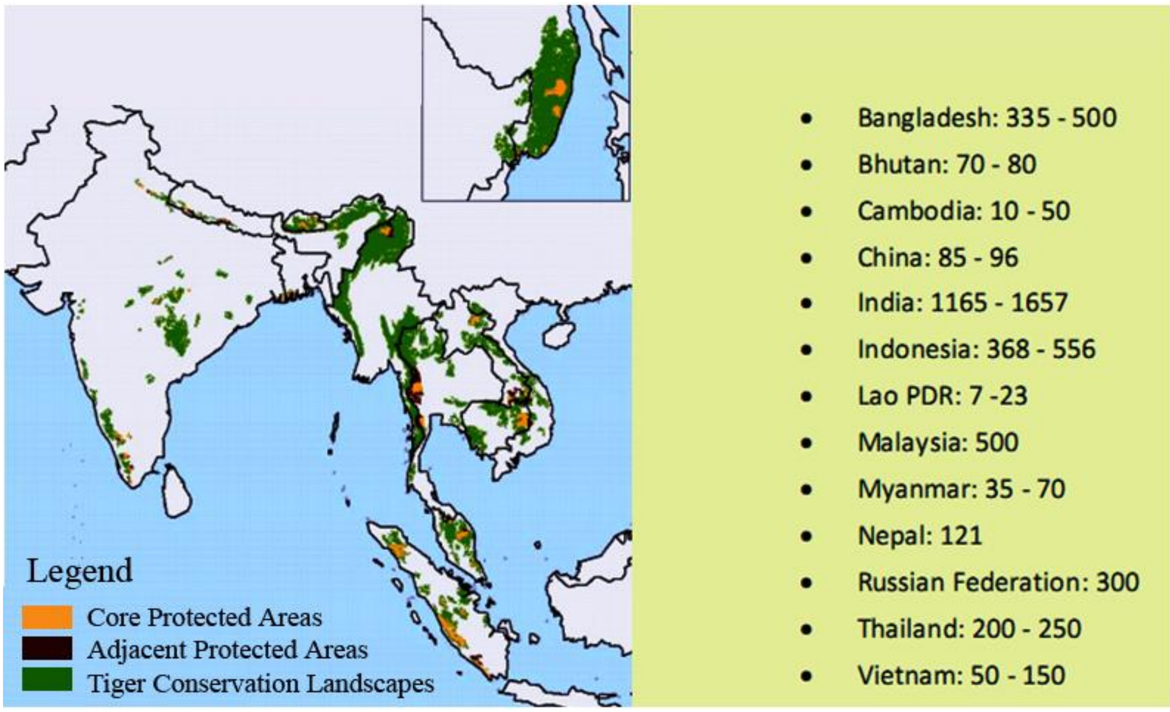


Figure 10: Tiger conservation landscapes and protected areas, showing estimates of national tiger numbers in tiger range countries (from GTI, 2009)

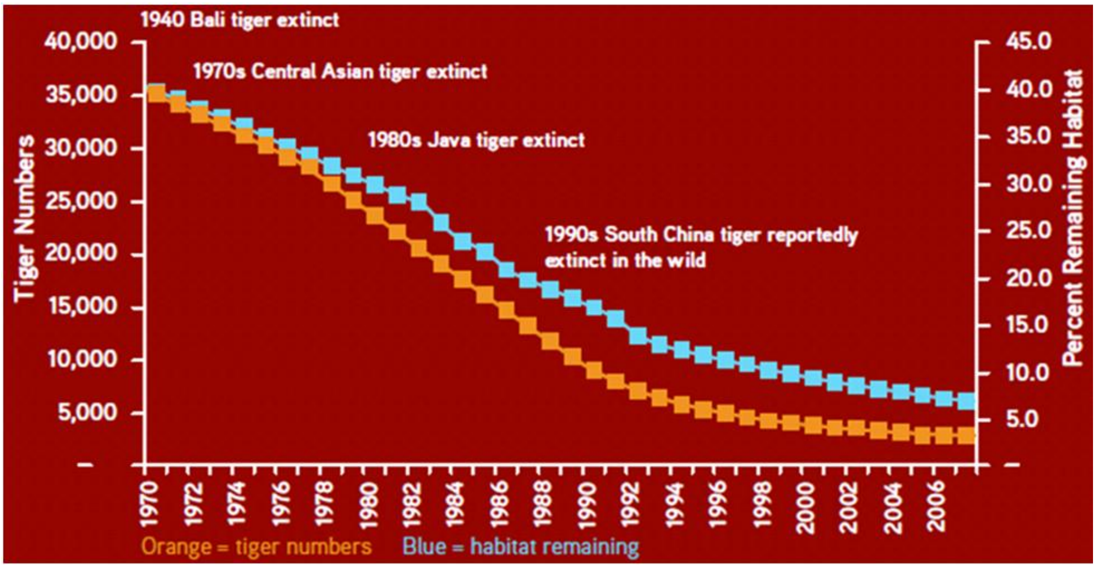


Figure 11: The trend of current tiger habitat and tiger population all over the world (Source: Wikramanazake et al., 2007).

2.2 Habitat Suitability Modeling (HSM)

Nowadays, HSM is gaining interest in conservation biology to assess the quality of habitat for a focal species within a study area. All animals can only live in an area where basic resources are present for them (Morrison *et al*., 2006). Habitat can be defined as an area which resources/conditions promote the existence of a species and allow the population to survive and reproduce (Morrison *et al*., 1998) and it may be characterized by a description of environmental features that are important for a species. It is a combination of food, water, shelter and space arranged to meet the needs of wildlife. A model means mode or measure which represents some part of the real world. Since the real world is unreachable by experimentation, researchers try to perform a simplification of reality in the computer or on the blackboard where it may be easily manipulated: this operation is called "modeling" (Morrison *et al*., 2006). A model can be conceptual, diagrammatic, mathematical or computational (Hall and Day, 1977). Habitat suitability is expressed by the quality of habitat from a species perspective based on a variety of resource attributes. It often quantifies a relative scale that ranges from 0 (unsuitable) to 1 (optimal habitat) (U.S. Fish and Wildlife Service, 1980; 1981). It also assumes that habitat is an important factor in deciding on the presence and relative abundance of the species (Farmer *et al.*, 1982).

A main purpose of habitat models is to define the relationship between biotic and abiotic factors and the species spatial distribution (Guisan *et al.*, 2000). The most important thing to build the habitat suitability model is to identify habitat preferences of the species from an ecogeographical point of view. HS models can then help with describing species-environment relationships and can help to derive a map of habitat quality. The important key for any habitat suitability model is the nature of the species data i.e., presence data, presence and absence data and abundance data (Eastman, 2006).

Figure 12 shows the habitat suitability modeling process. The independent data are the ecogeographical variables (EGVs) of soil, disturbances, and the potential of isolation whereas the species presence or presence-absence data form the response variable. All these variables constitute an input to the statistical habitat suitability model. The two major aims of a Habitat Suitability Model are explanation ("habitat factors ranking") and prognosis (habitat suitability map). For the explanation part, the habitat factors are ranked by their relevance for focal species habitat choice. The prognosis part provides an area-wide estimation of habitat suitability which is the same as the probability of occurrence. The final step of habitat modeling is to do an evaluation to check the quality of model prediction.

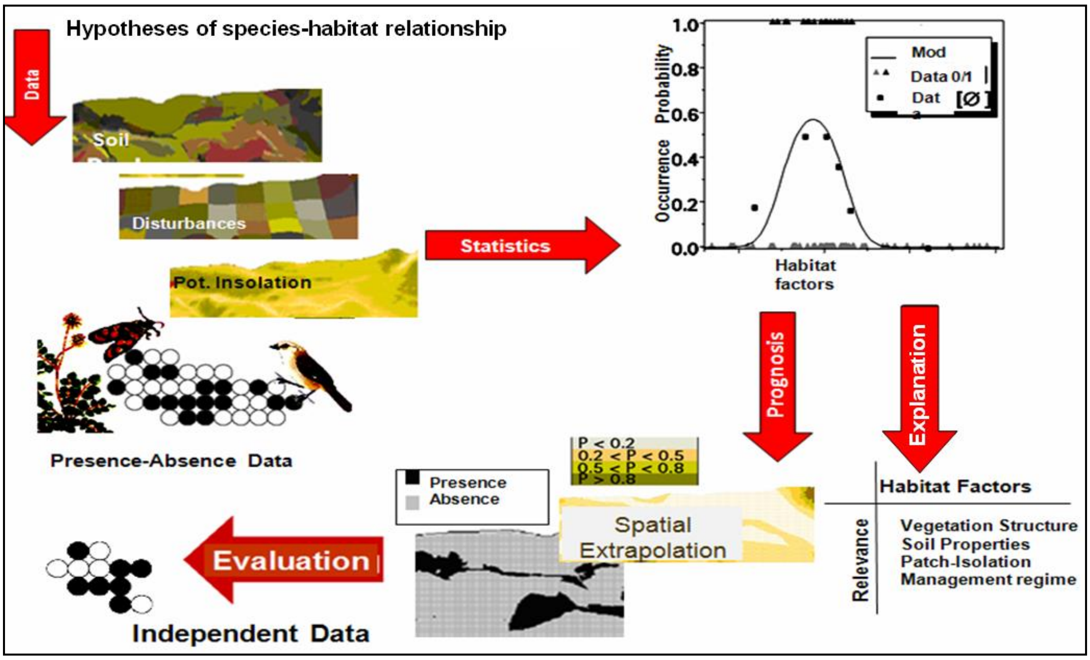


Figure 12: Habitat suitability modeling process (Modified from Schröder and Reineking, 2004).

2.3 Overview of Different Groups of Habitat Suitability Models

There are three groups of models classified by Sharpe (1990) and Levins (1996). They are based on the properties of generality, reality and precision. Guisan *et al.* (2000) agreed to Levins's classification and state that it is useful in a conceptual context. The first group of models focuses on generality and precision, and is called analytical (Pickett *et al*., 1994) or mathematical, and is developed to predict accurate response within a limited or simplified reality. An example of analytical models is the general logistic growth equation (Guisan *et al*., 2000). The second group of models is designed to be realistic and general properties. They are known as mechanistic, physiological causal or process models based on predictions of real cause-effect relationships. Hence, they may also be viewed as general because their relationship is considered as biologically functional (Woodward, 1987). Hence the second group is determined primarily by predicted precision, but rather on the theoretical correctness of the predicted response (Pickett *et al*., 1994). A third group of models is called empirical (Decoursey, 1992; Korzukhin *et al*., 1996), statistical (Sharp and Rykiel, 1991) or phenomenological (Pickett *et al*., 1994; Leary, 1985). This model provides precision and reality on the cost of generality. "*The mathematical formulation of such a model is not expected to describe realistic 'cause and effect' between model parameters and predicted response, nor to inform about underlying ecological functions and mechanisms, being the main purpose to condense empirical facts"* (Wissel, 1992). The empirical model can be derived from experiments and observations rather than theory. If species presence data is available in the study area, then empirical models can be created by relating the species occurrence data to habitat factors.

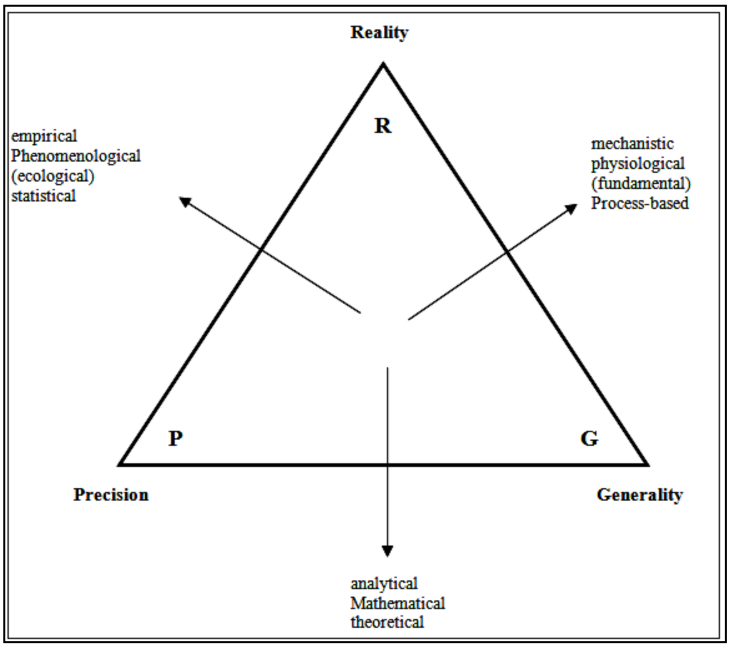


Figure 13: Model classification based on their intrinsic properties. After Levins (1996) and Sharp (1990) (Modified from Guisan and Zimmermann, 2000).

For mapping habitat suitability, most of the regression is used as the standard model. Among multivariate models, logistic regressions (Jongman *et al.*, 1987, Peeters and Gardeniers 1998; Higgins *et al.*, 1999; Manel *et al.*, 1999; Palma *et al.*, 1999) and Gaussian logistic regressions (ter Braak and Looman 1987; Legendre and Legendre 1998) are most frequently used. Hirzel *et al.* (2002) pointed out the commonalities of all these models as follows:

1. the study area is given as a raster map constituted by *N* adjacent isometric cells,

2. the response variable is presence/absence data of the focal species,

3. the independent EGVs are associated with every location of the study area and they describe features quantitatively (e.g. forest frequency, density, altitude, slope, distance to nearest town, road, etc.) (Hirzel, 2004), and,

4. EGV is then measured to classify habitats as unsuitable or suitable for the focal species.

There are different approaches of Habitat Suitability Modeling. These include Generalized Linear Modeling (GLM), General Additive Model (GAM), Ecological Niche Factor Analysis (ENFA) and Multi Criteria Evaluation (MCE). ENFA and GLM are examples of empirical models but MCE is a theoretical model (Hughes, 2009). The choice of the most appropriate model depends primarily on the type of response variable (Hirzel & Guisan, 2002). Williams (2003) classified habitat suitability models into two groups according to the type of response variables used. When the response variable is binary (i.e. presence/absence), a combination of multiple regression with binomial distribution and logic links can be used (e.g. GLM). ENFA has been widely used in HS models of presence only data (Hirzel & Guisan, 2002; Mertzanis *et al.*, 2008; Huck *et al.*, 2010). Both methods (GLM and ENFA) are quite robust and produce equivalent results when the quality and quantity of the data is good (Hirzel *et al.*, 2001). The Ecological Niche Factor Analysis- ENFA- is one of the approaches of presence only models. The principle of ENFA is to compute a suitability function by comparing environmental variable values of species' presence cells with respective mean values of the entire study area. It is built on the concept of marginality (i.e., the species distribution mean differs from the global distribution mean) and specialization (i.e., the species variance is lower than the global variance). The outputs are a so called score matrix, giving a ranking of EGV relevance for the habitat choice of a focal species and a habitat suitability maps. ENFA is recommended to be used in the case of small sample records of very rare species (Elith *et al.,* 2006).

2.4 The Role of RS and GIS in Large Area Habitat Modeling

Landscape level data sources from Remote Sensing (RS) and Geographic Information Systems (GIS) can provide a chance for scientists to draw habitat suitability models and evaluate potential habitat for wild flora and fauna (Larson *et al*., 2003). According to this, the significance of spatial data technologies, especially the application of remotely sensed data and GIS has greatly increased in recent years. RS and GIS are two associated tools and techniques that are suitable to tackle spatial analysis. RS can be defined as the utilization of sensors to collect spectral information about an object or phenomenon from a distance (handheld to aircraft to satellite levels) (Dalsted, 2011). Over the past two decades, geographers have developed sophisticated GIS technology that possesses the ability to store, map and analyze spatial data (Swenson, 2007). The increasing interest in GIS technology for the analysis of environmental and biological data has improved since the early 1990s (Johnston, 1999). The relationship between the focal species and environmental predictors can be statistically analyzed by means of a database produced by RS through a valuable mechanism (Stith and Kumar, 2002). The usage of RS is rapidly expanding in conservation and habitat rehabilitation efforts all over the world as the tool for detection and classification of objects on Earth (both in the atmosphere/oceans and on the surface). In order to classify land uses and natural resources in large areas, it is necessary to know where these resource types are located. Extensive field work over large areas is critical for mapping resource locations. RS and GIS can be used as tools to construct habitat models that can offer the ability to minimize extensive field work as well as to get updated information (ESD, 2012).The role of Remote Sensing (RS) and Geographic Information System (GIS) has developed in spatial analyses for many different and varied fields. Plenty of literature shows the abilities of RS. The application is gaining interest by researchers with various purposes in order to:

- model structural and compositional attributes of various habitat types,
- link spatial analysis and ecological theory,
- accurately assess large areas of habitat in the management of wildlife,
- allow for rapid qualitative and quantitative spatial assessments in a cost-effective ways,
- obtain the opportunity for large-scale modeling to examine the effects of proposed habitats at local and regional scales (Collin *et al.*, 1993),
- generate multivariate maps that could be analyzed in a model, and,
- quantify multi-dimensional habitat relationships across broad geographical areas (Joseph *et al*., 1998).

Owing to the above properties, in the field of wildlife Habitat Suitability Modeling, the number of researchers is increasing. RS and GIS are also essential tools used by civic planners, geologists, wildlife conservationists as well as ecologists in their related fields.

To define habitat suitability of large areas, multivariate models are applied in combination with RS and GIS. Spatial data may also be converted from one format to another using GIS, e.g. vector maps to raster maps, as well as point data into polygon data. These processes are crucial to set a good foundation for building the Habitat Suitability Model. In a study by Koeln *et al.* (1994), GIS is mentioned as a tool that has the ability to examine habitat selection and to build multivariate predictive models of potential habitat use. The studies of conservation ecology conjugate the power of GIS with multivariate statistical tools to formalize the link between the species and their habitat, in particular to quantify the parameters of HSM (Hirzel *et al*., 2002). The BioMapper software in which ENFA model is implemented is ecology-oriented GIS software (Hirzel *et al*. 2003). Required ecogeographical variables are first prepared in a GIS in order to use them as input for the ENFA.

2.5 Application of Ecological Niche Factor Analysis (ENFA)

Hutchinson (1957) developed the concept of the ecological niche to design habitat models. This concept is a multi-dimensional hyper volume comprised of the physical and biological environmental conditions that describe a species' suitable habitat. The ENFA model was designed on the basis of Hutchinson's niche concept (Hutchinson, 1957). It only requires species presence data and is different to other methods such as logistic regression and generalized linear models which require presence-absence data. The previous research of Hirzel *et al.* (2002) recommends that the empirical multivariate ENFA approach be applied where absence data are not available. The ENFA approach is appropriate in situations where absence data are difficult or impossible to collect and it has been used successfully with presence-only data in terrestrial mammal surveys (Reutter *et al*., 2003; Zimmermann *et al*., 2007) as well as with telemetry data (Freer, 2004; Zimmermann, 2004). A review of ENFA related papers has been undertaken and the results are highlighted below.

Hirzel *et al.* (2001) conducted a comparison study of ENFA and GLM with a virtual species by simulating three historic scenarios: spreading, at equilibrium and overabundant species. The results showed that the ENFA is very robust to the quality and quantity of the data and can give good results for all three scenarios. GLM did not show well for the spreading scenarios but produced better results than the ENFA in the overabundant scenario. Hirzel *et al.* (2002) used the ENFA to draw habitat suitability maps of alpine ibex (*Capra ibex*) in Switzerland. The results showed that ibexes are especially linked to high-altitude, steep and rocky slope and they tend to avoid forest and human activities. In the application of ENFA for alpine ibex, the authors mentioned that the evidence of marginality and specialization factors is very peculiar ecological requirements. Moreover, they observed that the interpretation of EGVs was very consistent with the experience of field specialists.

Santoes *et al.* (2006) also applied the ENFA model to identify areas of best habitat suitability in the Iberian Peninsula for the snake species *Vipera latastei*. The analysis has identified the environmental factors that limit the current distribution of this species, and has evaluated how human activities affect its current conservation status. The overall marginality indicated that this viper tends to live in average conditions throughout the study area. The ENFA also revealed that human-related activities caused a negative impact on the viper's habitat. For this study, the ENFA analysis proved to be an outstanding method to evaluate the factors that limit the distribution range of widespread species such as *V. latastei* and it can update the evaluation of conservation status.

Henirk *et al.* (2008) also tested the ENFA on tracking data of the northern gannet (*Morus bassanus*) in the western North Sea. They discussed that the ENFA has the capacity to provide satisfactory and precise predictions of distribution patterns and feeding habitats of animals in the ocean.

Sattler *et al.* (2007) used the ENFA to characterize species specific habitat requirements, to build habitat suitability map and examine interspecific differences in niche parameters for two cryptic bat species in Switzerland and Liechtenstein. The results of the ENFA models indicated that the ecology of *P. pipistrellus* differed markedly from that of *P. pygmaeus. P.pipistrellus* tolerated higher elevations and seemed to be distributed more widely in Switzerland than *P. pygmaeus.*

Xuezhi *et al.* (2008) conducted a habitat suitability study Giant Pandas (*Ailuropoda melanoleuca*) in Sichuan Province in China. The results show that giant pandas prefer coniferous forest with elevations higher than 2128 m.a.s.l. They avoid deciduous broadleaf forests, shrub land and human disturbances. Farmland showed to be a major threat to panda habitat.

Edgaonkar (2008) conducted a research on the ecology of the leopard (*Panthera pardus*) in the Bori Wildlife Sanctuary and Satpura National Park, India. He applied the ENFA model and showed that the habitat of the leopard in Satpura was especially linked to moist forests and to teak forests as well as to the areas of high prey species density. At a larger scale, in south-central Madhya Pradesh, the leopard habitat was positively associated with terrain ruggedness, sambar deer availability and forest cover. The leopard was weakly and negatively associated with the distance to villages. The author's conclusion on ENFA was that the model worked better at larger scales for a generalist species.

Podchong *et al.* (2009) applied the ENFA model to identify suitable habitats for sambar deer (*Cervus unicolor* Kerr) at the Phu-Khieo Wildlife Sanctuary (PKWS), Thailand. The results showed that sambar deer prefers to stay on level areas and avoid high steep slopes. High values of global marginality and specialization indicated that sambar deer prefer the habitat that is different from the average conditions of PKWS. The authors recommended categorizing EGVs for feeding into ENFA for the importance of model accuracy.

Brian *et al.* (2010) employed the ENFA and the Mahalanobis distance factor analysis (MADIFA) to explore the relationship between the niche of Giant Gartersnake (*Thamnophis gigas*) and the availability of habitats. The result of the ENFA indicated that *T. gigas* occurred in areas with a dense network of canals, close to rice agriculture, open water and linked with areas of low density of streams. The results of ENFA were in agreement with the major variables important for *T. gigas.*

WWF, WCS, the University of Montana and key stakeholders from China conducted collaborative research for the identification of Amur tiger habitat in the Changbaishan ecosystem, northeast China. They applied three habitat models: an ENFA, resource selection function (RSF) model and expert knowledge model. In their technical report (2010), for the result of the ENFA was mentioned that the tiger preferred habitats of a higher mean slope, a larger pure deciduous forest frequency and a greater distance from villages and large cities as well as a lower frequency of human dominated landscapes. Tigers also avoided primary and secondary roads. These three models indicated strong correlations in identifying relative values of landscape types.

Buschmann (2011) conducted research on Habitat Suitability Modeling for nesting sites of red kite (*Milvus milvus*) in an EU Bird Sanctuary in Lower Saxony by using the ENFA. The result showed that red kites prefer open cultural landscapes and their breeding habitat is characterized by special requirements for area sizes and spatial configuration of pasture patches.

3 MATERIALS AND METHODS

3.1 Study Area and Target Period

The study area of this study is in the core zone of HVTR. It is situated in Tanaing Township, Kachin State in Northern Myanmar (see Fig.14). It covers an area about 1,713 square kilometers. It was chosen as the study area because a former survey showed that most of the tiger presence points were located in it for the year 2003. The target period for this study is from November 2002 to May 2004, especially for the year 2003.

The Myanmar Forest Department (MFD) notified that the Hukaung Valley has an area of 2, 460 sq miles (6, 371 square kilometers) as the Wildlife Sanctuary to safeguard tigers and their habitats in the year 2004. Regarding the result of a National Tiger Survey Project conducted from 1998 to 2002, the area was found to be important for increasing the number of tigers. Therefore, MFD and WCS submitted proposals to extend the existing Hukaung Valley Wildlife Sanctuary with the adjacent area of 4, 248 sq miles (11, 002 sq kilometres). After land settlement, the Hukaung valley tiger reserve was gazetted on 1st March 2010 with the total area of 6, 708 sq miles (17,374 km^2). Having this extent, it is now becoming the world's largest protected area for this carnivore. It is also a habitat for other rare species such as the clouded leopard (*Neofelis nebulosa*), gaur buffalo (*Bos gaurus*), elephants and wild banteng cattle (*Bos javanicus*) and key tiger prey species, the sambar, muntjac and wild boar.

HVTR is bounded by high mountain ranges and the central part is filled by a plain. The elevation ranges from 126 m.a.s.l to 3440 m.a.s.l. Subtropical evergreen forests because of the to the tropical rain (monsoon) climate are found on the reserve. Its waters are drained by tributaries of the Chindwin river and separated of those of the Ayeyarwaddy by the Kumon mountain range east of the reserve. The Chindwin river in Myanmar is the largest tributary of the Ayeyarwaddy and separated from the Brahmaputra in neighbouring India by the Patkoi mountain watershed west of the Reserve.

The higher latitude and more continental location of the study area leads to special climatic conditions, producing lower temperatures than those normal for the region (Dobby, 1964). December is the coldest month with an average temperature of 17.8º C, and August is the hottest with 29.4º C. Temperature extremes range from 11.3 to 36.8º C. Low average temperatures between 18-21º C occur from November to February (winter season). Temperature increases rapidly in March (23.6º C on average) and remains high until October (between 25-29º C). The daily weather is characterized by extreme changes: misty morning weather with chilly temperatures, rapid heating up as the sun breaks through and wet nights with rain and dropping temperatures. Central Hukaung Valley is an alluvial plain. The streambeds between the mountain ranges are filled with rocks, pebbles and sands.

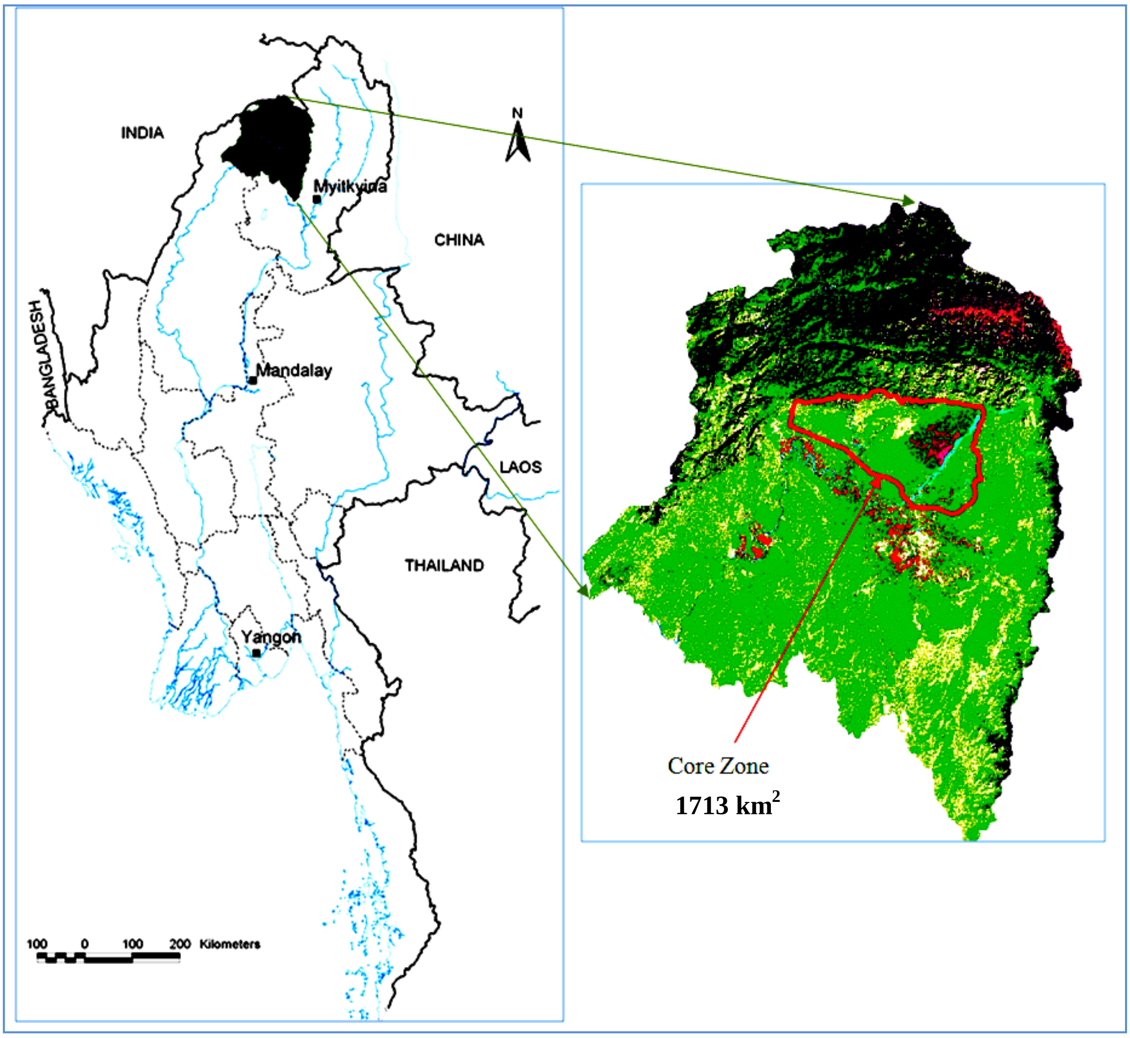


Figure 14: Study area (core zone) of the Hukaung Valley Tiger Reserve, Northern Myanmar.

The various forest types to be found in the reserve are dense lowland evergreens and subtropical moist evergreen forests, hill evergreen forests and bamboo. Forests still dominate, not only on the mountains, but also in the plains. A typical grassland, locally called "Kaing" (*Saccharum spontaneum* Linn.) is dominant species, and is believed to attract tigers especially for hiding as well as for hunting. Typical trees are Gangaw (*Mesua* *ferrea*), Kyilan (*Shorea assamica Dyer*), Sagawa (*Michelia champaca* Linn), Kalaung (*Dysoxylum binectariferum* Hook), Yinmar (*Chukrasia tabularis* A. Juss) and Thit Thingan (*Neonauclea griffithii* Hav.). Along the streams and on wet sites in the plain, Kyu (*Phragmites kaka* Trim) and Yon (Wallichia spp.) can be found. Rattan is widespread throughout the area. A new survey has identified at least 15 different species. Shifting cultivation (Taungya) is often followed by invading grasslands dominated by "thetke" *(Imperata cylindrica*) and Pet-waing (*Macaranga denticulata* Muell. Arg.). Bamboo species such as Wanet (*Dendrocalamus longispathus* kruz.), Wanwe (*Dinochloa m' clelladi* Gamble) and Wabo-myet-san-gye (*Dendrocalamus hamiltonii* Nees. and Arn.) can be found. Many species of medicinal plants can also be found in the forested areas in the Reserve. An overview of plant species in the Hukaung Valley is presented in Appendix I.

Hukaung Valley is a remote area still rich in large mammals, birds and reptiles as well. Apart from tigers, there are Asian elephants (*Elephas maximus*), Leopards (*Panthera pardus*), Clouded leopards (*Neofelis nebulosa*), Gaurs (*Bos gaurus*), Banteng (*Bos javanicus*), Gorals (*Naemorhedus baileyi*), Asiatic black bears (*Ursus thibetanus*), Malayan sun bear (*Helarctos malayanus*), Sambar Deer (*Cervus unicolor*), Hog deer (*Axis porcinus*), Red muntjac (*Muntiacus muntjak*), Eurasian wild boars (*Sus scrofa*), Hoolock gibbon (*Hylobates hoolock*), Great hornbill (*Buceros bicornis*), Ruddy shelduck (*Tadona fesuginea*) and rare fresh water turtles (*Amyda cartilaginea*). The Wildlife Conservation Society has identified 141 bird species so far. An overview of important animals is presented in Appendix II. HVTR is bounded by mid-elevation peaks to the north, east and west. This study was carried out in the flat core zone that contains prime habitat of tigers and that is the most important area for future management efforts.

3.2 Data Collection

From March to April 2010, the author collected the data for this study in the Hukaung Valley, Northern Myanmar. The author visited 10 villages around the core zone of the reserve. Interview surveys were conducted with local hunters, local field experts regarding their hunting experiences, their common hunting places, tiger killing information, the habitat use of the tiger and its prey species, land use situations and land use changes in the core zone. Subdivision of existing vegetation classes and ground truth collection in the core zone were also conducted with the help of Global Positioning Systems (GPS) and field experts. From the interview surveys, the points of secondary forests in the core zone were labeled on a topographic map for the years 2002-2004. The information on human threats in the core zone was also investigated. The data sets were provided by Wildlife Conservation Society (Myanmar Programme) and Hukaung Wildlife Office. Group discussions with the village leaders and elder villagers and field experts were held to obtain both past and present data. Questionnaires were prepared and completed during interviews (See Appendix III).

Datasets on tiger presence and land use mainly come from November 2002 to May 2004, mainly for the year 2003. A tiger habitat suitability map was drawn based on the location of the tigers from a survey carried out by the WCS and MFD from 2002 to 2004 with locations from the year 2003. The auxiliary data (DEM) and human activities/intrusions data such as settlements, roads, logging, gold mining, dynamite fishing, non-timber forest product collections and saltlick locations in the core zone were provided by WCS (Myanmar Programme) and the Hukaung Wildlife Office, Tanaing Township. The authorities and the field experts from Hukaung Wildlife Office, Myanmar Forest Department and Wildlife Conservation Society (Myanmar programme) supported data collection.

3.3 Data Sets

3.3.1 Landsat data acquisition

LANDSAT 7 ETM^+ is a satellite sensor which records 8 bands of reflected electromagnetic energy. These bands range from the visible spectrum (Red, Green and Blue bands) to short and long-wave Infra-Red heat bands. The data from each band is recorded in a matrix of 8-bit pixels. Each pixel of a band is given a gray value from 0 to 255 indicating the amount of energy reflected by by ground features in the wavelength spectrum of the reflective band. 11 scenes were ordered from the USGS Global Visualization Viewer (GloVis), to get the clearest images for classification. The best two scenes (October 2002/February 2003) were chosen to include the study area (see Fig. 15). Path and row of the upper one is 134/41 and that of the lower one is 133/42. These images have a spatial resolution of 30 meters for band 1 to 7 (except band 6 with 60 meters) and 15 meters for band 8 (panchromatic).

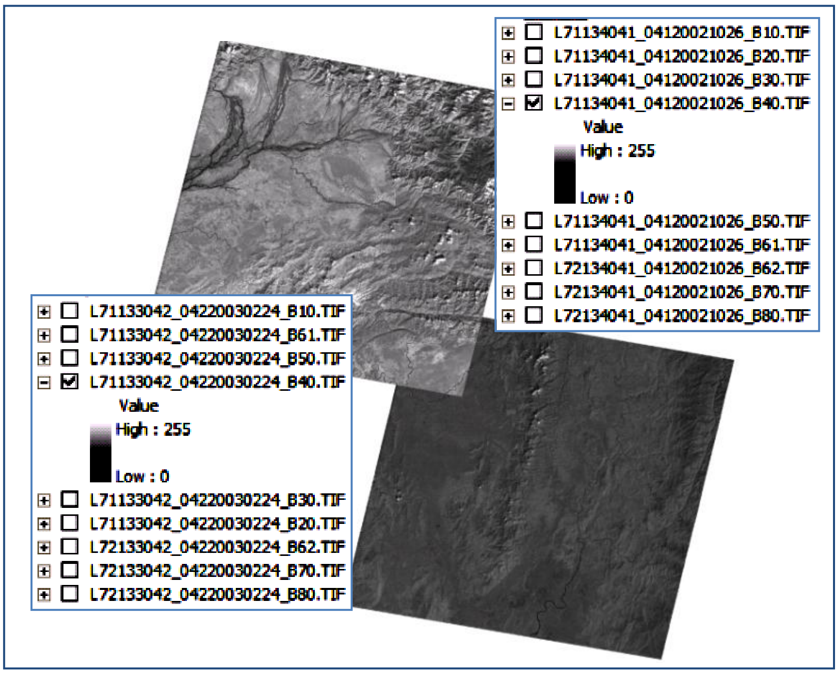


Figure 15: The Landsat imagery acquired on Oct 2002/Feb 2003 from USGS Global Visualization viewer (GloVis).

3.3.2 Species data

From November 2002 to June 2004, camera traps surveys were carried out by the Wildlife Conservation Society (Myanmar Programme) in collaboration with the Myanmar Forest Department to record tigers, identify individuals and estimate densities in the reserve.

The tiger data are in the form of GPS points which give the locations of tigers detected by camera traps and track and sign data. Most of the tiger presence points were recorded in the year 2003, including the beginning of the year 2004 and the end of the year 2002. There are 31 tiger presence points, including only 5 individuals recorded from the camera traps and the remaining were detected from track and sign survey (see Figure 16).

To use the species presence data, the information of camera trap settings and tiger population estimations were investigated in the study of Lynam *et al*. (2008). The survey area was covered at three sites of the reserve, comprising the total area of 3, 250km² (see in Figure 17), two sites being included in the core zone.

These sites are selected based on reliable local reports of previous surveys that confirmed the habitat used by tigers and their prey species. Before setting the camera traps, short reconnaissance surveys by foot and elephant were conducted. The camera traps were located at the places where tiger or prey signs had been detected during these surveys. The potential locations were recorded using GPS and marked on topographic maps using MapSource ™ software.

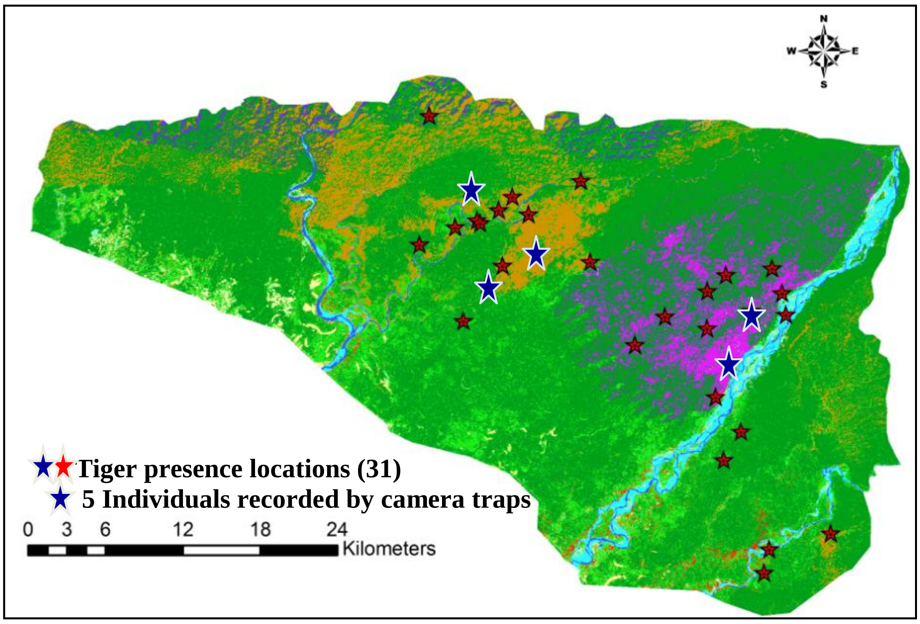


Figure 16: Tiger presence locations from camera trap and track and sign survey (2002-2004). 5 individuals (blue stars) were recorded by camera traps in the study area.

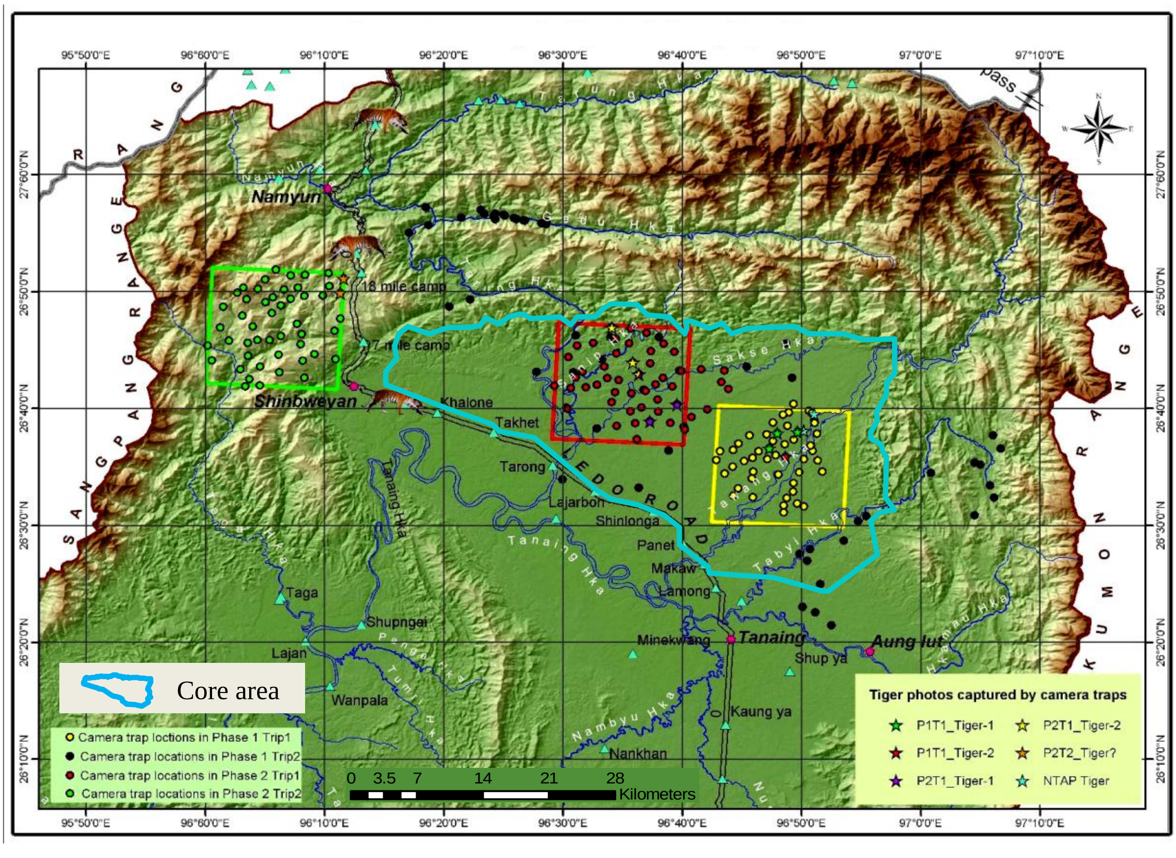


Figure 17: Locations of camera traps and captured tiger photos. (Source: WCS, Myanmar Programme).

Table 6: Survey efforts for tiger using camera-traps in the HVTR (Lynam et al., 2008).

Study site	Dates	Days	Total camera trap locations	No. traplines (Average locations per trapline)	Trap days
Tawang River	1.12.2002- 22.12. 2003	53	48	5(10)	**1,328**
Taron River	26 .11.2003- 11.02.2004	77	50	4(12)	**1,062**
Naga Hills	28.03.2004- 28.05.2004	60	49	4(12)	**1,069**
Total		**190**	**147**		**3,459**

According to the recommendation of Karanth and Nichols (2002), camera-traps having an auto focus 35-mm camera with a built-in flash attached to a passive infrared monitor were placed to maximize the probability of detecting tigers (Lynam *et al.,* 2008). At each site, potential 48-50 locations were selected for camera trap sampling. The final locations were on average 2.9 km apart (range 0.6-10.7 km), covering several hundred square kilometers. A pair of traps was located facing each other on opposite sides of trails or streambeds, approximately 0.4 m above the ground to record both sides of a tiger. It helps to validate the two unique stripe patterns on each individual tiger. Trap locations were divided into trap lines for sampling. Each site had four or five trap lines with an average of 10-12 camera trap locations (see Table 6). Camera traps were set to operate 24 h a day with an average of 18 days (12-26 days) for one trap line. All trap lines were established with the same procedure. To estimate the tiger population, tiger individuals were identified from acquired films using unique striping patterns on the flanks, shoulders, and hind quarters (Franklin *et al.,* 1999). By following the recommendations of Karanth and Nichols (2002), a capture–recapture approach (White *et al*., 1982) was employed to estimate numbers of a tiger's presence at each site. A total of 21 photographs of tigers were recorded across the three intensive sampling plots from 3, 459 trap days, 147 trap stations and 190 days of survey effort. 6 individual tigers were identified from 12 of these photographs. The remaining were partial or blurred shots of tigers and individuals could not be identified. Tiger densities fall in the range of 0.2–2.2 tigers/100 km^2, with 7–71 tigers inside a 3, 250 km^2 area of prime tiger habitat, where efforts to protect tigers are currently focused. According to their result of tiger estimation, it was assumed that tiger density of the range (3.4-38) is given in the study area of 1, 713 km^2.

3.3.3 Environmental data

The present study includes the environmental data of land use compositional variables, topographical variables and human factor variables. The landscape compositional variables were produced by means of segmentation-based land use classification. The training areas for land use classification were generated from the existing land use map (supervised classification map) that was produced by the WCS (Myanmar Programme). This map was classified based on training areas of a ground truthing survey and maximum likelihood method covering the classes in Table 7.

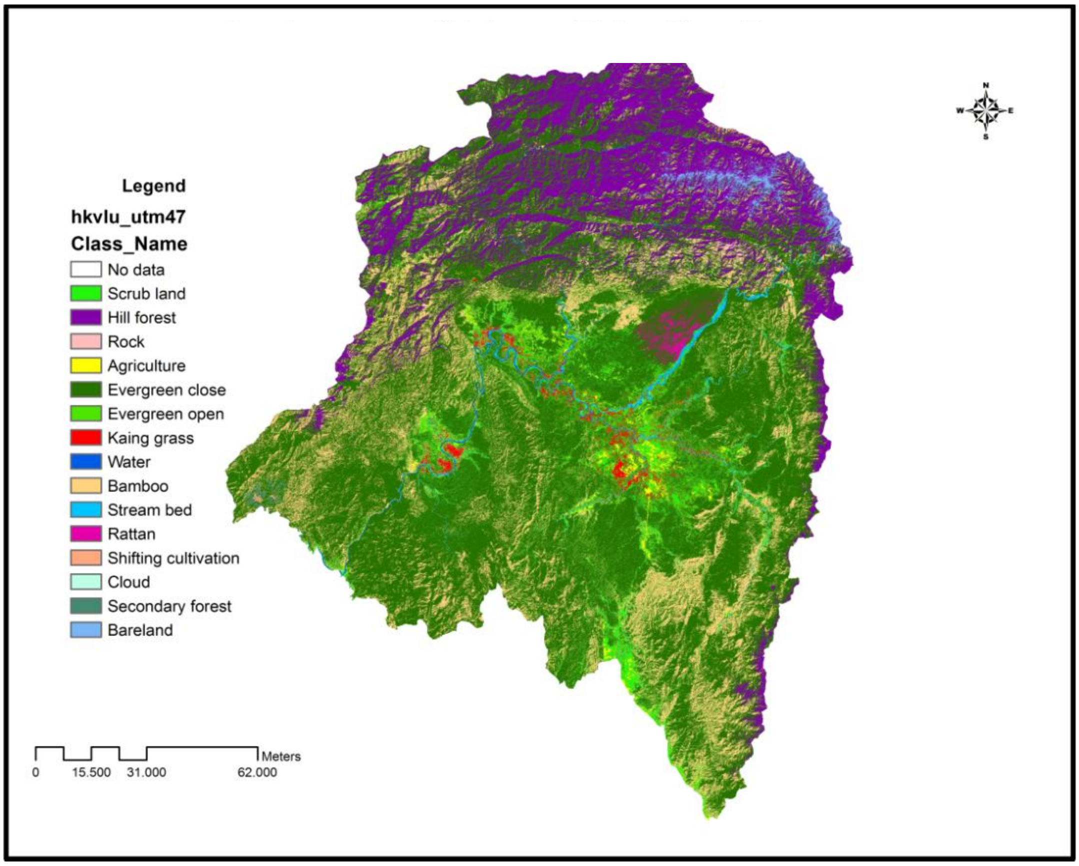


Figure 18: The existing land use classification map of the whole Hukaung Valley Tiger Reserve (Provided by WCS, Myanmar Programme).

There are 16 land use classes and the average clarification accuracy of the categories is 91%. Due to the distribution of erroneous single pixels (salt and peffer effect) all over the map, this existing land use map could not be applied directly for mapping habitat suitability. However training sites for the segmentation-based land use classification for this study were collected from the existing map. On the other hand, the spectral information of Landsat image was used in the classification processes. Out of 16 land use classes (see Fig. 18), the classes that are assumed to be important for tiger ecology were selected to collect training areas from the existing map.

Table 7: The classification items of existing reference land use map in which the classes marked with gray color were excluded in the segmentation-based land use classification of the core zone of the current study (Source: WCS, Myanmar Programme, 2003).

Value	Classification	Description
0.	No Data	No data areas
1.	Scrub Land	Covered with shrubs or forest young stands
2.	Hill Forest	Evergreen forest at more than 800 m.a.s.l
3.	Rock	Rock cliff
4.	Agriculture	Permanent agriculture land on flat area near villages
5.	Evergreen Close	Closed evergreen forest with more than 60% of crown density
6.	Evergreen Open	Opened evergreen forest or degraded evergreen forest with considerable open-space
7.	Kaing Grass	Tall grass in wet areas, this class is important for tigers and prey
8.	Water	Water surface areas
9.	Bamboo	Bamboo breaks can be clearly identified as yellow feature on 4, 5, 3 band combination.
10.	Stream bed	Stream bed along rivers and this class will be water surface in wet season
11.	Rattan	Rattan break were found in Tawang river by ground survey. It is difficult to classify in other places
12.	Shifting Cultivation	Cultivated lands in mountains especially in Naga areas, this class was difficult to be classified in digital analysis, these areas were classified mainly by a field survey
13.	Cloud	Cloud covered on image during image capturing by sensor
14.	Secondary Forest	Secondary growths occurred after shifting cultivation, in the Naga area, traditionally they used the land only one year and leave 8 to 10 years for next cycle
15.	Bare Land	No vegetation cover on land

In Table 7, the marked classes were not included in the segmentation based land-use classification. No data areas mean the areas are out of the boundary and they are unnecessary to classify. Hill forest, rock cliff, cloud and bare land were not included in the core zone. Shifting cultivation was classified in combination with agriculture. Other environmental variables are topographical variables such as aspect, elevation and slope and these variables were generated from digital elevation model (DEM) provided by WCS (Myanmar Programme). Locations of common hunting places (see Figure 19) were collected by doing interviews with the local hunters and heads of villages. The auxiliary data were provided by the HVTR Office, including saltlick areas, logging, non-timber forest products collection, dynamite fishing, settlement, etc. (see in Figure 19).

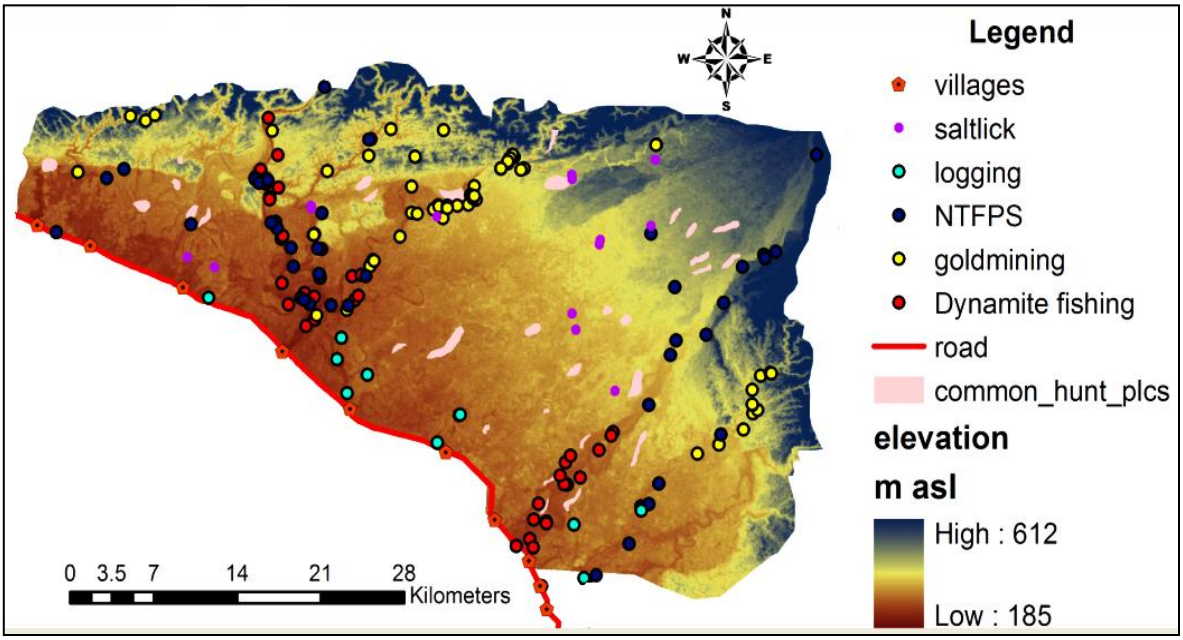


Figure 19: Environmental information used in the study, including topography, common hunting places used by the hunters and saltlick locations and human impact locations.

3.4 Data Preparation for the Study

3.4.1 Landsat image processing

The first step carried out for this study was Landsat image processing: image stacking, mosaicking and subsetting. Two Landsat scenes were merged to cover the study area. One scene was acquired in October 2002 and the remaining one in February 2003. The Landsat 7 images each contains 8 different images channels (bands, cf.3.3.1).

With Erdas Imagine software, the two images were stacked together in order to get a single image. After then, image mosaicking was done by using the tool "histogram and feather". A subsetting process was conducted in order to break out the portion of the required study area. All of these step by step procedures which include a color correction are shown in Figure 20.

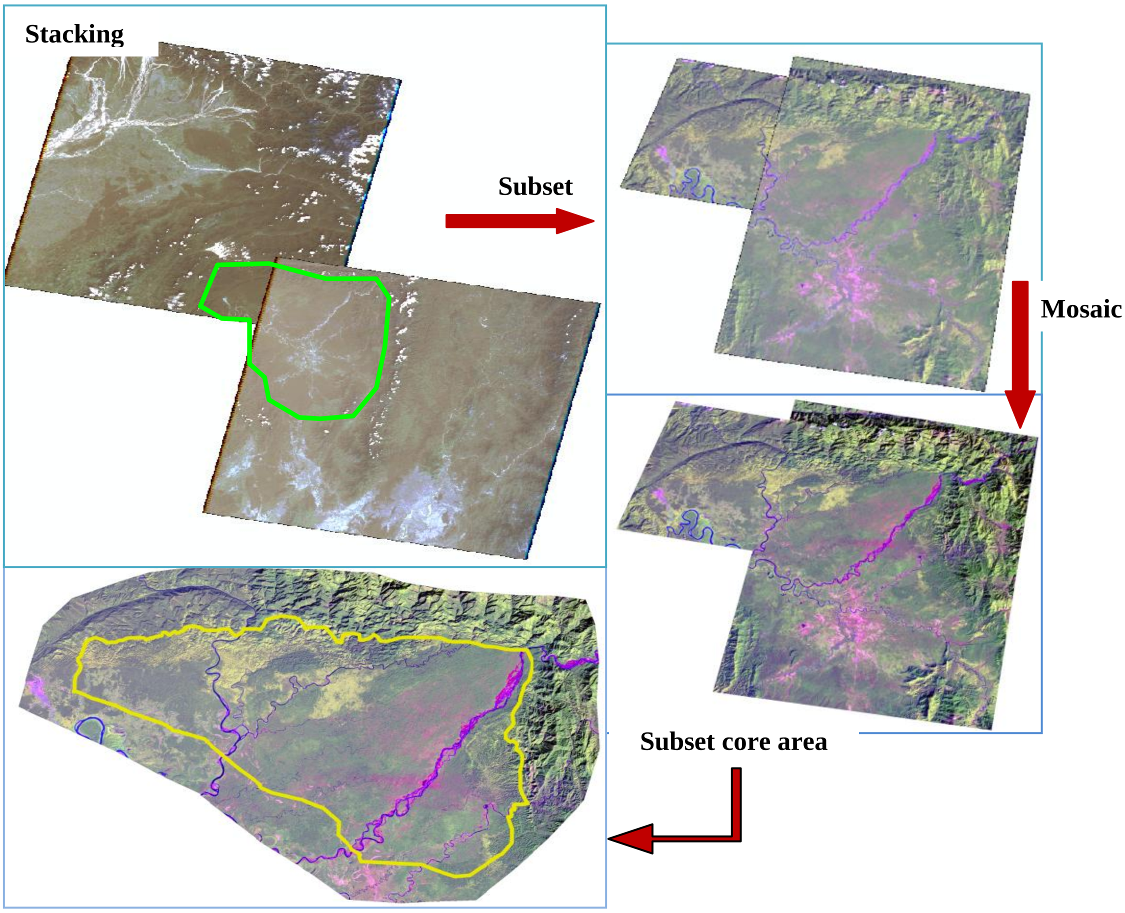


Figure 20: Step by step procedures of Landsat image processing: image stacking, mosaicing and subsetting the required area.

3.4.2 Segmentation-based land use classification: Object-oriented image analysis

Segmentation means the grouping of neighboring pixels into regions (or segments) based on similarity criteria (digital numbers, texture). Image objects in remotely sensed imagery are often homogenous and can be delineated by segmentation. In remote sensing, the process of image segmentation is defined as: *"....the search for homogenous regions in an image and later the classification of these regions*" (Mather, 1999). It can also be regarded as object-oriented image analysis. The concept of object-based analysis as an alternative to pixel-based analysis emerged as early as the 1970s (de Kok *et al.*, 1999). It is based on always the basic processing units are objects (segments). Different approaches exist, but one approach, implemented in the software package eCognition (Baatz and Schape, 2000), is a so called a multi-resolution segmentation procedure.

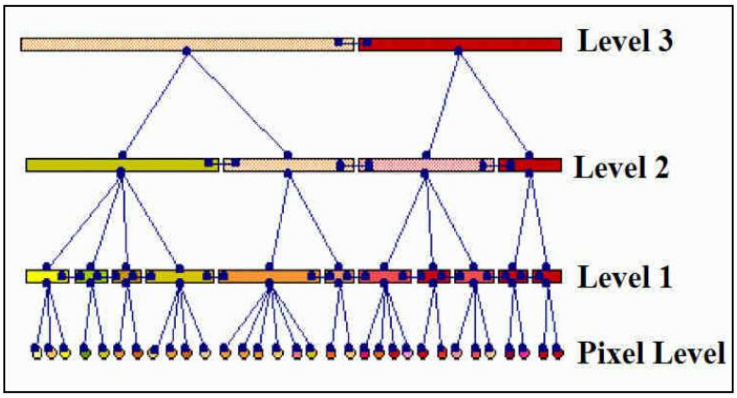


Figure 21: An example of level hierarchy in eCongition showing the basic concept of object-oriented image analysis (Definiens, 2003).

The image objects are built in the first step of the classification. Different colors are applied for different classes (Meng *et al.*, 2009). Subsequently, bigger segments are created by merging pairs of image objects using homogeneity criteria (Rahman and Saha, 2008). A homogeneity criterion is defined as a combination of color homogeneity (i.e. standard deviation of the spectral color) and shape homogeneity (i.e. compactness and smoothness of the shape) (Meng *et al.*, 2009). The process ends when the increase of homogeneity is below a defined threshold.

A scale parameter is an important factor to determine a limit of change of heterogeneity throughout the segmentation process. It can also decide the average image object size. Therefore a higher scale parameter will allow for more merging ability in order to get bigger objects, and vice versa (Rahman and Saha, 2008). Partition of images to set useful objects is a fundamental procedure for successful image analysis as well as for image interpretation (Gorte, 1998; Baatz and Schape, 2000; Blaschke *et al*., 2000). The segment-based classification can effectively avoid the "salt and pepper phenomenon" (Meng *et al*., 2009).

To prepare the landscape compositional variables for modeling habitat suitability, segmentation-based land use classification was conducted based on fuzzy logic in combination with knowledge rules. First of all, the Landsat image was imported to eCognition and the color composition of the displayed image was changed. Based on the spectral characteristic and spatial resolution of the Landsat image, 14 levels of segmentation were tested to identify the best suitable parameters (Table 8).

Table 8: Separated segmentation processes with various parameters in eCognition 3. The level 8 in red showed the best one for segmentation of this study.

Name	Scale Parameter	Color	Shape	Smoothness
				Compactness
Level 1	8	0,9	0,1	0,9/0.1
Level 2	8	0,7	0,3	0,5/0,5
Level 3	10	0,8	0,2	0,5/0,5
Level 4	10	0,9	0,1	0,5/0,5
Level 5	10	0,9	0,1	0,8/0,2
Level 6	10	0,9	0,1	0,6/0,4
Level 7	10	0,9	0,1	0,9/0,1
Level 8	10	0,7	0,3	0,5/0,5
Level 9	15	0,8	0,2	0,6/0,4
Level 10	20	0,8	0,2	0,5/0,5
Level 11	25	0,8	0,2	0,6/0,4
Level 12	30	0,7	0,3	0,5/0,5
Level 13	30	0,6	0,4	0,5/0,5
Level 14	50	0,7	0,3	0,5/0,5

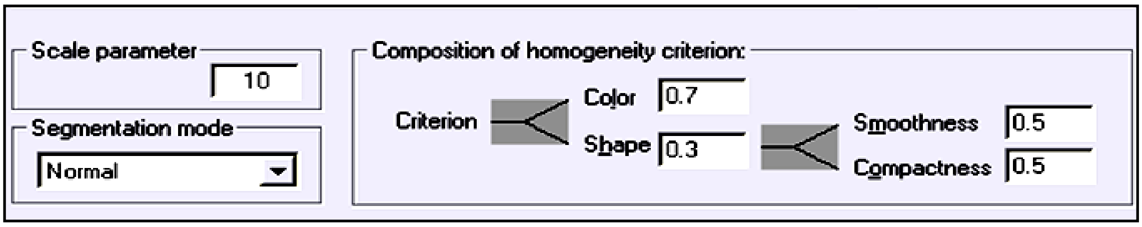


Figure 22: The scale parameter and composition of homogeneity critera (Screenshot from the segmentation process of eCognition).

On the basis of prior knowledge of the study area and visual inspection of the number and shape of image objects, the level 8 was selected for the final classification procedure of land cover in eCognition. This Level 8 had a *scale parameter* of 10, with 70% of the criterion dependent on *color* and 30% on *shape*. The later factor was divided between *smoothness* and *compactness*, with the criterion dependent 50% and 50%, respectively (see Fig. 22).

After segmentation, the objects were identified as vegetation classes with different colors. All image objects were classified using a class hierarchy which is based on fuzzy logic. Each class of classification, the scheme contains a class description. Examples of the conducted procedures of segmentation and classification for this study are illustrated in

Figure 23. The classification scheme had been constructed based on feature classes which are expected to be relevant for tiger ecology. 13 main land use classes were included in the classification process in eCognition. They are evergreen closed forest, evergreen open forest, and evergreen open forest with rattan, secondary forest, agriculture, water, stream bed, hill evergreen forest, hill forest, scrubland, bamboo and shade (missing data). Most of these classes, such as bamboo, evergreen closed forest, evergreen open forest, agriculture, streambed and water are classified based on the spectral color information of the Landsat image. For the remaining classes, training areas (sample areas) were selected based on not only the secondary data sources (ground truth points /existing land use map) but also the reflection values of image segments.

The following expert rules were also used in segmentation-based land use classification to get reliable classification results:

- evergreen closed and evergreen open forest exist up to 900 m.a.s.l. (Kermode, 1964),
- evergreen open forest with rattan can grow between 230 - 365 m.a.s.l. (depending on the species),
- kaing grass cannot be found in areas which are more than 2.5 km away from water (based on the Kaing Grass Survey conducted by WCS, Myanmar Programme),
- Hilly evergreen forest is found in areas of elevation between 900 and 1500 m.a.s.l. (Kermode, 1964), and,
- Hill forest is found in areas more than 1, 500 m.a.s.l. (Kermode, 1964).

Class related features were also considered. For example, kaing grass was chosen as a class similar to agriculture. For the analysis of segment's spectral reflection, a natural color (3, 2, 1) was also used for kaing grass.

The problematic classes were also encountered especially for the classes of agriculture and kaing grass. In this context, manual classification and visual interpretation based on ground truth knowledge were also used. By using a standard false color composite (image bands 4, 5, 3), automatic classification was executed.

Then, the result of segmentation-based classification was exported in shape file format (polygon features). To change to raster format, it was then imported into GIS software

(ArcGIS). The required mapping operations were performed in ArcGIS, such as smoothing long and narrow polygons, digitizing river classes, merging the further required classes and filtering unclassified pixels.

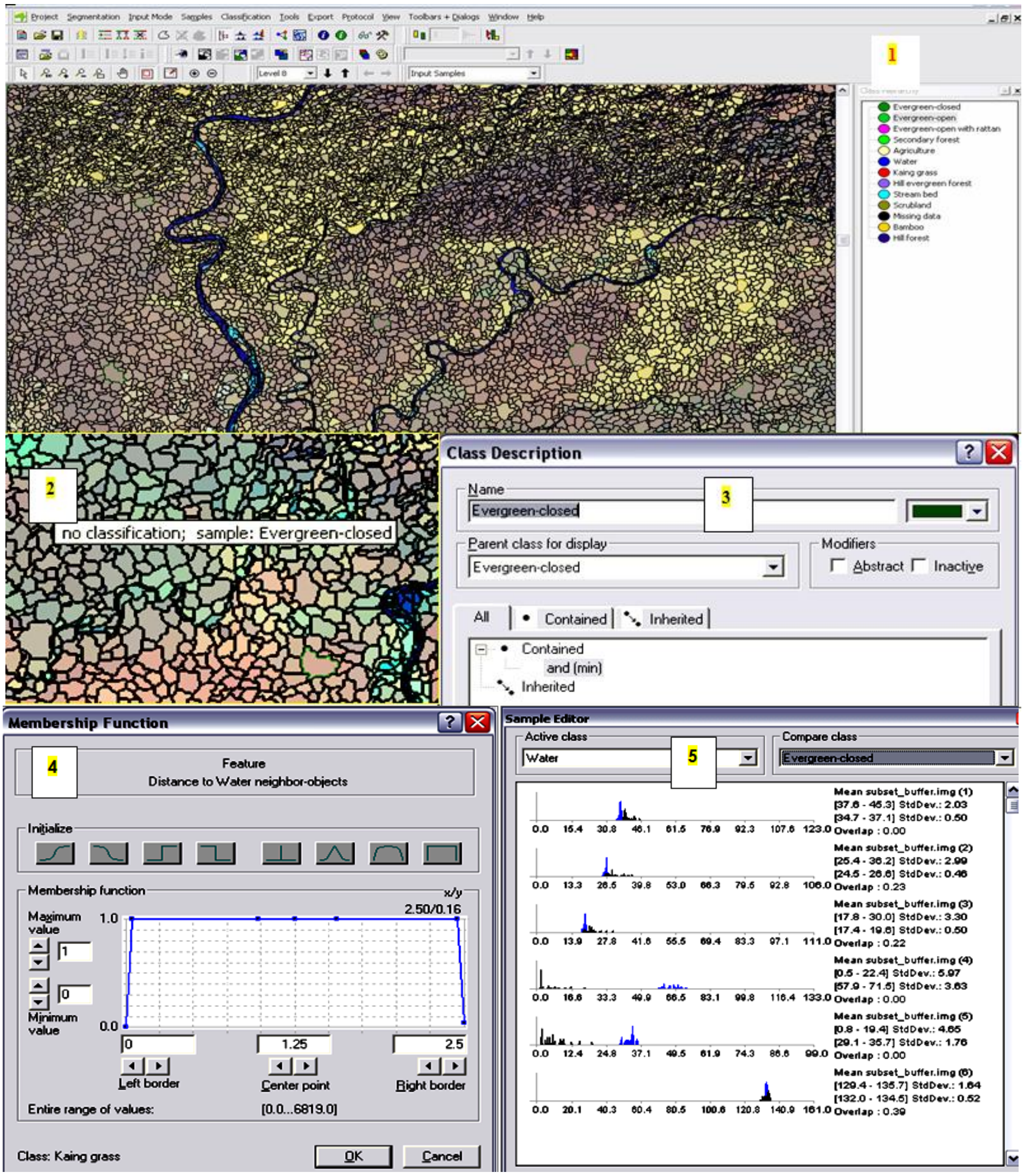


Figure 23: Illustration of segmentation boundaries (1), sample selection (2), class description (3), inputting class related features (4) and comparison between selected classes (5).

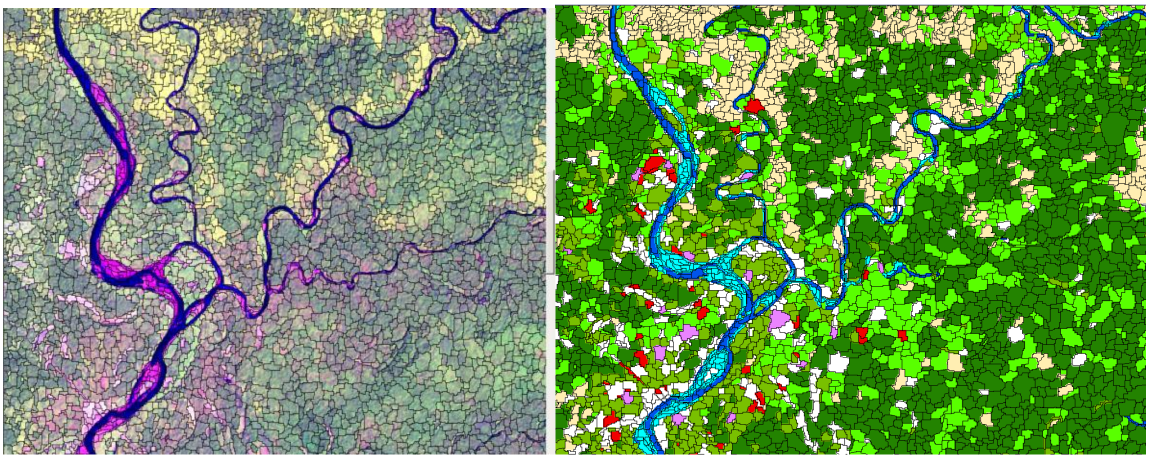


Figure 24: The maps showing before and after classification in eCognition.

3.4.3 Vector to raster transformation method

Before changing to raster format, an outer rectangle shape file must be created in order to set all the classes within the same extension. The point features had to be changed into polygon features before doing raster formatting to do union with the outer rectangle shape file. The value of 0 and 1 were added to the attribute table, forming '1' for the variable value and 0 for the value of outer cells of that variable. Raster format of value (0, 1) was produced in this way. A setnull process was used to change 0 values to no data to get (nodata, 1) of raster map to assign any cell with a value equal to '0' to 'no data' and have the remaining cells retain their original value.

All over the Hukaung valley rivers of 1st, 2nd and 3rd order are distributed as shown in Figure 25. Access to water sources is essential for the tiger and its prey species.

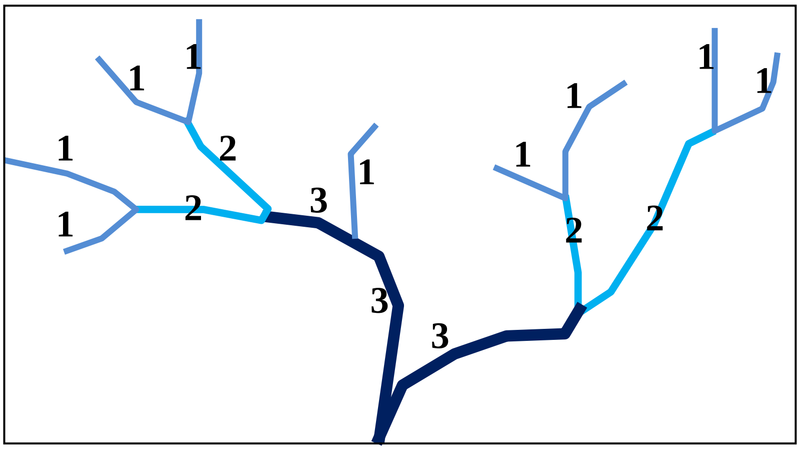


Figure 25: An example of river orders distributed all over the study area. In this figure, the widest river-3 was denoted as 3rd order, river-2 as 2nd order and river-1 as 1st order.

For getting more detailed information on tiger-water source relationships, river-3(5 pixels wide), river-2 (3 pixels wide) and river-1 (1 pixel wide) were subdivided and created in raster format of broad, narrow and small rivers respectively.

In addition, the important features such as the Ledo road and settlement classes were also digitized based on the spectral reflection pattern in the satellite image as well as GPS locations of villages from the socioeconomic survey. These features were transformed into raster format. Then, 3 river classes, Ledo road and settlement classes were merged into segmentation-based land use maps. Then, all land use classes were exported individually by using the tool of "extraction by attributes".

Using a raster calculator, all land use classes were merged again group by group to overlap systematically, forming the first group of line format (road and river1, 2, 3). Second, open land form (settlement, agriculture, kaing grass, scrubland, etc.) and the final one of forest form (evergreen closed forest, evergreen open forest, and so on). Then final land use classification map was created and the unclassified pixels were delineated using the filtering process (3*3 moving window) in the raster calculator tool of ArcGIS. The unknown pixels were assigned with the value of the most frequent occurring class around these pixels. The value of the rectangle in the filtering process will be increased and this process will terminate when all the unclassified pixels were filled with one individual value. Then the isnull process was carried out to lose the cells of non-focal majority.

The core area (1, 713 km^2) was cut out from the classified area of 3200 km^2 (16 land use classes). After extracting, the segmentation-based classification land use map retained 14 land use classes, which will be shown in the results section. Then, human-factor variables were also prepared by means of conversion tool (vector to raster). For e.g. settlement area (vector) was transformed into a raster layer by the following procedures:

- make union of the settlement_vector polygon and the outer_rectangle_shp.file
- set the value 1 and 0 in 'add field' of attribute table to change polygon to raster format (0, 1)
- perform setnull process to get raster format (no data, 1)
- extract by a mask to get the desired extension.

3.5 Scale level of analysis

This is a landscape level study based on remote sensing data (satellite image). A fundamental characteristic of an image in remote sensing is the spatial resolution or the size of the area on the ground which is represented by one pixel in the image. According to this, spatial resolution is considered as similar to the scale of the observation (Hay *et al.*, 1997). Scale related concepts are becoming important in the fields of biology, geography, geomorphology, hydrology, landscape ecology and meteorology (Clark, 1990; Turner *et al.*, 1991; Lann and Quattrochi, 1992) in order to explore multi-scale data and models (Hay *et al.*, 1997). Scale levels of the landscape area are a critical concept for habitat modeling. There are several reasons to set a scale in a prominent role (e.g. issues in environmental and biosphere require understanding of patterns and processes at very large scales). Information of habitat cover on the landscape scale play an important role in studies of large home ranged species like the tiger and migratory birds. Turner *et al*. (2001) defined a landscape as an area that covers habitat types of spatial heterogeneity or ecological processes which are relative to the organism or processes of interest. Scale influences the conclusions drawn by an observer and it must be suited to the process of interest.

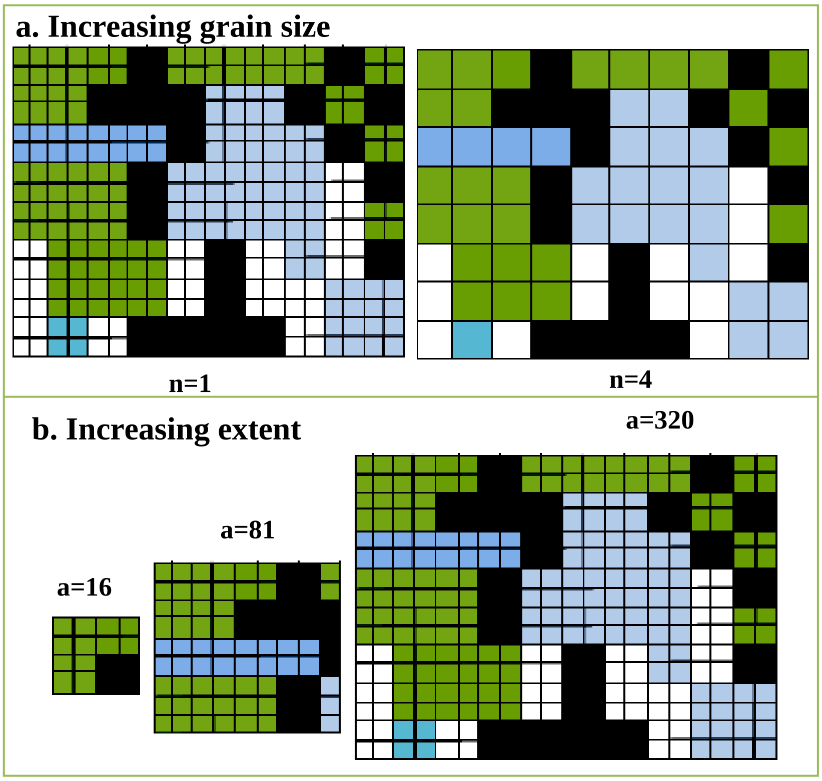


Figure 26: The two major components of spatial scale in a landscape data set: grain size (a) and extent (b); the number of cells (grains) are indicated by 'n' and the total area (extent) is indicated by 'a' (Modified from Turner et al., 1989).

Scale is a prominent topic in landscape ecology (Turner *et al.*, 1989). Landscape studies can define the spatial distributions of habitat types that are required for long-term survival of species. Spatial scale is characterized by its two major components: extent and grain (see Figure 26). The extent means the size of the overall study area. For example, maps of 100 km^2 and 100,000 km^2 in size differ in extent by a factor of 1000. The grain denotes the cell size for the grided maps or the minimum unit of maps composed of polygon (Turner *et al*., 2001). For example, a fine grain map can provide the information of 1 km units whereas a coarser one can organize that of 10 km (Turner *et al*., 1989). Schneider (1994) defined the scale used for the time, space and mass component of any quantity by stating that "*scale denotes the resolution within the range of a measured quantity*." More detailed definitions of scale-related definitions are shown in Table 9. For drawing a habitat suitability map for a wide-ranging species, such as the tiger, it is necessary to choose a large scale of landscape that includes a good habitat. The habitat suitability model (ENFA) can only handle the input data of raster maps with the same scale.

Spatial extent: All the ecogeographical (EGV) map layers were prepared in grid format and brought exactly to the same spatial extent to make them overlayable in the BioMapper software. The spatial extent of the study area lies between North latitude 26° 24′ 55″ to 26° 47′ 51″and East longitude 96° 15′ 55″to 96° 56′51″ with an area of 1, 713 km^2, comprising various landscape types such as evergreen closed forests, evergreen open forests, bamboo forests, rattan forests, settlements, road, etc.

Spatial resolution: The grain (cell size) of the maps was 30 m by 30 m which is the cell size provided by Landsat 7 imagery. As spatial reference, the UTM-Universal Transverse Mercator system (datum WGS 84 and zone 47 North) was used for all map layers.

Table 9: Definitions of scale-related terminology and concepts (Source: Turner et al. 1989)

Term	Definition
Scale	The spatial or temporal dimension of an object or process, characterized by both grain and extent
Resolution	Precision of measurement: grain size, if spatial
Grain	The finest level of spatial resolution possible for a given data set: e.g., pixel size for raster data
Extent	The size of the study area of the duration of time under consideration

3.6 Accuracy assessment of segmentation-based classification (Confusion/Error matrix)

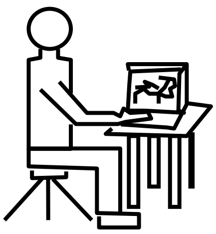
In this study, the confusion matrix was used to assess the accuracy of the segmentation-based classification. Other names of confusion matrix include error matrix or-more general-contingency table. It is the only way to effectively compare two maps quantitatively (Congalton and Green, 1999). The goals of an accuracy assessment are to assess how well classification was conducted. The confusion matrix summarizes the relationship between two data sets: the classification (map) and existing reference information.

Figure 27 is used for an example of a confusion matrix. The columns of this matrix represent the actual "ground truth" from field verification done at sample point, while the rows shows the actual classification for those sample points. The diagonal line represents the points (or image pixels) classified correctly whereas the off-diagonal elements were miss-classified. The overall classification accuracy can be computed as the total number of correctly classified elements (the sum of the diagonal cells) divided by the total number of cells.

Classified Data	Reference Data				
	D	C	AG	SB	Row total
D	65	4	22	24	115
C	6	81	5	8	100
AG	0	11	85	19	115
SB	4	7	3	90	104
Column total	75	103	115	141	434

Land Cover Categories
D = deciduous
C = conifer
AG = agriculture
SB = shrub

OVERALL ACCURACY
(65+81+85+90)/434=
321/434 = 74%



Per class:

Producer's accuracy
D = 65/75= 87%
C = 81/103= 79%
AG = 85/115= 74%
SB = 90/141= 64%

User's accuracy
D = 65/115= 57%
C = 81/100= 81%
AG = 85/115= 74%
SB = 90/104= 87%

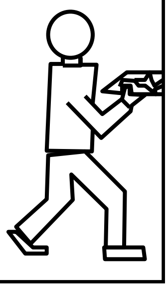


Figure 27: An example of an error matrix to quantify classification accuracy (Modified from Congalton and Green, 1999).

The confusion matrix also provides accuracies for each land use class based on class-specific exclusion errors (omission errors) and inclusion errors (commission errors) (Card, 1982; Congalton, 1991; Congalton and Green, 1999).

Omission errors can be calculated by dividing the total number of correctly classified sample units in a category by the total number of sample units in that category from the reference data (the column total) (Congalton, 1991; Story and Congalton, 1986). This measure is often called the "producer's accuracy," because from this measurement the producer of the classification will know how well a certain class was addressed (Congalton, 1991).

Commission errors are calculated by dividing the number of correctly classified sample units for a category by the total number of sample units that were classified in that category (the row total) (Congalton, 1991; Congalton and Green, 1999; Story and Congalton, 1986). This measure is also called "user's accuracy," indicating for the user of the map the probability that a sample unit classified on the map actually represents that category on the ground (Congalton and Green, 1999; Story and Congalton, 1986). For further analysis of accuracy of the classified map, the Kappa Statistic is frequently used to calculate the degree of agreement between a reference map obtained by a random classification having the same marginal frequencies like the actual classification and the actual classification itself. The Kappa statistics K_{hat} is computed as follows:

$$\hat{K} = \frac{\text{observed accuracy - chance agreement}}{\text{1 - chance agreement}}$$

$$\hat{K} = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{k}(x_{i+} \times x_{+i})}$$

Where k is the number of rows (land-cover classes) in the matrix,

x_{ii} is the number of the observation in row i and column i (main diagonal)

x_{i+} is the marginal total for row i

x_{+i} is the marginal total for column i *and*

N is the total number of observations.

If the Kappa value is greater than 0.8, a strong agreement or accuracy between the actual classification result and the ground reference information is indicated. If the Kappa value is between 0.4 and 0.8, it represents a moderate agreement or accuracy between the classification map and the ground reference information. If it is less than 0.4, poor agreement or accuracy is suggested.

There were 14 land use classes in the produced land use map. The existing reference land use map (from WCS, Myanmar Programme) does not have the classes of settlements and road and hence they were not included in the accuracy assessment. They were exclusively merged into the segmentation-based classification map in ArcGIS (see Section 3.4.2). The missing data (i.e. no data) were also ignored for the accuracy assessment. Altogether 10 classes were included in the accuracy assessment of this study. ArcGIS (Hawth's tools) is used to generate random points. Excel software is applied to perform the following steps to calculate the error/confusion matrix. The class of kaing grass is used to demonstrate an example (see Figure 28). First of all, the segmentation-based land use map and the reference map (from WCS, Myanmar Programme) were adjusted to have the same extension.

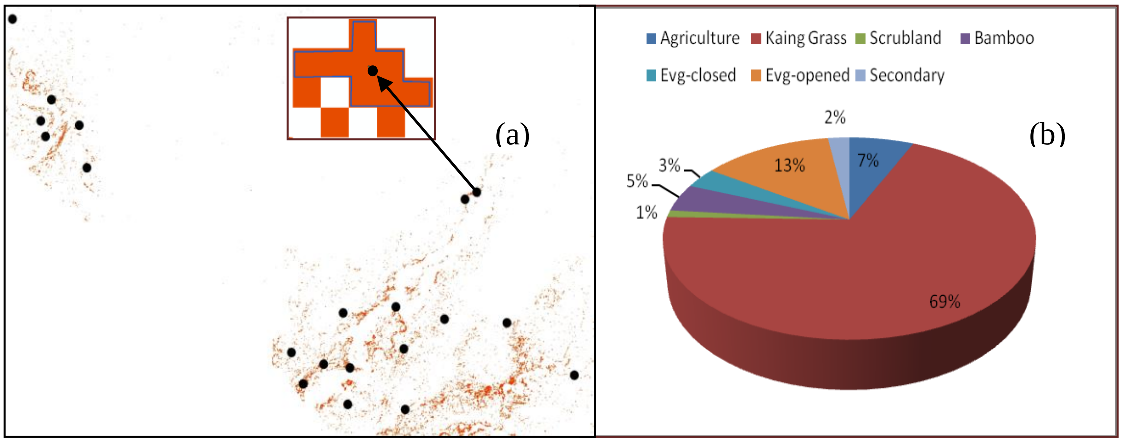


Figure 28: (a) Random points on polygon features of reference kaing grass (100%) and (b) classified cell area of kaing grass (69%) in segmentation-based classification land use map.

The more detailed method for the preparation of the confusion matrix for this study is as follows:

1. The polygon features were extracted from the reference land use map
2. 20 random points were generated on each class of polygon features by using Hawth's tool in ArcGIS

3. Polygons (shape file) were drawn around each random point. The polygon must be as pure as possible (preferably100% of the respective class)
4. Then the segmentation-based land use map was extracted by using a mask of individual reference rasters to define the expected classified area in the segmentation-based classification map

The reference map could not support the secondary forest data for this study. The points from the field survey were used as the reference data for this class. For the accuracy assessment of the class secondary forest, polygons (5*5 pixels/0.02km^2) around each point were drawn around each reference point. The unit of the matrix is “cell numbers”. Finally, the confusion matrix was expressed by counting and comparing the cell numbers. The result of the accuracy assessment will be shown in the results section.

3.7 Identification of Tiger Preferences and Transformation Method into Quantitative EGVs

Ecogeographical variables (EGVs) are spatially defined variables that are associated to any location of the study area and describe the situation quantitatively (Hirzel *et al.,* 2004). From the literature review and expert interviews, the tiger preferences of certain vegetation classes as well as its behavior to avoid certain man-made landscape features were identified. Four major variables groups of potential tiger habitat preferences that were possibly translated into distances, areas and lengths were examined. Altogether 36 potential tiger preferences were identified. Four major variables groups of potential tiger habitat preferences that were possibly translated into distances, areas and lengths were examined.

1). **Topographical variables**: Digital elevation model (DEM) provided the topographical variables that were included to account for the effects of landscape characteristics on the species’ occurrence. Seven variables were identified for topographies as shown in table 10. They are slope (%), elevation (meters above sea level) and distance to flat/north/east/south/west. Elevation values of every landscape cell were generated by cell-based extraction. Spatial analyst tool in ArcGIS was used to calculate the slope (%) of each pixel. Biomapper software cannot meaningfully process the aspect values. So, layers of aspects as flat, north, east, south, and west were exported individually in the raster calculator. The aspects were calculated in a way that all aspect angles of the full 360˚ circle were covered by one of the following aspect classes (class names given in blackets):

For flat (flat): VALUE eq-1,

For the north aspect (north): VALUE>=0 AND VALUE < 45 OR VALUE>=315 AND VALUE<360,

For the east aspect (east): VALUE>=0 AND VALUE <315,

For the south aspect (south): VALUE>=315 AND VALUE<225,

For the west aspect (west): VALUE>=225 AND VALUE<315.

Then an Euclidean distance tool was used to generate distance measure ranges for each aspect. 7 quantitative maps of geographical variables were created (see Figures in results section).

Table 10: Environmental variables for the quantitative mapping of tiger preferences with respect to topographical variables.

Preferences	EGVs name	Definition	Source
Slope -<30% slope	slope	Slope of every landscape cell	Latt *et al*. (2004).
Elevation -(200-800 m.a.s.l)	elevation	Elevation of every landscape cell	WWF, WCS *et al.* (2010)
Aspect -close-by areas with all aspects around the tiger presence cell (Seem to use the aspect of mountain slopes to avoid extreme conditions) of direct sunlight)	dist_flat dist_north, dist_east, dist_south, dist_west,	Distance (m) to the next cells	Karanth (2006)

2). **Human factor variables**: Tigers avoid the sites that are affected by human activities, including the variables of settlement, road, dynamite fishing areas, gold-mining areas and areas of logging and non-timber forest product collection. Human interference variables were included to account for the impact of human-induced activities on the tiger habitat. Except road, the qualitative variables of human interferences were transformed into quantitative variables by means of distance analysis by using the tool of Euclidian distance of ArcGIS. Length of line features were used to conduct the length analysis. The road is line features and so a length analysis was applied using the tool linestats in ArcInfo with the common line: (l_road_core) = LINESTATS(road), NONE, 30 , LENGTH, 3000), meaning that inside a radius of 3,000 m, running meters of all line features were added up, the resulting raster have a spatial resolution of 30 m. Each raster cell contains the running meter sum as cell value. The applied radius of 3,000 m was based on an area that falls into the range of the tiger's daily movement (2-11 km).

Table 11: Environmental variables for quantitative mapping of tiger preferences for avoiding human interferences.

Preferences	**EGVs name**	**Definition**	**Source**
- too close to settlements	settlem_dist	Distance (m) to next settlement polygon	Own hypothesis
- too much human traffic noise	le_road	Length of road in 2826 ha plot around focal cell (m)	WWF, WCS *et al.* (2010)
- too close to noise from dynamite fishing	dyfish_dist	Distance (m) to next dynamite fishing area	Own hypothesis
- too close to gold-mining areas	goldm_dist	Distance (m) to next gold mine area	Latt *et al.* (2004)
- too close to NTFPs collection areas	ntfps_dist	Distance (m) to next areas of NTFPs collection	Own hypothesis
- too close to logging areas	loggin_dist	Distance (m) to next logging area	Own hypothesis

3). **Variables referring to tiger hunting places**: The variable of common hunting places was collected during interviews with local hunters. These areas are indeed preferred as hunting places by the tiger because they can support high densities of prey species. The saltlicks are the areas used by the animals to supplement their nutrition. Lots of prey species can be observed around the saltlicks. Saltlick locations used by prey species were assumed to be preferred habitat of the tiger.

Table 12: Environmental variables for the quantitative mapping of tiger preferences with respect to tiger hunting places.

Preferences	**EGVs name**	**Definition**	**Source**
- close-by areas with high prey densities around tiger presence cells	comhup_dist	-Distance (m) to next common hunting place polygon	- Own hypothesis - Correlation between tiger and human hunting places
- close-by areas with regular prey species appearance	saltli_dist	-Distance (m) to next saltlick point	- Own hypothesis, - Correlation between the tiger and nutrient source for prey species

The vector formats of saltlick points and common hunting places (polygons) were rasterized to get the EGVs referring to tiger hunting places. The Euclidean distance function in the spatial analyst tool of ArcGIS was used to transform qualitative to quantitative ecogeographical variables referring to tiger hunting places.

4). **Landscape compositional variables**: Landscape composition variables are essential environmental variables and concern whether there is enough cover for stalking, water supply and food resources for wildlife. These variables were derived from the segmentation-based land use classification map, including river 1, river 2, river 3, evergreen closed forest, evergreen open forest, and evergreen open with rattan forest, secondary forest, agriculture, bamboo forest, kaing grass area, scrubland and streambed. Quantitative landscape compositional EGVs were created by using software products of ArcGIS and ArcInfo. Distance-related, area-related and length-related measures were utilized to derive quantitative landscape compositional variables (see in Table 13). Altogether 21 EGVs were created for the landscape compositional group. By using the tool of Euclidean distance, distance related variables were created. The output raster contains the range of distances from every cell to the closest source cell (see Figures of Results session). Focal statistics calculation was applied to produce the area-related variables. 3,000 m radius was used based on tiger's daily movement. The output raster explains the area sum of each land use class in a 2,826 hectare plots around the focal cell. Linestats in ArcInfo was also used to develop length related EGVs. The used command line for an example of river1_length was: (river_1_length) = LINESTATS(river_1), NONE, 30, LENGTH, 3000). This process summed up running meters of river_1 lines inside the analysis radius of 3,000 m around the focal cell and produced a raster with 30 m resolution, the raster cells containing the running meter sums. The other line structures such as river2, river3 and road were also created by changing the name of variables shown in red color in the command line.

Table 13: Environmental variables for quantitative mapping of tiger preferences with respect to landscape composition.

Preferences	EGVs name	Definition	Source
-Sufficient length of river1,2,3 classes River3=75m buffer River2= 45mbuffer River1=15m buffer	le_river1,2,3	Length of rivers in 2, 826 ha plot around focal cell (m)	- Own hypothesis - Expert interviews

Table 13(cont.): Environmental variables for quantitative mapping of tiger preferences with respect to landscape composition.

Preferences	**EGVs name**	**Definition**	**Source**
-Sufficient area of evergreen closed forest -Nearest distance to next evergreen closed forest polygon	evgclos_area evgclos_dist	-Area sum of evergreen closed forest polygons in 2,826 ha plot around focal cell -Distance (m) to evergreen closed polygon the plot around focal cell	- Johnsinth (1983)
-Sufficient area of evergreen open forest -Nearest distance to next evergreen open forest polygon	evgop_area evgop_dist	-Area sum of evergreen opened forest polygons in 2,826 ha plot around focal cell (ha) Distance (m) to evergreen open polygon in the plot around focal cell	- Karanth and Sunquist (2000), - Khan et al. (2007), -Vegetation type as shelter and food resource for prey species - Expert interviews
-Sufficient area of evergreen open forest with rattan -Nearest distance to next evergreen open forest with rattan polygon	ha_rattan dist_rattan	-Area sum of evergreen open with rattan polygons in 2,826 ha plot around focal cell -Distance (m) to evergreen open with rattan polygon in the plot around focal cell	- Vegetation type as shelter and food resource for prey species - Expert interviews
-Sufficient area of secondary forest -Nearest distance to next secondary forest polygon	secfor_area secf_dist	-Area sum of secondary forest polygons in 2,826 ha plot around focal cell -Distance (m) to secondary forest polygons in the plot around focal cell	- Vegetation type as food resource for prey species and as corridor - Expert interviews
-Sufficient area of agriculture -Nearest distance to next agriculture polygon	agri_area agri_dist	-Area sum of agriculture in 2,826 ha plot around focal cell -Distance (m) to agriculture polygon in the plot around focal cell	- Vegetation type as food resource for prey species - Expert interviews
-Sufficient area of bamboo -Nearest distance to next bamboo polygon	bambo_area bambo_dist	-Area sum of bamboo polygons in the 2,826 ha plot around focal cell -Distance (m) to bamboo polygon the plot around focal cell	-Vegetation type as shelter and food resource for prey species -Expert interviews
-Sufficient area of kaing grass -Nearest distance to next kaing grass polygon	kaing_area kaing_dist	-Area sum of Kaing grass in 2,826 ha plot around focal cell -Distance (m) to Kaing Grass polygon in the plot around focal cell	- Area used as hunting ground -Expert interviews, literature review

Table 13(cont.): Environmental variables for quantitative mapping of tiger preferences with respect to landscape composition.

Preferences	EGVs name	Definition	Source
-Sufficient area of scrub land -Nearest distance to next scrubland polygon	scrubl_area scrubl_dist	-Area sum of scrub land in 2,826 ha plot around focal cell -Distance (m) to scrub	-Vegetation type as food resource for prey species - Expert interviews and literature
-Sufficient area of stream Bed -Nearest distance to next streambed polygon	streamb_area streamb_dist	-Area sum of streambed in 2,826 ha plot around focal cell -Distance (m) to	-Area used as corridor -Expert interviews, Literature review

3.8 Creation of Species Presence Boolean Raster Map

The tiger presence Boolean or binary (presence/absence) raster (Idrisi format) map is important as it is the response variable for habitat modeling. This map was used as the dependent variable in ecological niche factor analysis by linking it with independent EGVs in the BioMapper software.

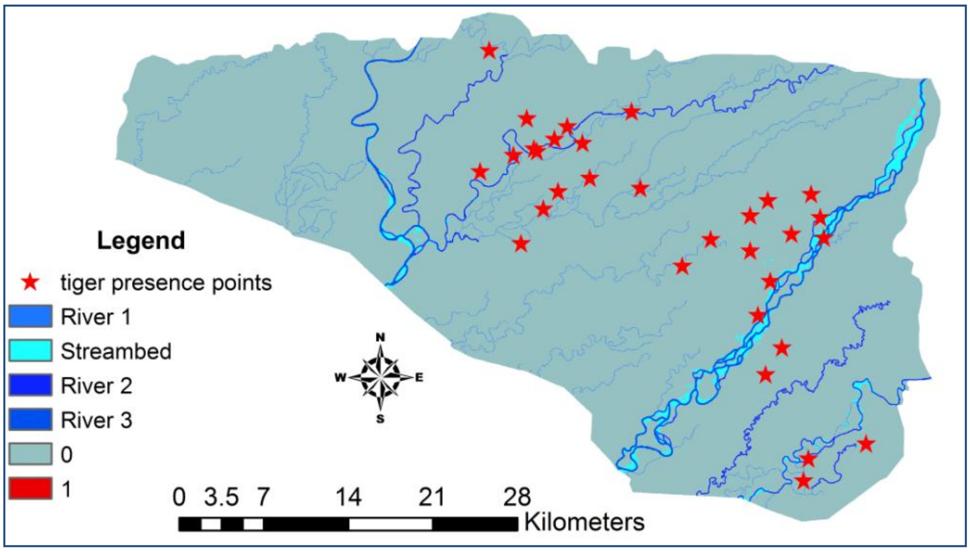


Figure 29: Boolean map (0/1) together with the distribution of tiger presence points in the years 2002-2004 (red stars).

Altogether 31 tiger points (see in Figure 29) were collected from the camera trap survey and track and sign data. Tiger presence points were transformed into raster cells by using the analyst tool of ArcGIS in order to convert to raster format. Then, the species presence raster map was extracted to get the same extension like the independent variables layers.

This map was prepared in the form of a Boolean 'work' map. The cells in this map are composed of a value of '1' or '0'. '1' means a proof of tiger presence in the respective landscape cell and all other cells carried the value '0'. However, a '0' was no proof that the underlying area was unsuitable for the species (Hirzel *et al*, 2004).

3.9 EGVs Categorization for Variable Selection

EGVs categorization became necessary to ensure model reliability. The underlying principle was that ENFA cannot be computed with more EGVs than species presence points (31 in this study) (Hirzel *et al.*, 2002). Therefore, the 36 EGVs were divided into three main categories:

a) Topographical features: elevation, slope and aspect (cell-based extraction)

b) Land use related features such as forest and open land (area/length and distance)

c) Human-factor features (length and distance).

Practically, it is best to have at least three times more presences than EGVs in an ENFA model. It was hence not allowed to use more than 10 EGVs at a time, because of the 3l points of species presence available for this study. As a consequence, the large category of land use related features was subdivided into four groups (see Table 14), with a total of 6 groups of quantitative EGVs. Finally, a separate ENFA was performed for each group on the 1st level of the variable selection.

1. Topographical EGVs,
2. Forest distance-related EGVs,
3. Forest area-related EGVs,
4. Open land distance-related EGVs,
5. Open land area-related EGVs, and
6. Human factors EGVs.

A very detailed structure of the EGVs categorization for the separate ENFA model runs on level-1, level-2- (area-related EGVs and distance-related EGVs), level- 3 (forest-related EGVs and open land-related EGVs) and their score calculation is shown in Appendix VII. The preliminary and final model can be seen in the results section.

All these variables were prepared in the form of grids with cell sizes of 30*30 m. Then, they were transformed into an Idrisi format for feeding the ENFA model. Topographical variables were used to explore tiger preferences for elevation, slope and aspect. Land use features were included not only to explore the species' habitat preferences for vegetation types but also to explore the avoidance behavior of the species regarding these land use classes. The human-factor features were also included to analyse the impact of human-induced activities on the tiger habitat.

Table 14: Categorization of EGVs to ensure model reliability. Each color in the table represents one group of EGVs to perform separate ENFA runs for on level 1.

EGVs 30*30m/IDRISI	Area/Length-related(ha/m)	Distance-related (m)	Cell-based extraction
I. **Topographical features**		1.Aspect-flat 2.Aspect-north 3.Aspect-east 4.Aspect-west 5.Aspect-south	6. Slope (%) 7.Elevation (m. a. s. l)
II. **Land use related features**	**Forest** 8.Evergreen-close 9.Evergreen-open 10.Secondary-forest 11.Bamboo 12.Evergreenopen_rattan **Open land** 13.River-large (length-m) 14.River-narrow(length-m) 15.River-small (length-m) 16.Streambed 17.Agriculture 18.Kaing-grass 19.Scrubland	**Forest** 20.Saltlicks 21.Evergreen-close 22.Evergreen-open 23.Secondary-forest 24.Bamboo 25.Evergreenopen_rattan **Open land** 26.Streambed 27.Agriculture 28.Kaing-grass 29.Scrubland	
III. **Human-factor features**	30.Road (length-m)	31.Settlement 32.Logging 33.Dynamite fishing 34.Goldmining 35.NTFPs_collection 36.Common hunting places	

3.10 Preparation of EGV Layers for the Statistical Model

Normality testing is an important concept in the preparation of statistical modeling. If the data are not normally distributed, the result may lead to incorrect conclusions as well as biasing effects on correlation coefficients (Hatcher *et al.*, 1994). Ecological niche factor analysis requires normality. So, it is important to test the normality assumption before using ENFA.

Before building the statistical habitat model of the present study, the distributions of EGVs, were tested for normality by using software SAS. The program procedures, Univariate and Capability were performed for each EGV. The outputs are as follows:

1) **A moment table** that contains the mean, standard deviation, variance, skewness, kurtosis and test for normality together with other statistics (Hatcher *et al.*, 1994)

2) **A Quintiles table** provides mode, median, 25^{th} percentile, 75^{th} percentile, and related information (Hatcher *et al.*, 1994)

3) **An extreme observations table** that gives the information of the five highest values as well as five lowest values of analyzed variables along with missing values (Hatcher *et al.*, 1994)

4). A **histogram** and **boxplot** along with normal probability plot. The capability procedure routines of pp-plot, qq-plot, gchart and histogram were also performed to test for normality. The general form for the SAS program to perform the normality test of a variable can be seen in the Appendix V.

Regarding the positive values of skewness and kurtosis, each variable in the analysis carried a longer tail and an off-centered peaked distribution. According to pp-plot, gchart, qq-plot and the histogram, it can be assumed that the samples were not drawn from a normally distributed population. For this study, mainly the *p* value of the Kolmogorov-Smirnov (KS) test was checked to decide whether the distribution of each EGV is normally distributed or not. For all EGVs, *p* values of KS showed less than 0.05, meaning all analyzed EGVs showed a statistically significant departure from normality. Box-Cox transformation is a particular approach to normalize data sets which are not approximately normal. The Box-Cox linearity plot provides a proper way to find a suitable transformation without involving a lot of trial and error fitting (Handbook of Statistical Methods, 2003). A "Box-Coxised" map gives better results than a "brute" map (Hirzel *et al.*, 2002). According to the results of a normality test in SAS, all 36 EGVs were significantly different from normality. The Box-Cox algorithm of the BioMapper software can normalize EGVs. Box and Cox (1964) developed the procedure for estimating the best transformation to normality by means of the following formula:

$Y' = (Y^{\lambda} - 1)/\lambda \quad (\text{for } \lambda \neq 0)$

Where Y'= transformed variable value, λ = transformation parameter

Y' = ln Y (for λ= 0, the natural log of the data is considered instead of using the above formula).

The vertical axis of Box-Cox normality plots represents the correlation coefficient from the normal probability and the horizontal axis the value of λ. An example for a variable before and after Box-Cox transformation is given in Figure 30.

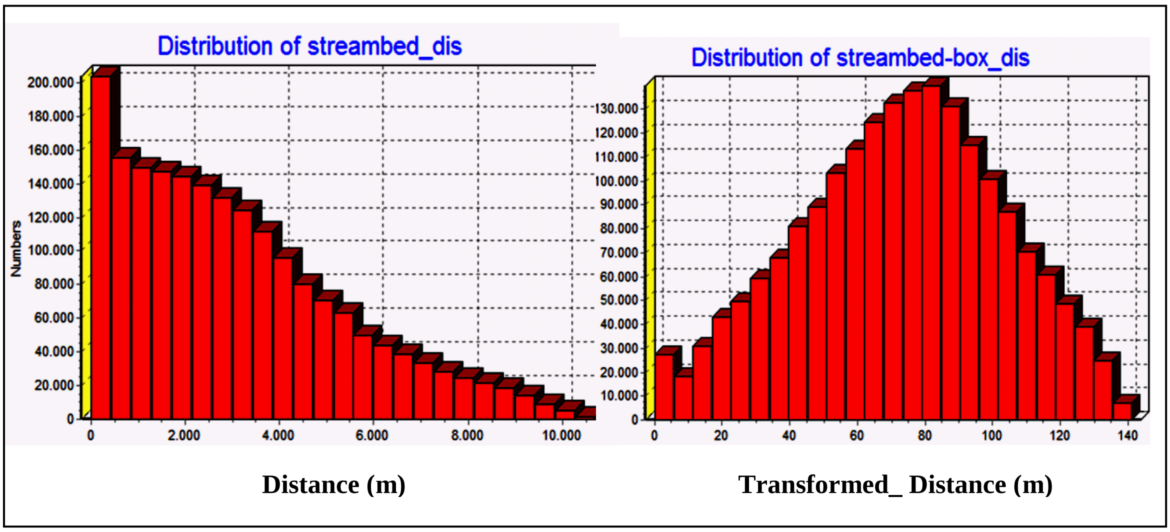


Figure 30: Variable of distance to streambed (m) was normalized by using the Box-Cox algorithm in the BioMapper software 4. The left figure represents the distribution before the transformation and the right one the resulting histogram after the Box-Cox transformation.

3.11 Presence-only Habitat Suitability Model; Ecological Niche Factor Analysis

Ecological Niche Factor Analysis (ENFA) is a multivariate empirical approach to study geographic species distributions. It does not require absence data. The working principle is based on the procedures of:

- Summarizing all variables into a few uncorrelated, ecologically relevant factors, and

- Computing suitability functions by comparing environmental variable values of species presence cells with respective mean values of the entire study area.

It is built on the concept of two fundamental assumptions: Marginality and specialization. If the species distribution mean differs from the global distribution mean ($m_S \neq m_G$) (see Figure 31), this is called the marginality (*M*). Formally it can be shown by the mathematical equation 1.

$$M = \frac{|m_S - m_G|}{1{,}96 * \sigma_G} \quad \textbf{(eq.1)}$$

Where ***M*** = The marginality of a species

m*s* = The mean of the species distribution

m*G* = The mean of the global distribution

σ*G* = The variance of the global distribution

A large value (close to one) of the marginality means that the species lives in a very particular habitat in the reference study area. Division by σ_G is needed to remove any bias introduced by the variance of the global distribution. The coefficient weighting (1.96) *σ_G assures that the marginality value lies between zero and one.

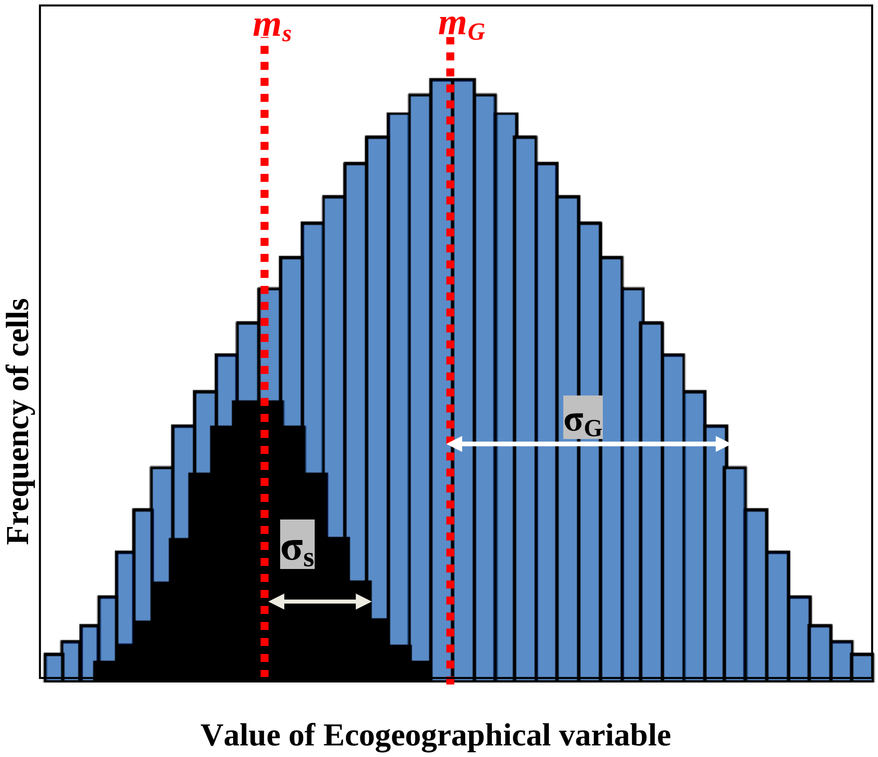


Figure 31: Marginality and specialization value represented for one variable. The dark area means the species distribution on that variable whereas the blue area represents the distribution for the whole set of cells. The difference in distribution means of a variable for species presence cells (m_s) and the global set of landscape cells (m_G), quantifies the species marginality. Specialization is the ratio of standard deviation of the global distribution σ_G to that of the species distribution σ_s (Modified from Hirzel et al., 2002).

A middle value (close to 0.5) denotes species habitat which is not too different from the mean condition of the reference area. But, a larger value (close to 1) means that the species has a particular habitat preference regarding the reference area. This equation (1) mainly explains the principle of the method. The operational equation of marginality to be implemented using BioMapper software is as follows:

$$M = \frac{\sqrt{\sum_{i=1}^{V} m_i^2}}{1.96} \qquad \textbf{(eq. 2)}$$

Where ***M*** = The overall marginality to compare species' marginalities within different study areas

m_i = The marginality of the focal species on each EGV, in units of standard deviations of the global distribution

The higher the coefficient values of an EGV the further the species departs from the mean available habitat regarding the corresponding variable (Hirzel *et al.*, 2002). Negative coefficients on the marginality factor express that smaller values of an EGV are preferred by a species whereas positive coefficients shows a species preference for higher values of the corresponding EGV.

Specialization defines how much different is the variance of the EGV values which can be found in species presence location than the global variance; it is known as the ratio of the variance of the global distribution (**σ_G**) to that of the focal species (**σ_S**). It can be expressed by Equation 3:

$$S = \frac{\sigma_G}{\sigma_S} \qquad \textbf{(eq. 3)}$$

S = The specialization of a species

σ_G = The variance of global distribution

σ_s= The variance of species distribution

The higher the specialization factor the stronger is the contribution of that EGV to species specialization. Equation (3) mainly expresses the principle of the ENFA method. The optional definition of specialization implemented in the BioMapper software is:

$$S = \frac{\sqrt{\sum_{i=1}^{V} \lambda_i}}{V} \qquad \textbf{(eq.4)}$$

Where ***S*** = Overall specialization (range from 1 to infinity),

V = The number of EGVs

λ_i = The ratio of the variance of the global distribution **(**σ_{Gi}**)** to that of the species distribution **(**σ_{si}**)** for any EGV condition in the model

The larger the global specialization value becomes the narrower the species niche (Bryan and Metaxas, 2007). Both global marginality and specialization values depend mainly on the reference area of the study (Derek *et al.*, 2009).

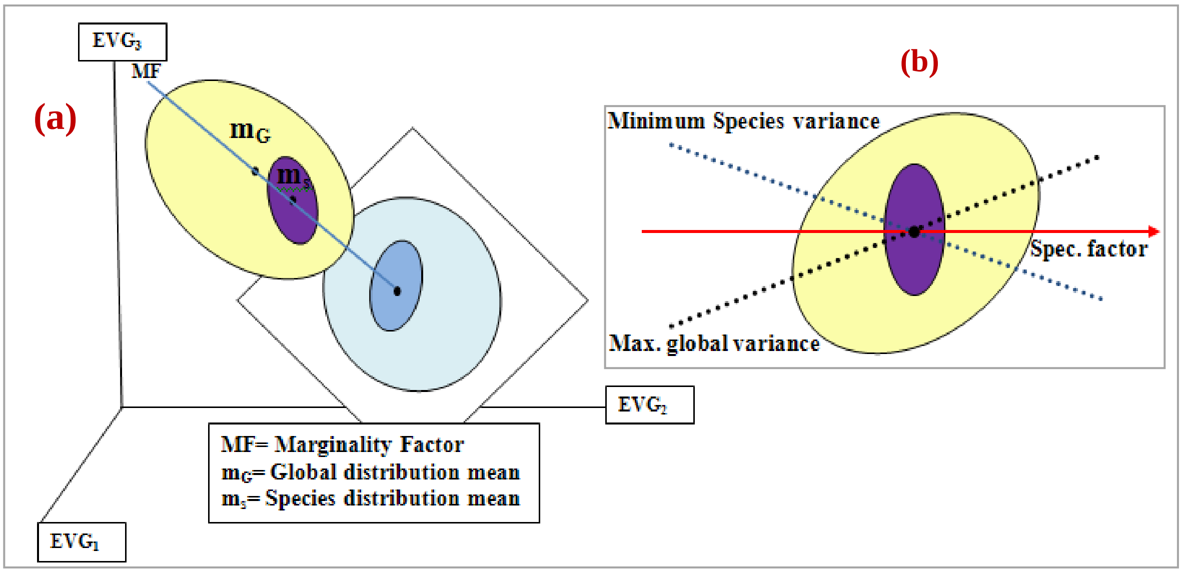


Figure 32: Geometrical interpretation of Ecological Niche Factor Analysis (Hirzel ,2005). (a). Extraction of marginality factor (b). Extraction of specialization factors (Modified from Hirzel et al., 2002).

Figure 32 (a) represents a 3 dimensional EGV space. The larger ellipsoid (yellow balloon) represents a global distribution of 3 EGVs, whereas the small violet balloon is the subset of cells of 3 EGVs at which the focal species was detected. The straight line is drawn running through the centre of the two ellipsoids and then it passes the global distribution mean and species distribution mean (μ_G) and species distribution mean (μ_s). The species marginality is the difference between global distribution mean and species distribution mean. To extract the specialization factors, two ellipsoids were projected onto a plane perpendicular to the marginality factor for changing the ellipsoids into a sphere (Hirzel *et al.*, 2002). Orthogonal to the marginality factor, a first specialization factor can be produced as uncorrelated factor by computing the axis that maximizes the ratio of the variance of the global distribution (yellow) to that of the species distribution (violet) (see Figure 32-b). The other uncorrelated specialization factors were produced by extracting subsequently and restored each EGV, describing how specialized the focal species is in the available condition of habitat in the study area. The successive specialization factors are ordered by decreasing coefficient value. Hence, most of the information is retained in the first few factors (Hirzel *et al.*, 2002).

The ENFA model normally applied Idrisi raster maps which are grids and have continuous values. Each cell of a map contains the value of one variable. Before conducting the ENFA, all the EGV maps are normalized as far as possible. The species Boolean map is used to link EGVs in the analysis. To avoid model overfitting because of the large number of EGVs and to assure model reliability, Hirzel *et al.* (2008) suggest to categorize EGVs into groups such as land use related features, geographical features, etc. ENFA can be computed separately group by group, keeping the best EGVs from each model run. The outputs of ENFA are:

a). **A score matrix** (cf. Table 15) which is ranking the environmental variables based on their importance for habitat selection in a study area. It can give the information of species-environment relationship by means of marginality and specialization values. In the rows of the score matrix the EGV contributions (variable coefficients) to each factor are given.

Table15: Score matrix sorting the EGVs by decreasing coefficient values of the marginality factor. The coefficient values on the marginality and specialization factors provide the basis for the ecological interpretation of species-habitat relationships.

EGVs	**Factors of Marginality and Specialization**			
	Factor 1 **100% marginality**	**Factor 2** **--% specialization**	**------**	**Factor n** **--% specialization**
Variable 1	Coefficient value$_{11}$	Coefficient value$_{21}$	------	Coefficient value$_{n1}$
Variable 2	Coefficient value$_{12}$	Coefficient value$_{22}$	-----	Coefficient value$_{n2}$
-----	-----	-----	-----	-----
Variable n	Coefficient value$_{1n}$	Coefficient value$_{2n}$	-----	Coefficient value$_{nn}$
Global				
Marginality	----			
Specialization	----			
Tolerance:1/S	----			

In the score matrix, coefficient values of the ecological niche factors explain how marginal and specialized the species are in terms of the various relevant EGVs (Hirzel *et al.*,2002). The first factor explains 100% of the marginality and it may also explain some amount of specialization. The next factors take account only for specialization. The coefficients' signs have meanings only for the marginality factor. These signs have no interpretation for specialization. A negative sign indicates a species' preferences for low value of the respective EGV whereas a positive sign indicates a preference for a higher value. A high value of global marginality (*M*) means the species range is different from average conditions of all EGVs. The species' tolerance is measured by the inverse of the specialization factors (Sattler *et al*., 2007). A low value of tolerance (close to 0) indicates that the species is bound to a narrow niche whereas a high value (close to 1) means the species accepts a wide spectrum of habitat conditions (Hirzel *et al.,* 2002). Habitat suitability of any cell for the global distribution is calculated by the first few important factors, accounting for 100% of marginality and some proportion of specialization. The best EGVs are determined by the highest coefficient values on marginality and specialization. The final ENFA model can be summarized by extracting the variables of highest scores.

b). **The Habitat suitability (HS) map** gives an area-wide prognosis of habitat quality/species spatial distribution. Hirzel *et al*. (2002) described standard robust methods to compute the suitability for the cells of the whole study area for the focal species. The detailed explanation of habitat suitability computation can be found in the published main ENFA paper of Hirzel *et al.* (2002). Habitat suitability maps created in the BioMapper software are based on four different habitat suitability algorithms, namely median, distance geometric mean, distance harmonic mean and minimal distance algorithms. Out of these four, the median algorithm is recommended to be used in the type of non-systematic species distribution data (Hirzel, 2004). Before BioMapper 3.0, median algorithm was the only available. It gives good results in most situations and can process quicker than the others. The other three algorithms have no assumption regarding the distribution of species points and are based on functions of the distance between the species occurrences in the environmental space. But in the case of small sample size, the Harmonic mean algorithm should be taken into account to get better results rather than the other three ones (Hirzel, 2004).

This study relies on a small number of species presence points. The Harmonic mean was suited for that small sample to create the tiger habitat suitability map (Hirzel, 2004). This algorithm is commonly used to define home ranges and activity centres from detection locations (Dixon and Chapman, 1994) in the geographic space. The function of this algorithm is:

$$H_H(\mathbf{P}) = \frac{1}{\frac{1}{N}\sum_{\substack{i=1 \\ \mathbf{P}\neq\mathbf{O_i}}}^{N} \frac{1}{\delta(\mathbf{P},\mathbf{O}_i)}}$$ **(eq. 5)**

Where ***H*** = The harmonic mean

P = Species' observation points

N = N-dimensional environmental space (the number of EGVs)

$\mathbf{O_i}$ = The harmonic mean of the distances of all observation points.

The effect of this mean algorithm is to give a (too) high weight to all observations while keeping the information of observation density in the factor space. Therefore, it has a tendency to overfit the data, which might be good when in case of small sample sizes (Hirzel, 2004).

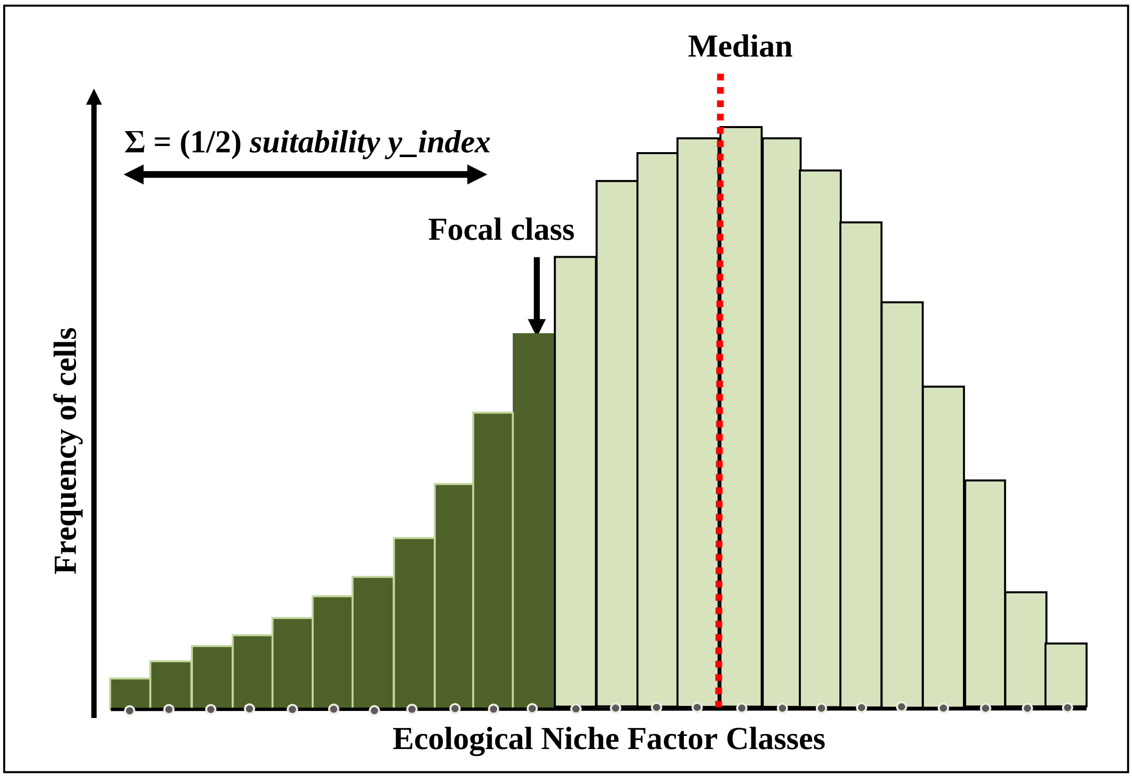


Figure 33: Computing habitat suitability by using the median algorithm; the farther the location (arrow) is from the median (dotted line), the lower its suitability (Hirzel et al., 2003). HS of any cell for the whole area is calculated from its location (arrow) relative to the species distribution (dark green) (Braunisch et al., 2008). The global suitability is derived by computing a weighted mean on these "partial suitabilities" (Modified from Hirzel et al., 2002).

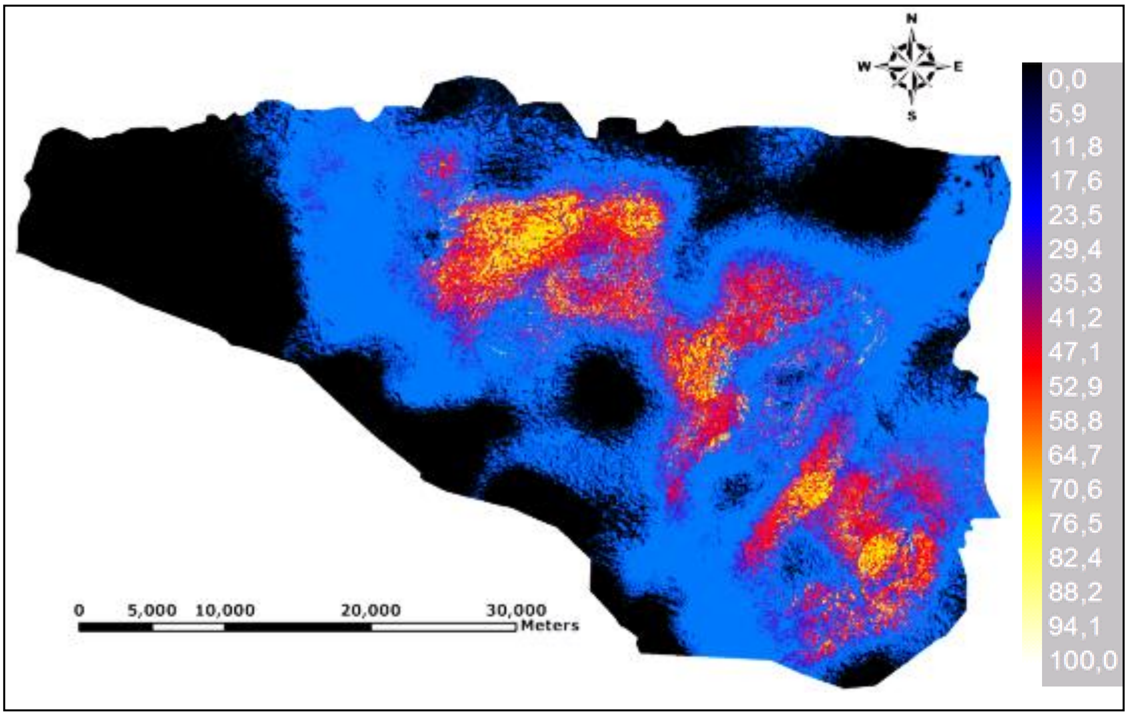


Figure 34: An example of a habitat suitability map computed with the ENFA model. The color bar on the right side represents the habitat suitability range (0 to 100); light shading denotes areas more suitable and dark shading denotes less suitable.

3.12 Model Evaluation

Model evaluation is of paramount importance for checking the predictive power of the habitat suitability map which is composed of pixels, carrying HS values from 0 to 100. The higher the value of the suitability index the more suitable is the habitat for the focal species. Most of the applied evaluation measures in former studies were based on presence- absence models by using the HS threshold of 0.5. Below the threshold unsuitable habitat is assumed while above the threshold the habitat expected to be suitable for the focal species.

Many evaluators are also based on a confusion matrix that counts presence and absence evaluation points (Fielding and Bell, 1997). Presence only model evaluation was applied for this study because absence data was not available for tigers. Presence only models are more difficult to assessing model evaluation than presence-absence models, because standard statistics such as Kappa cannot be applied. The main problem is that half of the confusion matrix is missing and so it is impossible to assess specificity (see Table 16).

Table 16: The confusion matrix used for model predictions against the actual observation. (a) for presence-absence models and (b) is for presence only models, missing half of the matrix.

(a)	***Observed 1***	***Observed 0***
Predicted 1	True +	False +
Predicted 0	False -	True -

(b)	***Observed 1***	***Observed 0***
Predicted 1	True +	**False +**
Predicted 0	False -	**True -**

Among the evaluation measures for the presence-only models, the continuous Boyce index has become the most accurate for computing the predictive power (Hirzel *et al.*, 2006). BioMapper software provides this threshold-independent evaluator; a way to relieve the threshold constraint is to partition the HS range into several bins, instead of only two groups. It calculates two frequencies for each class *i*, such as the predicted frequency (P_i) and the expected frequency (E_i). The predicted frequency can be calculated by Equation 6 and the expected frequency can be calculated by means of Equation 7.

$$P_i = \frac{p_i}{\sum_{j=1}^{b} p_j} \qquad \textbf{(eq.6)}$$

Where p_i = no. of evaluation points predicted by the model in HS class i

$\sum p_j$ = The total number of evaluation points

$$E_i = \frac{a_i}{\sum_{j=1}^{b} a_j} \qquad \textbf{(eq.7)}$$

Where a_i = area covered by HS class i,

$\sum a_j$ = The overall number of cells in the whole study area.

Finally the predicted-to-expected (*P/E*) ratio F_i for each class can be calculated by Equation no. 8.

$$F_i = \frac{P_i}{E_i} \qquad \textbf{(eq.8)}$$

A predicted-to expected ratio (F_i) curve can be derived that explains the model quality by measures such as robustness, HS resolution and deviation from randomness ($F_i = 1$). If F_i <1, the model delineates the suitable species areas (Hirzel *et al.*, 2006) and it can be denoted as unsuitable class. On the other hand, high suitability classes posses the value of

F_i >1. A good model shows a monotonic increase of the F_i curve (see the yellow dotted line in Figure 35).

But, the Boyce Index is sensitive to the number of HS classes and to their boundaries (Boyce *et al.*, 2002). To tackle this issue, a moving window of width (eg. W=10% or 10 on the HS range from 0 to 100) is used to substitute for fixed classes to compute the HS. HS of the first class covers the suitability range (e.g. 0, 10). Over the HS class, the F_i value is plotted as a line (red plotted line in Figure 35) at the average value of the HS class, e.g. 10/2=5. That means if the HS range of class i is 10, then the F_i value will be plotted over the HS value of 5. Then, window is shifted a small amount to the right covering the suitability range (1, 11) and the F_i value is plotted over the HS value of 6. This process continues until the window finally arrives at the end of the possible range (90, 100). By this iterating process, a continuous Boyce index can be computed to form a smooth P/E curve. In this study, according to the recommendation of Hirzel *et al.* (2006), the window size '20' was used to derive the best results.

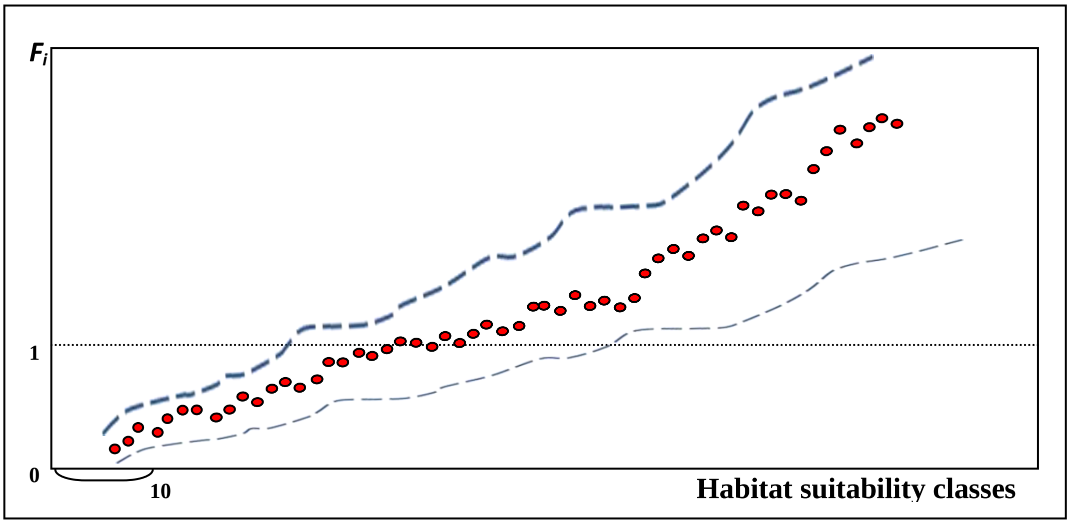


Figure 35: Computing the continuous Boyce index by using a moving window of width 10. HS of the first class covers the suitability range (e.g. 0, 10). F_i *value is plotted as a line (red plotted line) at the average value of the HS class (10/2=5). (Modified from Hirzel, 2006).*

A cross-validation process can be applied to calculate a confidence interval to address the applied ENFA model performance. It evaluates and compares the algorithms by dividing data into two segments: one is used to train a model algorithm and the other is used to validate the model (Refaeilzadeh *et al.*, 2008). K-fold cross validation is the basic form for the optimal use of small data sets to calibrate and evaluate a model (see Figure 36).

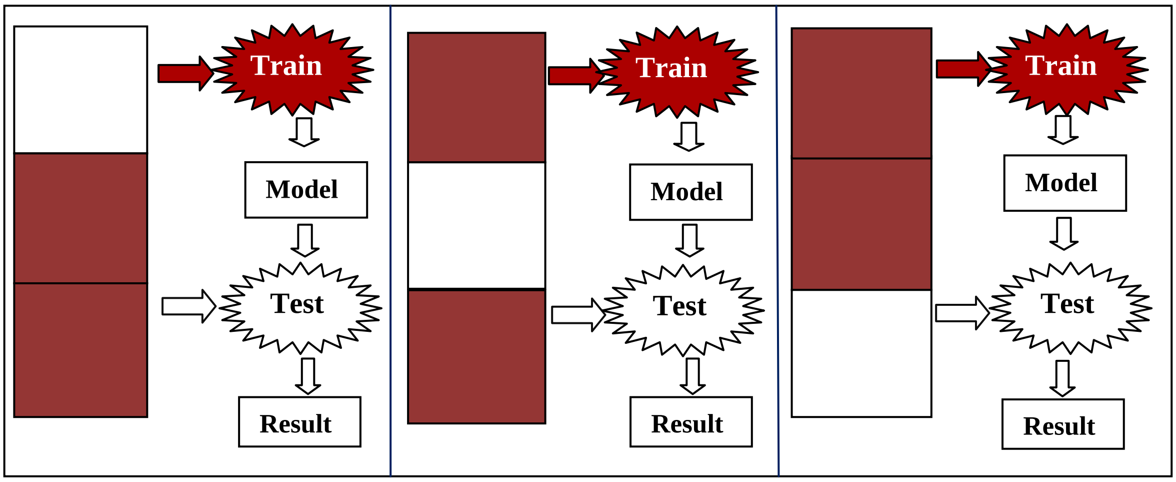


Figure 36: Procedure of three-fold/partition cross validation process (k=3); the darker colored data sets are used for calibrating/training while the lighter one is used for validation (Modified from Refaeilzadeh et al., 2008).

This study was based on a small dataset of tiger presence points (31). Hence, a cross-validation process was used to split the dataset randomly into "*k*" equally sized independent partitions. The '*k-1*' partitions were used to calibrate the model and the evaluation was done based on the left-out partition. This process is repeated '*k*' times and different partitions of the data set are moved out each time for validation. The central tendency and variance were assessed by the '*k*' evaluations. Based on the number of species' presence points, the number of partitions can be changed between 3 and 10. The shape, variance and confidence interval of curves resulting from the cross-validation process can provide meaningful interpretation. The variance reflects the model robustness whereas the confidence interval represents model sensitivity to calibration points. A constantly increasing linear curve results for a perfect model to give good information on all HS values. Figure 37 demonstrates examples of the best model that exhibits this monotonic increase of the F_i curve and a bad model which F_i curve falls down in high HS areas (Hirzel, 2006).

In this study, for model accuracy assessment, 6 groups of EGVs were categorized as level 1 of ENFA model. Then, EGVs that scored highest level were picked out and the next ENFA models were performed till to get the preliminary and final/best ENFA models. A variety of ENFA models covering all possible combinations of the best EGVs from variable selection with at least 6 EGVs at a time were performed (see Appendix VIII). Altogether 129 times of combination (eight out of 9, seven out of 9 and six out of 9 without replication) were performed. The model with the highest value of the Boyce index and at the same time good F_i curve characteristics was chosen as the best (final) model. According to the highest Boyce index value, a 3-fold cross validation (as in Figure 36) was used based on Huberty's rule in Biomapper 4. The data set was randomly split into 3 partitions of which 2 were used to calibrate whereas the remaining one was used to evaluate the model. Mean and standard deviation as well as a median and 90% confidence interval were used to assess the central tendency and variance of the model. The evaluation outputs can be found in the results section.

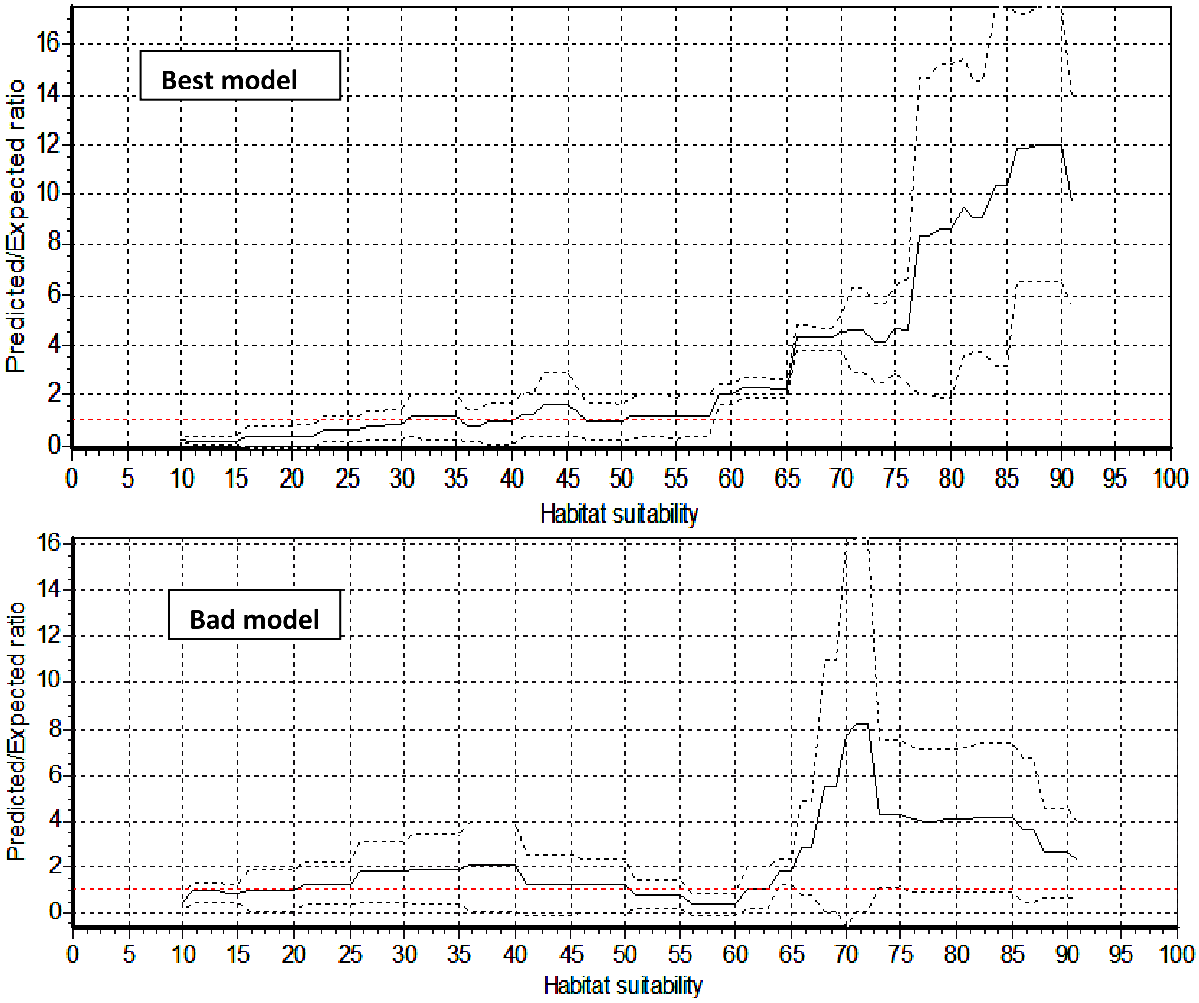


Figure 37: An example of the best model and the worst model. A good model has monotonic increase, stability variance, significant maximum F_i value in high HS areas whereas in a bad model the F_i values fall in high HS areas.

3.13 Reclassification of the habitat suitability map

Reclassification of the HS map is an important workstep to let the HS map show only a few classes, making it clearer for park managers to interpret and decide for priority protection areas for future reserve management. HS values (0 to 100) need to be classified into categories to get more clear and relevant predictions. The information of the $\boldsymbol{F_i}$ curve (Predicted/Expected ratio) helps to reclassify the HS maps into few meaningful habitat suitability classes (Hirzel *et al.*, 2006). The optimal number of categories on the horizontal habitat suitability axis can be defined by means of the confidence interval around the continuous $\boldsymbol{F_i}$ curve (cf. fig. 38). But the categories result from those points of the HS range, over which the curve is entering $\boldsymbol{F_i}$ values > 1 and over which it changes its curve shape. The line value of $\boldsymbol{F_{i=}}$1 denotes a boundary of the graph. Values lower than 1, indicate that the model predicts less presence than expected by chance (unsuitable habitat). On the other hand, values greater than 1 indicate a positive predicted/expected ratio and with constant increase of this ratio, the underlying HS range can be categorized into intervals of higher habitat quality (unsuitable, marginal, suitable and optimal habitats, see Figure 38).

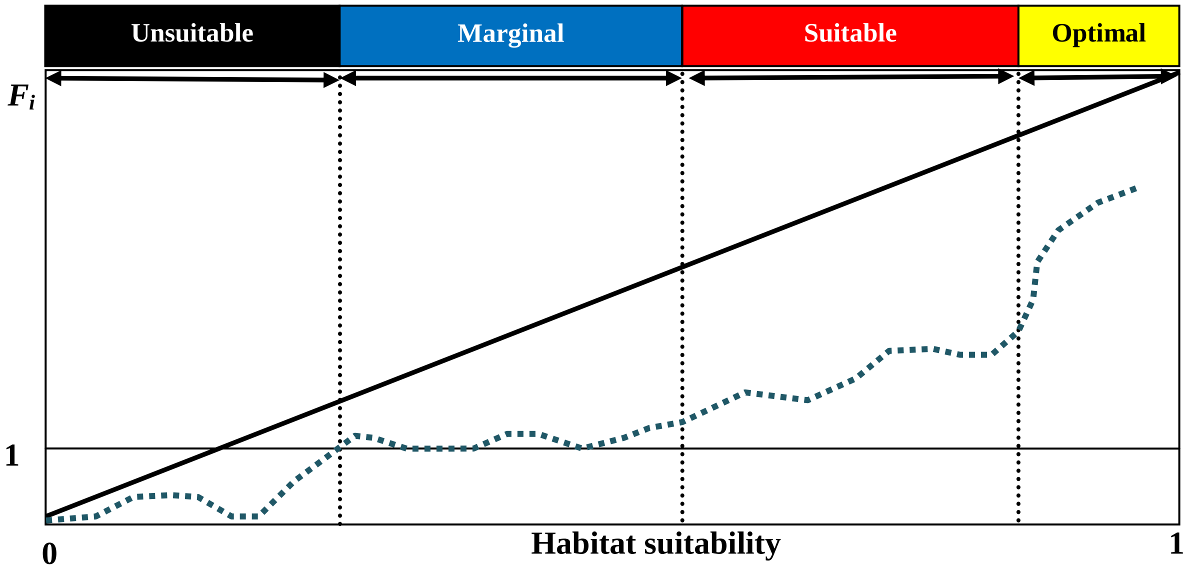


Figure 38: Reclassification of the HS map based on the trend of the $\boldsymbol{F_i}$ *curve. Arrow lines can be applied to define the HS category boundaries by drawing vertical lines. The horizontal line along* $\boldsymbol{F_i}$*=1 is the curve of a random model (Modified from Hirzel et al., 2006).*

3.14 Framework of the Study

The framework contains the input data sets, the main data preparation and data analysis steps. The data sets involved USGS Landsat image, reference/existing land use map, auxiliary data and species presence data. The auxiliary data includes Digital Elevation Model (DEM) and human factors. From the literature review and expert interviews, the tiger preferences of certain vegetation classes as well as its behavior to avoid certain man-made landscape features were identified. By using the satellite image and the existing reference land use map, object oriented image analysis was performed to create the land use map for the study season from which in subsequent steps landscape compositional variables were derived. Layers of topographical variables, human-factor variables and a tiger presence Boolean map were produced by using auxiliary data and tiger presence points (31). Then, the segmentation-based land use classification was assessed for accuracy using an error matrix. All the required variables were transformed into quantitative EGVs of Idrisi format and they were categorized into land use related features, topographical features and human-factor features. BioMapper Software 4 (Hirzel *et al.*, 2008) as a multivariate statistical tool was used to run the ENFA model for generating the score matrix and the tiger habitat suitability map. The ENFA model evaluation was performed to check the quality of model prediction. The software products of Erdas Imagine, eCognition and ArcMap /ArcInfo were used to produce GIS maps in this study.

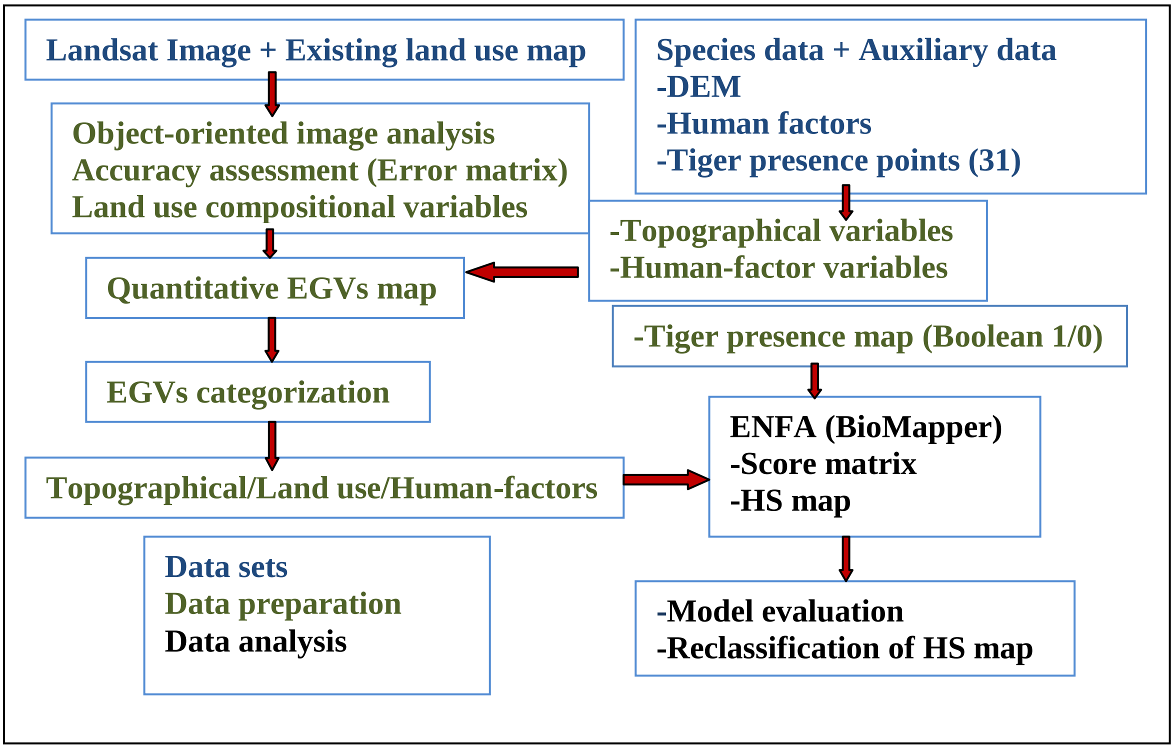


Figure 39: The framework summarizing the steps involved in the study. The blue colored text represents the data sets; the green text denotes data preparation and the black the data analysis.

4 RESULTS

4.1 Creation of Land Cover Map

A segmentation-based land use classification map of a Landsat 7 satellite image was created by an object-oriented image analysis with the help of an existing land use map and ground truth data. The classification results are displayed in Figure 40; the proportions of land cover categories are indicated in Table 17.

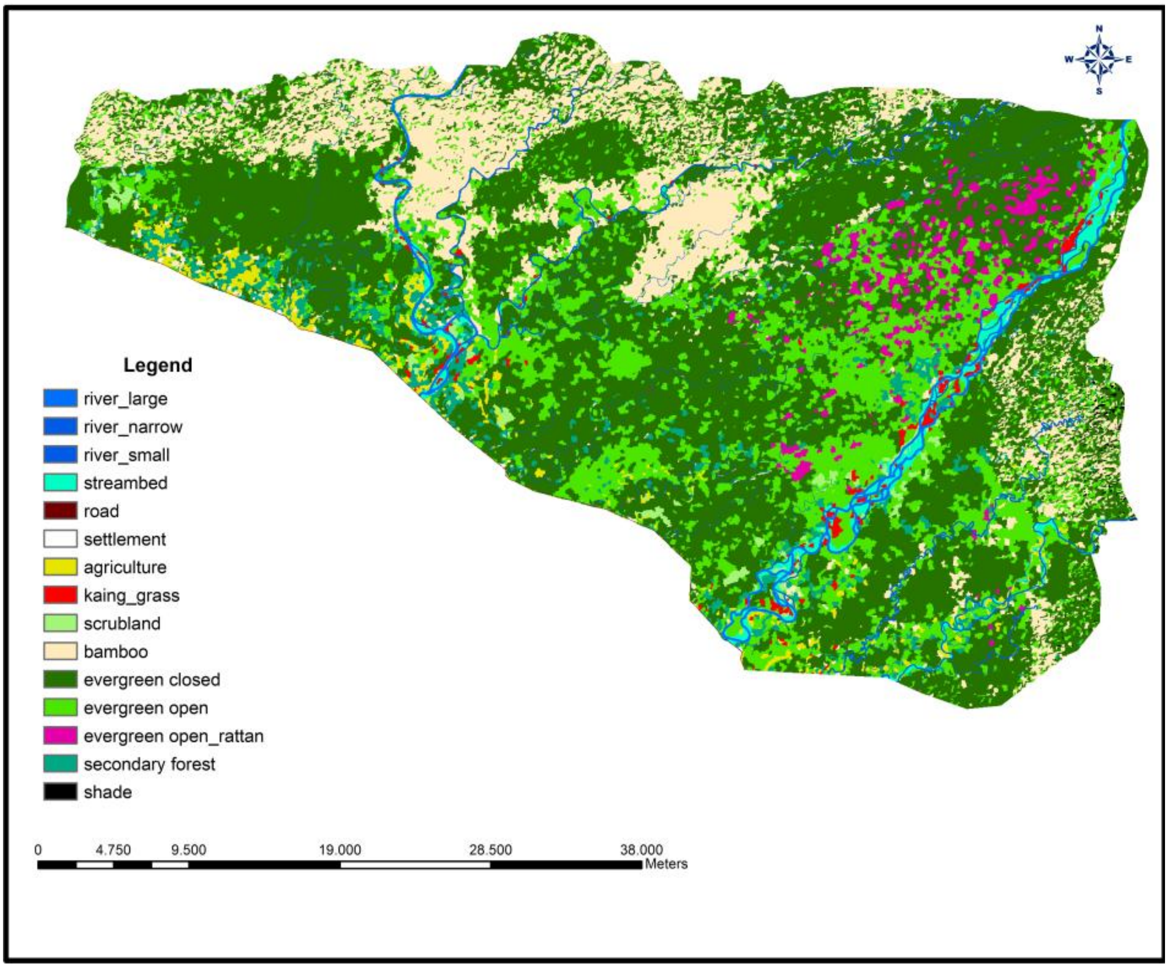


*Figure 40: The land cover categories of the core zone of HVTR, covering an area of 1713 km^2; pixel size is 30*30 m (classification based on merging of Landsat 7-Oct 2002 and Feb 2003 scenes).*

All these land cover and vegetation types are verified based on tiger ecology through literature reviews and experts' knowledge. Among all of them, evergreen closed forest (50%) displayed the most dominant land cover type of the core zone of the HVTR. Evergreen open forest and bamboo forest also occupied large proportion of the study area. The description of each category will be explained in Table 17.

Table 17: The spatial extents of land cover classification and their description.

Land cover categories	Area (km^2)	(%) of entire	Description
River-3-large	20.2	1.17	River with 75 m width
Rver-2-narrow	21.9	1.27	River with 45 m width
River-1-small	15.7	0.9	River with 15 m width
Streambed	24.5	1.43	Streambed along rivers which will be water surface in wet season
Road	1.58	0.1	Ledo road constructed in late colonial times at the end of World War II
Settlement	0.38	0.02	Villages along Ledo road
Agriculture	27.4	1.60	Permanent agriculture land on flat area near villages and shifting cultivation in the forest
Kaing Grass	11.78	0.7	Grass in wet areas
Scrubland	15.26	0.89	Land cover with shrubs or young stands
Bamboo	271.58	15.85	Bamboo break clearly identified as yellow feature on 4, 5, 3 band combination
Evg-closed	859.8	50.2	Evergreen closed forest with more than 60% of crown density
Evg-opened	345.3	20.15	Evergreen open forest or degraded evergreen forest with considerable open-space.
Evergreen oppen_rattan	35. 73	2.1	Rattan break was found along the Tawang river by ground survey. It is difficult to classify in other places.
Secondary forest	59.72	3.48	This class occurred after shifting cultivation.
Missing data	2.45	0.14	-
Total	**1713.4**	**100**	

4.2 Quantitative EGVs maps

4.2.1 Topographical EGVs

In ArcGIS, a cell-based extraction tool produced EGV layers of elevation and slope whereas a distance measure tool created a layer of aspect orientation (i.e. distance to flat/north/east/south/west slopes). The statistical descriptions derived for each topographical EGV are summarized in Table 18. The slope % ranges from 0-54.8 with mean 4.2% and the standard deviation of 5.3%. The core zone of Hukaung Valley Tiger

Reserve is located at elevation ranges from 185-612 meters above sea level with a mean value of 261 m.a.s.l. and a standard deviation of 41 m.a.s.l. Table 18 also shows statistical information of aspect orientation.

Table 18: Statistical description of topographical EGVs.

No.	EGVs	Measure	Min	Max	Mean	Std	Unit
1.	Slope	slope	0	54.8	4.2	5.3	%
2.	Elevation	elevation	185	612	261	41	m above sea level
3.	Aspect-flat-dis	distance	0	153	35	19	m
4.	Aspect-north-dis	distance	0	424	54	44	m
5.	Aspect-east-dis	distance	0	511	49	40	m
6.	Aspect-south-dis	distance	0	371	54	38	m
7.	Aspect-west-dis	distance	0	376	44	37	m

Figure 41 and 42 show some examples of maps of topographical EGV layers that formed the first group of input data to run the ENFA model. In each map, the red color denotes low values and the blue color denotes high values. The remaining EGV maps of distance to flat/north/west are shown in the Appendix IV.

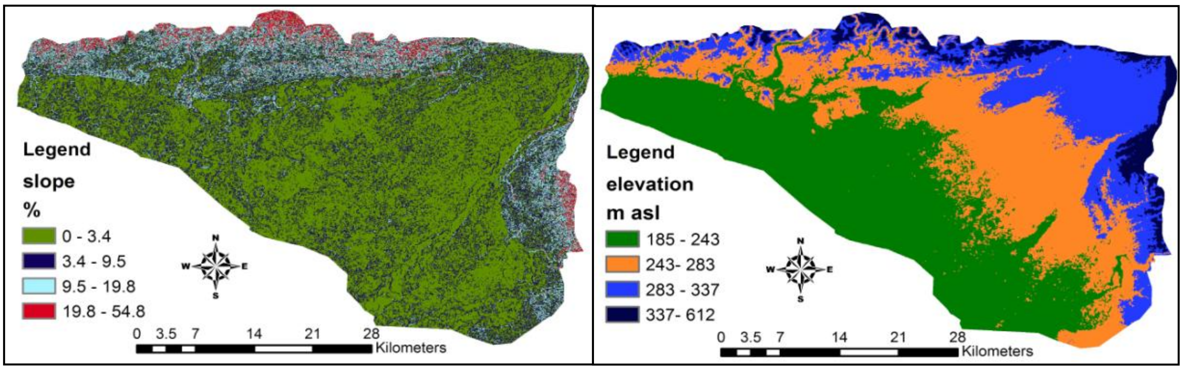


Figure 41: EGV layers of elevation and slope derived from of cell-based extractions.

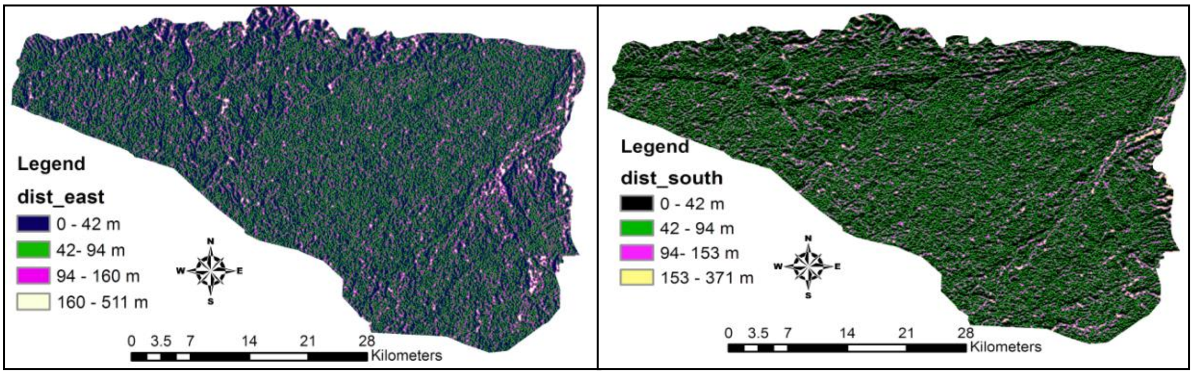


Figure 42: Two examples of EGV layers of distance to east and south aspect slopes.

4.2.2 Human-factor EGVs

For human-factor features, a distance measure was applied to produce the quantitative variable layers with regard to avoided features by the tigers. The statistical descriptions of each human-factor EGV are summarized in Table 19.

Table 19: The statistical description of human-factor EGVs.

No.	EGVs	Measure	Min	Max	Mean	Std	Unit
1.	Settlement_dist	distance	0	40074	15018	9032	m
2.	Logging_dist	distance	0	33153	11884	7482	m
3.	Dynamite-fishing_dist	distance	0	29208	9637	6409	m
4.	Gold mining_dist	distance	0	19591	6838	4348	m
5.	NTFPs collection_dist	distance	0	14652	5107	3340	m
6.	Common hunting places_dist	distance	0	14797	3842	2756	m

The quantitative variables of settlement and logging owed the longest distances such as 40,074 and 33,153 m respectively. Figure 43 explains the distances of the focal cells to the nearest cells of human-made features or areas of human activities (distance to settlement / common hunting places/dynamite fishing areas). The red color in each map shows the shortest distance whereas the green colour represents the longest distance. The remaining maps of human-factor EGVs are given in Appendix IV.

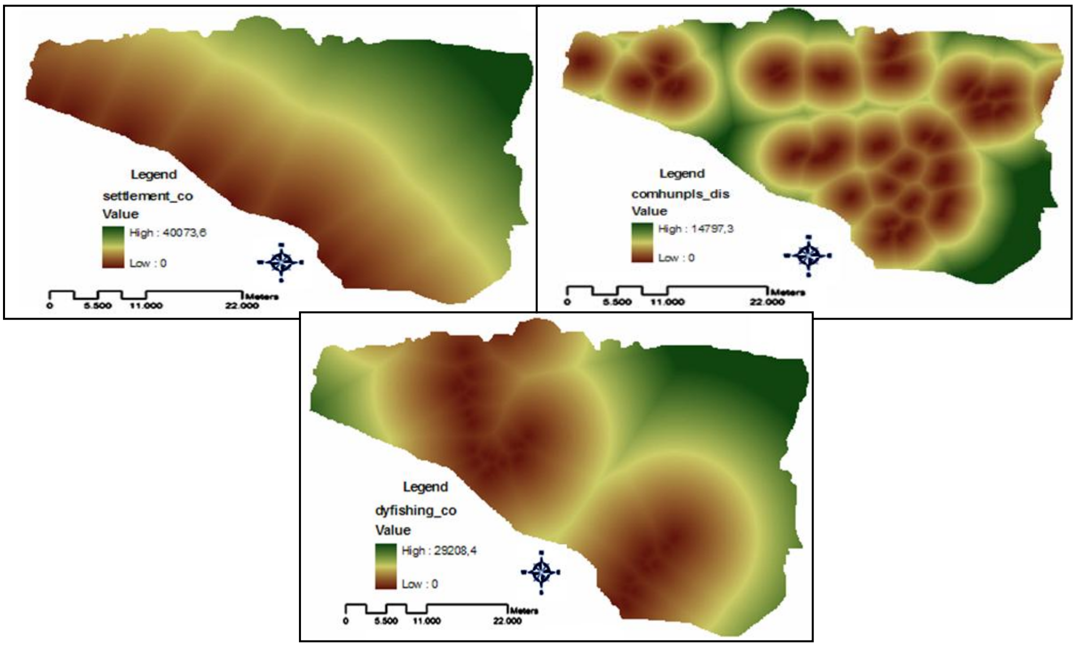


Figure 43: Example layers of distance-related human-factor EGVs with regard to tiger avoidance behavior.

4.2.3 Landscape-compositional EGVs

4.2.3.1 Distance and area-related landscape-compositional EGVs

Distance and area-related landscape-compositional EGVs were produced by using distance-measures and radius analysis tools in ArcGIS. The statistical descriptions (minimum, maximum, mean, standard deviation and units) for distance and area-related EGVs are summarized in Table 20. Again, for distance measures, e.g. evergreen-closed forest_dist, the distance measure explains how far a focal cell is from the nearest cell of that land cover class. In case of evergreen-closed forest_dist, values range from 0-1,682 m, with a mean value of 96 m and 175 m of standard deviation. The value '0' again means that the focal cell falls into the area of the respective land cover class.

For secondary forest_area, a radius analysis revealed the area sum secondary forest around the focal cell, ranging from 0.09-1,052 ha with a mean value of 104 ha and a standard deviation of 151 ha.

Table 20: Statistical description of area and distance-related landscape compositional variables.

No.	EGVs	Measure	Min	Max	Mean	Std	Unit
1.	**Evergreen-closed_dist**	**distance**	**0**	**1682**	**96**	**175**	**m**
2.	Evergreen-opened_dist	distance	0	1761	191	206	m
3.	Secondary Forest_dist	distance	0	4791	1045	832	m
4.	Bamboo_dist	distance	0	5580	801	941	m
5.	Evergreen-opened-rattan_dist	distance	0	42538	10346	10743	m
6.	Saltlicks_dist	distance	0	18619	7402	4096	m
7.	Streambed_dist	distance	0	10691	3044	2300	m
8.	Agriculture_dist	distance	0	9436	2637	1999	m
9.	Kaing grass_dist	distance	0	11137	3362	2235	m
10.	Scrubland_dist	distance	0	18360	5315	4355	m
11.	Evergreen-closed_area	area	197	2647	1421	512	ha
12.	Evergreen-opened_area	area	71	1910	566	345	ha
13.	Secondary Forest_area	area	0.09	1052	104	151	ha
14.	Bamboo_area	area	0.09	2334	467	554	ha
15.	Evergreen-opened-rattan_area	area	0.09	788	178	204	ha
16.	Streambed_area	area	0.09	506	69	97	ha
17.	Agriculture_area	area	0.09	964	75	132	ha
18.	Kaing grass_area	area	0.09	227	42	52	ha
19.	Scrubland_area	area	0.09	324	64	70	ha

Figure 44 and 45 show some example maps of distance and area-related EGVs with regards to landscape composition. In the distance-related maps, the dark-red color denotes the value '0' whereas the green colour represents the highest values of measurement.

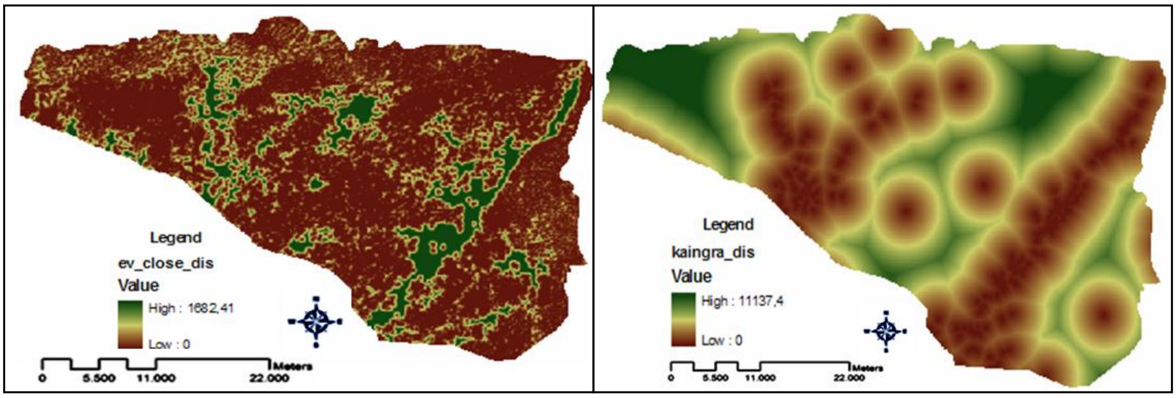


Figure 44: Example layers of distance-related landscape compositional variables: distance to evergreen closed forest and distance to kaing grass area.

In Figure 45, the dark-red color denotes a small area of the respective land cover class around the focal cell. The high values are represented by green color. High values in each EGV layer explain large areas of the added land cover whereas low values indicate small areas of that land cover around the focal cell. The value zero explains absolute absence of the respective land cover in the radius analysis. The remaining maps of distance and area-related EGVs are shown in the Appendix IV.

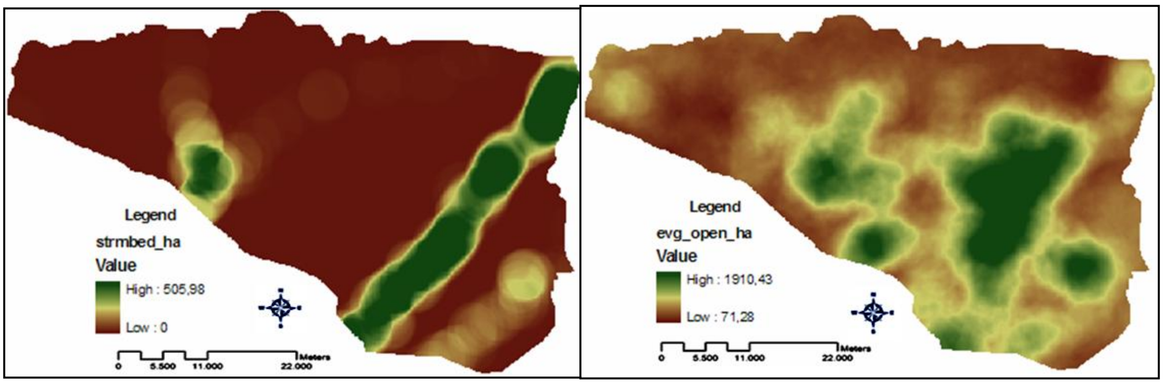


Figure 45: Example layers of area-related landscape compositional variables. The green symbolizes cells with large areas of streambed and evergreen open forests around the focal cell.

4.2.3.2 Length-related landscape compositional variables

Length-related variables were derived using a respective GIS tool (ArcInfo Line Stats) calculating the length of linear features in a circular neighborhood around each cell. Road, and three river classes were addressed as linear features. Table 21 shows the statistics derived from the line stats analysis. For example, for river-3 (the widest river class), its length ranges from 0-19836 m around the focal cells. The value zero denotes absolute absence of river-3 in the 3,000 m radius circle. A mean value of 2112 m and a standard deviation of 4249 m were derived.

Table 21: The statistical description of length-related EGVs in circular radius of 3,000 m.

No.	EGVs	Measure	Min	Max	Mean	Std	Unit
1.	Le_ river-1	length	0	44771	8623	7874	m
2.	Le_river-2	length	0	23213	3899	4865	m
3.	Le_ river-3	length	0	19836	2112	4249	m
4.	Le_ road	length	0	6623	465	1477	m

Examples of length-related variables are shown in Figure 46 in which the value on the scale bar represents the extent of the length possessed by the linear landscape features. The remaining length-related EGVs maps will be attached in Appendix IV.

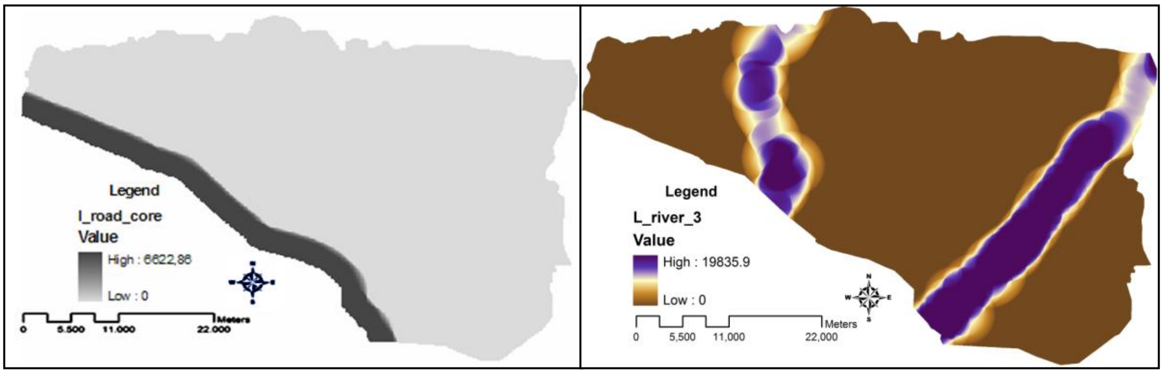


Figure 46: Example maps of length-related EGVs: Length of road elements (left) and of river-3 elements (right) in a circular analysis window around each landscape cell.

All EGV maps of this study were generated based on the Universal Transverse Mercator (UTM) co-ordinate system. UTM allows for a continuous Cartesian co-ordinate system to measure the distances between points (Freer, 2004). All the EGV maps were created in Idrisi format and to be processed using BioMapper software. All EGVs maps of this study were produced using GIS-based distance measures, radius analysis (for length and area-related EGVs) and cell-based extraction. The distance measures provided the distance of the focal cell to the nearest cell of a certain land use class. In case the distance value was 0, the focal cell was located inside an area of the respective land use class. The radius analysis was performed to measure the area sum of selected land use classes around the focal cell as well as length of linear land cover features around the focal cell. For the radius analysis, a 3 kilometre radius was determined based on tigers' daily movements (2-11 km). A cell based extraction function produced a raster layers with cell values for slope

(%) and elevation (meters above sea level). Distances and lengths were measured in the projection unit (meters) and the area was measured in hectares.

4.3 Accuracy Assessment of Segmentation-based Land Use Classification Map

All remote sensing-based thematic maps may contain lots of errors due to geometric errors, incorrectly labelled training sites, un-distinguishable classes, etc. Owing to this, the produced land use map required an accuracy assessment before doing a scientific investigation. Without doing this, the classification accuracy for the map is unknown.

For this study, the classification accuracy was assessed using a confusion matrix or error matrix which produces three basic accuracy measures: producer's, user's and overall accuracy. This was achieved by using the land use map of WCS (Myanmar programme) which was produced based on ground truth areas and comparing it with the classification result of the current study's land use map for the respective reference areas. The error matrix allows to perform this comparison on a category-by-category basis. The relationship between the two sets of information is presented in table 22: showing 79% of overall accuracy, 77% mean producer's accuracy and 73% mean user's accuracy.

Table 22: Confusion matrix that assesses the accuracy of segmentation-based land use classification. The main diagonal of the matrix (in red colour) contains the pixels that were allocated to the correct class. Offdiagonal pixels of the matrix represent commission and omission errors of the classification in comparison with the reference data.

	Name	Reference data (no. of cells)										Row	UA
	of class	W	SB	Agri	KG	ScrL	Bam	Evgclo	Evgop	R	SecF	Total	(%)
Classified Data (no. of cells)	W	370	170	2	0	7	8	28	0	0	23	608	61
	SB	41	1448	0	0	23	1	0	0	0	9	1522	95
	Agri	3	22	541	12	18	2	0	5	6	10	619	87
	KG	12	119	55	123	7	0	0	0	0	0	316	39
	ScrL	0	18	13	2	138	0	0	0	0	0	171	81
	Bam	7	0	0	8	9	1165	170	4	0	1	1364	85
	Evgclo	1	1	22	6	0	32	1378	10	23	20	1493	92
	Evgop	5	17	39	24	6	24	59	206	124	25	529	39
	R	0	0	0	0	0	0	3	0	340	0	343	99
	SecF	0	0	209	4	23	0	33	4	18	287	578	50
	Column total	439	1795	881	179	231	1232	1671	229	511	375	7543	Mean UA:73%
	PA (%)	84	81	61	69	60	95	82	90	67	77	Mean PA=77%	
	OA= Overall accuracy, PA= Producer's accuracy, UA= User's accuracy											OA= 5996/7543=79%	
W (water), **SB** (streambed), **Agri** (agriculture), **KG** (kaing grass), **ScrL** (scrubland), **Bam** (bamboo),													
Evgclo (evergreen closed forest), **Evgop** (Evergreen open forest), **R** (rattan), **SecF** (secondary forest)													

Omission errors correspond to non-diagonal column elements (e.g., 41 pixels of streambed plus 3 pixels of agriculture plus 12 pixels of kaing grass plus 7 pixels of bamboo plus 1 pixel of evergreen closed forest plus 5 pixels of evergreen open that should have been classified as 'water' were omitted from that category in the current classification). Producer's accuracy is a complement of the omission error.

The row totals shows the numbers of pixels assigned to the classes. Commission errors (errors of inclusion) are correspond to the off diagonal row elements (e.g., 170 pixels of 'streambed' plus 2 pixels 'agriculture' plus 7 pixels of scrubland plus 8 pixels of bamboo plus 28 pixels of evergreen closed forest plus 23 pixels 'secondary forest' were improperly included in the water category). User's accuracy is a complement of the commission error and this is an indicator of the probability that a pixel classified into a given category actually represents that category on the ground (Story and Congalton, 1986). For example, for the water class, user's accuracy (61%) results from by dividing the total number of correctly classified pixels (370) by the total number of pixels that were actually classified as water (608). The remaining (39%) is the commission error of the water class. A calculation of the producer's accuracy determined by dividing the total number of correctly classified pixels in the class water (370) by the total number of the pixels of that class derived from the reference data (439). The result reveals a value of 84%, representing an omission error of 16%. In that case, although 84% of reference areas have been correctly identified as water, only 61% of the areas that should be classified as eater are actually water in the map. Details on the omission and commission errors of each class can be seen in the confusion matrix as indicated in column and row totals of the matrix (marginal frequencies). User's accuracy ranges from 99% (of rattan) to 39% (kaing grass) whereas producer's accuracy ranges from 95% (bamboo) to 60% (scrubland). The possible reason for low values will be discussed in chapter 5.

In order to further evaluate the accuracy of the segmentation-based classification, the Kappa statistic was also calculated to derive the degree of agreement between the current confusion matrix and the one of a random classification having the same marginal frequencies. The analysis revealed a Kappa value (K_{hat}) of 0.76. This value indicated that the observed classification is clearly better than a random classification (with a K_{hat} value of 1 indicating a perfect classification accuracy). The overall accuracy is calculated based on the data along the main diagonal and excludes the offdiagonal data (i.e., errors of omission and commission). But K_{hat} (0.76%) includes also the non-diagonal elements in the analysis. This is why a higher overall accuracy compared to the K_{hat} value is expected. In this study both accuracy measures only show a relatively small difference.

4.4 Normality Test of EGVs

ENFA requires normally distributed input data. Before running an ENFA model using the BioMapper software, all EGVs maps were tested for normality using SAS software. The results showed that all EGV data possessed the *P* value of the Komogorov Smirnov test (KS-test) below 0.05; all EGVs distributions were significantly departing from normality. Owing to this, all input EGV layers for the ENFA model were normalized by using the Box-Cox algorithm in the BioMapper software. A general form of the SAS program to perform the normality test is given in Appendix V and the KS test results of all EGVs are shown in Appendix VI. The following are examples of statistics that were produced by the SAS program.

Test	--Statistic---		-----p Value------	
Kolmogorov-Smirnov	**D**	0.264242	Pr > D	<0.0100
Cramer-von Mises	**W-Sq**	3002.848	Pr > W-Sq	<0.0050
Anderson-Darling	**A-Sq**	15862.62	Pr > A-Sq	<0.0050

(Distance to streambed)

Test	--Statistic---		-----p Value------	
Kolmogorov-Smirnov	**D**	0.513218	Pr > D	<0.0100
Cramer-von Mises	**W-Sq**	116207.2	Pr > W-Sq	<0.0050
Anderson-Darling	**A-Sq**	538770.8	Pr > A-Sq	<0.0050

(Distance to river-1)

4.5 Ecological Niche Factor Analysis

4.5.1 Preliminary ENFA model: Score matrix and model evaluation

The Boolean species presence map and 36 EGV raster (Idrisi format) layers were used as input data for the ENFA. In ENFA modeling, very highly correlated variables need to be excluded such as EGVs of distance to logging areas, distance to settlement and length of road (see Figure 47). Out of them, the distance to settlement variable was retained for analysis because it is more important for tiger ecology than the others. Finally, the ENFA was processed using 34 uncorrelated EGVs.

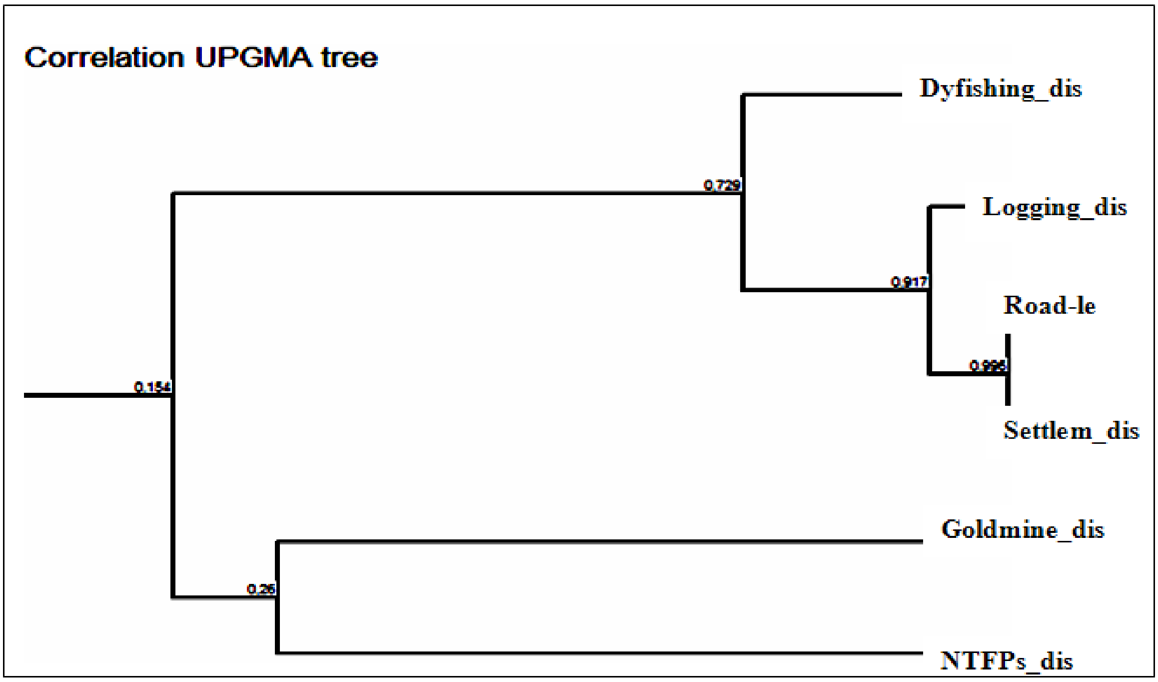


Figure 47: The correlation tree of human-factor variables that represents very high correlation between logging_dis and road_le/ settlem_dis and settlem_dis and road_le.

ENFA produced two outcomes. The first one is a score matrix (Table 23 on page 94) that allows ecological interpretation by explaining the contributions of variables to the derived factors. The second result is a habitat suitability map (see Figure 50 on page 98). These two outputs help to better understand ecological relationships between the tiger distribution in the HVTR and environmental conditions in the area.

All 34 EGVs were constituted as input groups in the Ecological Niche Factor Analysis using the BioMapper software together with the tiger presence Boolean map. The ENFA produced the score matrix of the preliminary model (Table 23) which shows the EGVs sorted by their coefficient values on the marginality factor whereas signs of the coefficients are important for interpretation on the margianlity factor, they have no meaning for specialization. The highest specialization value indicates the strongest contribution of the respective EGVfor species' specialization.

Table 23: The score matrix of the preliminary ENFA model with 9 EGVs: % in brackets explains the amount of variance explained by each factor. Negative coefficient values of the distance-related variables on the marginality factor indicate that tigers prefer closer locations to corresponding EGVs whereas positive values of area-related variables mean that tigers prefer locations with higher values of that EGV. The signs of the specialization coefficient value have no meaning for interpretation.

EGVs	Factors of specialization				
	F (1) 100% Marginality	**F (2) Spec. 2**	**F (3) Spec. 3**	**F (4) Spec. 4**	**F (5) Spec. 5**
	Spec. 1: (16.6%)	**(42.4)%**	**(11.8)%**	**(8.4)%**	**(7.6)%**
evgopen_area	0.497	0.146	0.030	-0.115	-0.356
evgclos_area	-0.470	-0.400	0.069	0.429	0.057
evgopen_rattan_area	-0.406	0.102	0.314	0.018	-0.690
streambed_dist	-0.331	-0.041	0.441	-0.296	-0.009
settlem_dist	0.320	-0.883	0.317	0.111	-0.495
kaing_ha	0.259	0.032	0.563	0.354	0.248
dist_south	-0.181	-0.058	0.263	0.130	-0.136
dist_east	0.167	0.050	0.456	-0.296	0.154
slope	-0.166	-0.141	-0.086	-0.688	0.211

Global	
Marginality:	**0.691**
Specialization (S):	**1.705**
Tolerance (1/S):	**0.586**

The score matrix (Table 23) shows the variance explained by the first five factors and the coefficient values of the most important 9 EGVs out of 34 computed in the ENFA model. The value of overall marginality M is equal to 0.691, showing that the tiger's habitat is not too different from the mean conditions in the core zone (study area). A low value of tolerance (close to 0) indicates that species tend to live in a very narrow range of conditions. The tolerance for the core area is relatively high, meaning the tigers are not too picky about their living environment. But the core area has special characteristics when compared to other regions. The marginality coefficients of the first factor show that the tigers are essentially linked to large areas of evergreen open forests, kaing grass areas, close distances to streambeds as well as to south aspects and lower slopes. They tend to avoid large areas of dense evergreen closed forest and large areas of evergreen open forest with rattan. They want to stay farther away from the settlement and east aspects. The next factors account for specialization. Among all coefficient values, the value of distance to settlement (0.88) contributes very strongly to the specialization factor.

But, the results of model evaluation showed that the preliminary model has a low predictive power as displayed in Figure 48. In this model, the trend of the F_i curve together with the Boyce Index (0.423+/-0.44) showed unsatisfactory results, leading to a choice of the best EGVs out of the 9 variables of the full preliminary model.

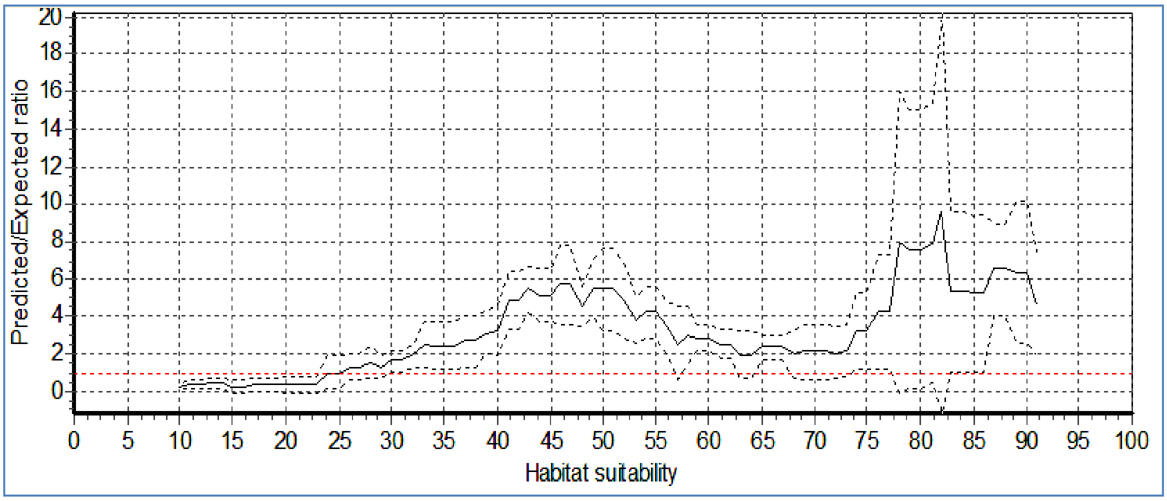


Figure 48: Preliminary model evaluation with continuous Boyce Index value produced by cross-validation procedures computed in the BioMapper Software.

4.5.2 Final /Best ENFA model: Score matrix and model evaluation

Due to a low predictive power of the preliminary model, the final model was performed by choosing the best EGVs out of 9. Table 24 shows the results of the final/best ENFA model composed of 6 EGVs. In this table, the highest marginality value is found for the "evergreen closed forest area" (-0.627). The negative sign of this coefficient value showed that the tiger tends to escape dense areas of evergreen closed forest. The tiger also prefers staying near to streambeds (streambed_dist=-0.442). The results also showed that the kaing grass area (0.346) is to be favored by the tigers. The value of dist_south (-0,242) means that the tigers are associated with the south aspect. On the other hand, they tend to prefer larger distances to human settlements (0.428) and avoid east aspects (0.224). The second factor accounted for 48.9% of species' specialization, explaining the greatest part of the species' niche specialization, more than twice as much as factor 1 (21.4%) and 3 times as much as factor 3 (14.5%). Half of the species specialization comes from factor 2 and the largest number of specialization is located on settlem_dist with -0.861. That means the variable of settlem_dist contributes very strongly to the overall species' specializations value**.**

Table 24: The score matrix of the final ENFA model with 6 EGVs that explains ecological correlation between EGVs and the factors.

EGVs	Factors of specialization					
	F (1) 100% Marginality	F (2) Spec. 2	F (3) Spec. 3	F (4) Spec. 4	F (5) Spec. 5	F (6) Sped. 6
	Spec. 1: (21.4%)	(48.9)%	(14.5)%	(6.9)%	(4.5)%	(3.7%)
evgclos_area	-0.627	-0.483	-0.216	-0.294	-0.56	-0.094
streambed_dist	-0.442	0.017	-0.433	0.501	0.604	-0.541
settlem_dist	0.428	**-0.861**	-0.103	-0.026	0.190	-0.140
kaing_area	0.346	0.100	-0.629	-0.483	-0.002	-0.649
dist_south	-0.242	-0.067	-0.239	-0.501	0.494	0.373
dist_east	0.224	0.101	-0.550	0.420	-0.204	0.345

evgclos_area: Area of evergreen closed forest	**Global**	
streambed_dist: Distance to streambed		
settlem_dist: Distance to settlement		
kaing_area: Area of kaing grass	Marginality (*M*)	0.517
dist_south: Distance to south aspect	Specialization (*S*)	1.777
dist_east: Distance to east aspect	Tolerance(1/*S*)	0.563

The value of global marginality *M* is equal to 0.517, showing that the tiger's habitat is not too different from the mean available conditions in the core zone (study area). The tolerance for the core area conditions expressed by the model variables is relatively high (0.563), meaning the tigers are not too picky about their living environment (Hirzel *et al.*, 2006). The first four factors were used to calculate the habitat suitability map. Factors 5 and 6 have very low information (i.e. explained variance) to interpret and so these factors were ignored for computing the habitat suitability map. The continuous Boyce index was used to evaluate the final ENFA model by computing its predictive power as recommended by Hirzel *et al.* (2006). The cross validation procedures produced the predicted-to expected ratio P/E ratio or $\boldsymbol{F_i}$ curve (see Figure 49). The Boyce index value was (0.847±0.09428). The P/E ratio increases with increasing habitat suitability, meaning that a model has a good predictive ability (Hirzel *et al.*, 2006). Moreover, the greater the value of the Boyce index the higher is the predictive power of the model.

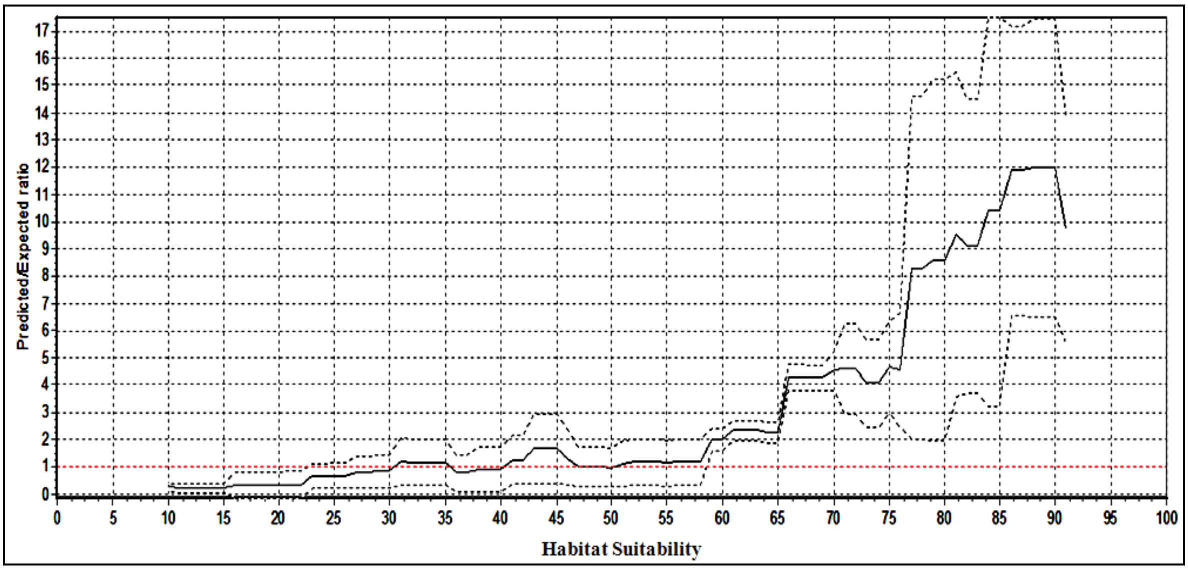


Figure 49: The F_i curve produced by a cross-validation process; the solid line represent the mean model result out of the cross-validation process and the dashed lines show the standard deviation. The red dashed line F_i =1, indicates a random model.

In Figure 49, P/E ratio was located below the area-adjusted frequency=1 at the lower level of the habitat suitability range (up to 30), meaning the model predicts low species presence numbers for unsuitable areas. This is an indicator for good models. Then the ratio increases continuously along the habitat suitability range (58 to 90) that represent suitable classes. The shape of the F_i curve increases in an exponential way for the high suitability areas.

4.5.3 Habitat suitability map

The habitat suitability map (Figure 50) is one of the major outputs of the ENFA model. It was built from the first four factors of the final model (Table 24). These factors accounted for 91.7% of the total sum of the factors' eigenvalues (i.e. 100% of the marginality and 91.7% of the specialization). They explained 96% of the information and were used to build the HS map. The result map indicates the distribution and extent of tiger habitat zones of different quality in the core zone of the HVTR. The HS values range from 0 to 100, composed with a rainbow color type. Zero denotes unsuitable areas represented by dark colors where the tiger was not recorded. The light shading on the map represents high HS areas for the tigers. The highest quality habitat areas are mostly located in the middle zone of the core area. In the HS map, unsuitable areas for tigers are in the interior of dense bamboo forest in the western part of the map as well as in the high altitudes areas (see north/ north-east area in the map). They prefer large distances to human settlements as well as to other man-made features and human disturbances (logging, agriculture) near and along the Ledo road (along the south and south-west part of the map).

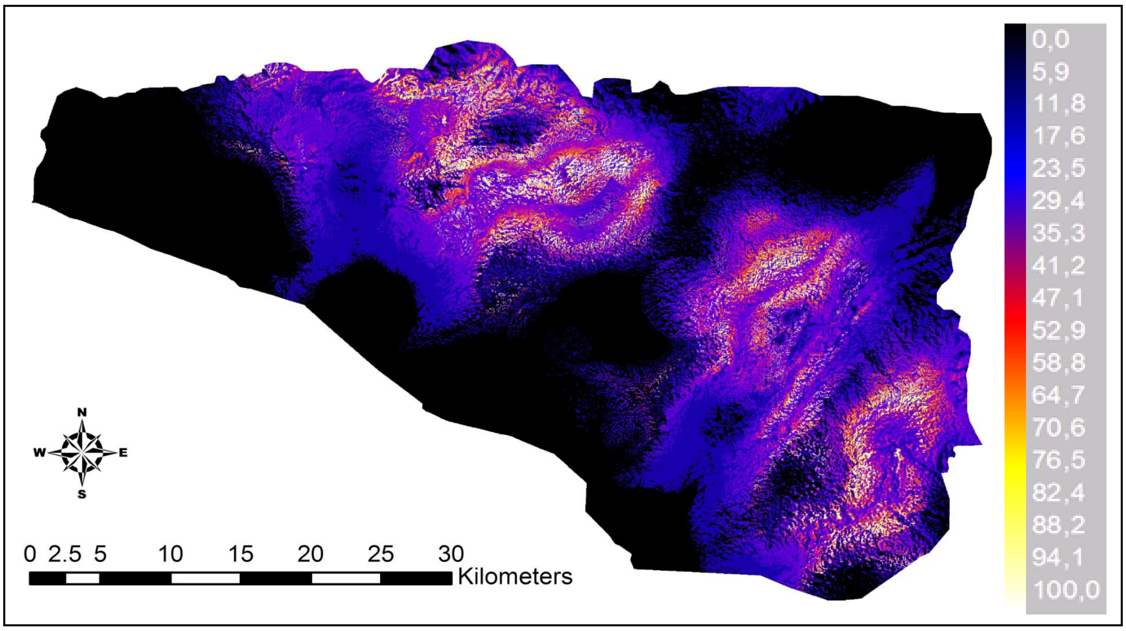


*Figure 50: Tiger habitat suitability map of the study area as computed from ENFA. The scale bar on the right indicates the habitat suitability values ranging from 0-100, represented by each shade in the map. Light shading denotes areas more suitable for tiger and dark shading denotes areas less suitable. Cell size is 30*30 m. A large format version of that map is shown in the appendix IX.*

4.5.4 Reclassification of habitat suitability map

The reclassification process is a very important step. The lower number of classes can help the park and reserve managers to use the reclassified map as a planning tool of management for the future conservation of the tigers as well as to establish wildlife corridors. Trends in the F_i curve help to reclassify the habitat suitability map. The HS class boundaries were reclassified by means of the steps of the F_i curve as suggested by Hirzel *et al*. (2006). The HS range (0-100) was reclassified into 4 classes. They are 'unsuitable' (0-30), 'marginal' (31-58), 'suitable' (59-76) and 'optimal' (77-100) as shown in Figure 51. The reclassified HS map is given in Figure 52.

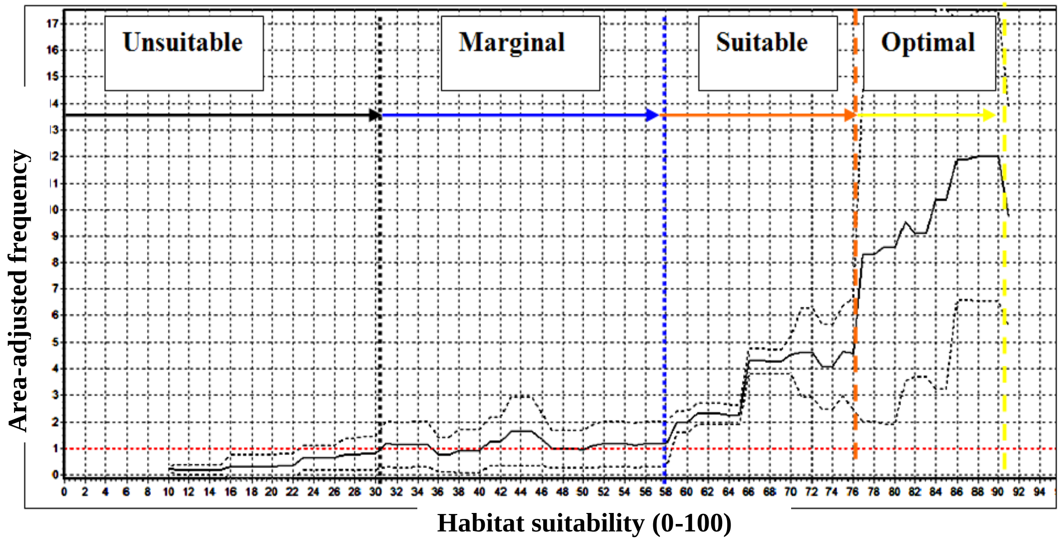


Figure 51: Determination of HS class boundaries by using the trend of the Fi curve. Y axis represents the predicted to expected ratio and X axis represents the HS range.

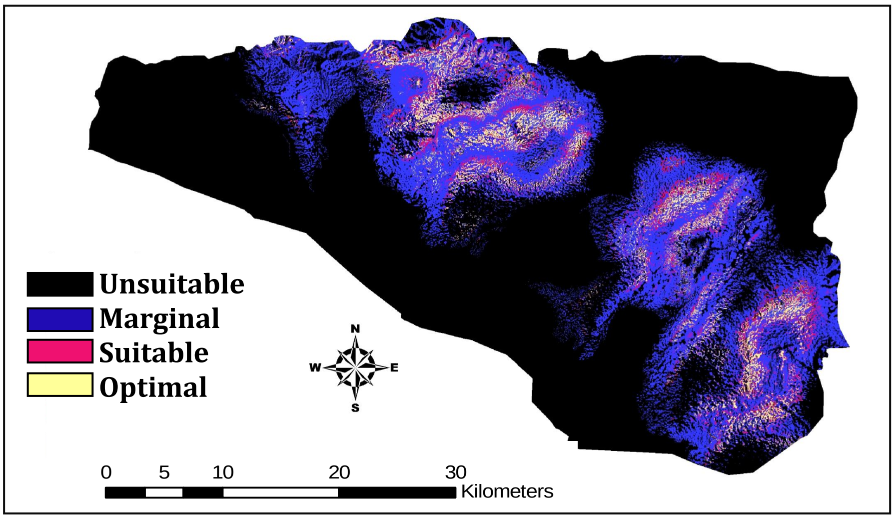


Figure 52: HS map after the reclassification process based on the HS range in which the black box means the 'unsuitable' class (0-30), the blue box denotes the 'marginal' class (31-58), the orange box means the 'suitable' class (59-76) and the yellow box represents the 'optimal' class (77 -100). A large format version of that map is shown in the appendix IX.

Figure 52 exhibits the total surface coverage of habitat suitability. This reclassified map is clearer to distinguish the habitat categories than the original continuous HS map directly produced by ENFA**.** It can provide few zones of high habitat quality. From a management protection point of view, the reclassified map makes the reserve managers to decide more considerably about future habitat management (for e.g. to define the management zones based on the HS categories such as core zone, zones of sustainable utilization and buffer zone).

5 DISCUSSION

5.1 Discussion of Methods

5.1.1 Land use changes and tiger detection information in the study area

A land use change assessment between 2000 and 2010 was carried out using WCS (Myanmar programme). Conversion of forest areas to commercial plantations accounted for major changes outside the core zone. Township development activities (for e.g., 200,000 acres for mono crop plantation projects) straddle the south-west part from the historical Ledo road. Fortunately, in the core study area (see Figure 53), there have been no major land use changes. According to this, the habitat suitability map as one main result of this study can be used in determining the high priority areas for the future protection of the tiger and its prey species.

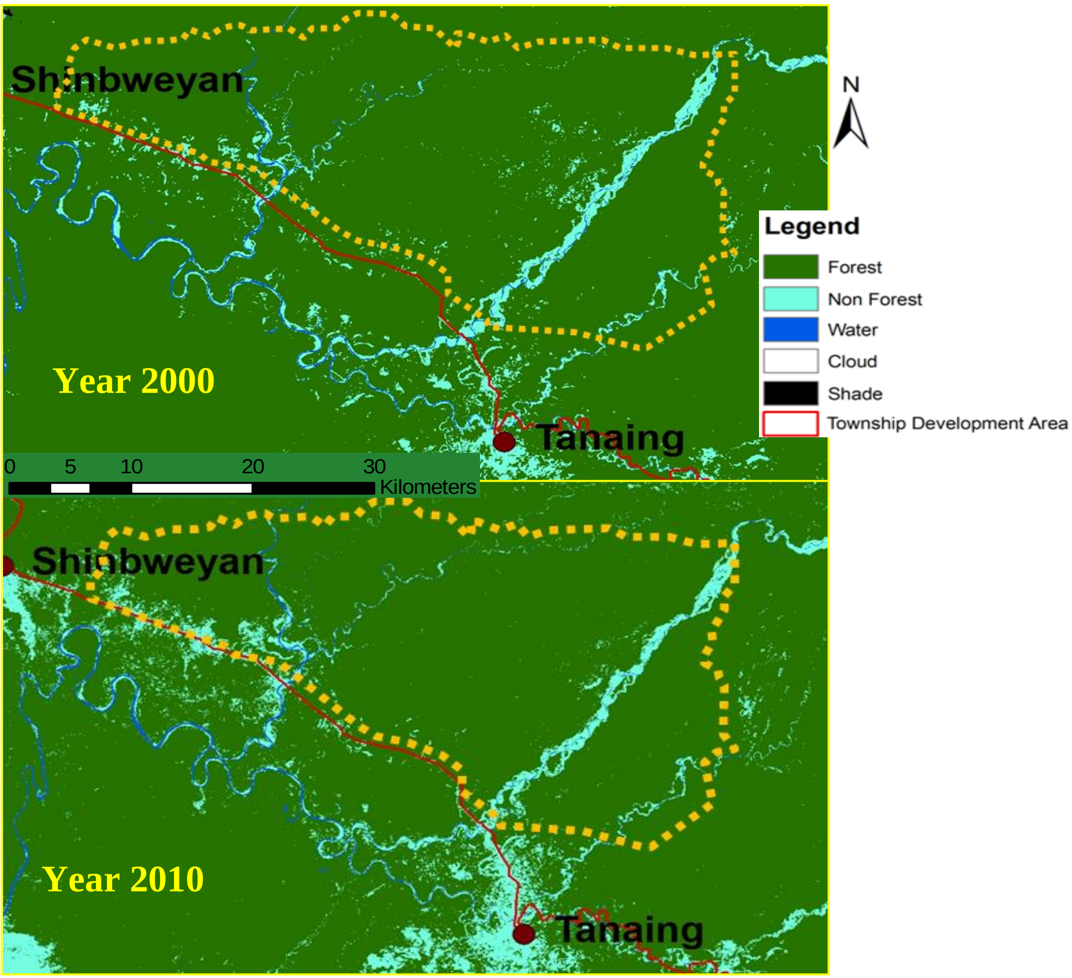


Figure 53: The comparison of land use changes between the year 2000 and 2010, showing that no major land use changes occurred in the core study area (yellow dashed line) (source: WCS, Myanmar programme, 2011)

Up to the year 2010, the location of the tiger tracks and signs were recorded by the tiger survey team (see Figure 54). Due to political constraints, the tiger survey team could not enter into the core zone after that time, leading to a lack of tiger information for the year 2011.

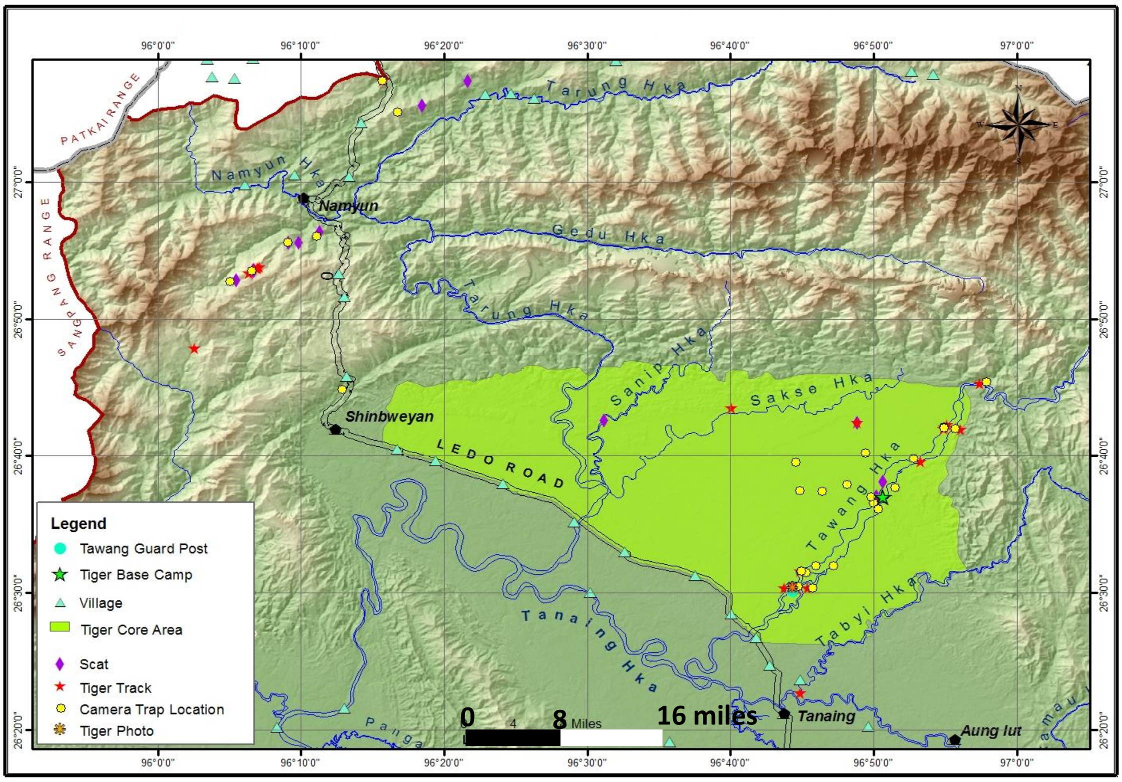


Figure 54: Detection of tigers' tracks and signs in the core zone of HVTR for the year 2010 (Source: WCS, Myanmar programme, 2010)

5.1.2 Major issues of data availability

Landsat image acquisition: This study was conducted for a large landscape (1,713 km^2). High spatial resolution remote sensing imagery (QuickBird and IKONOS) can provide rich spatial information regarding classification, but they would be very expensive for this large area based study. So, 30 m resolution Landsat images were ordered freely and it made this study much more cost effective. But, a single scene of Landset imagery was not available for the whole study area at the same date. Due to these issues, two scenes acquired on different dates (Oct 2002 and Feb 2003) were merged to cover the study area.

There were two main reasons to use the 2002/2003 Landsat images which hold temporal differences to the reference land use map of WCS from the year 2000. The first reason was that most of the tiger locations were detected in this period, especially in the year 2003.

The second reason was that there was no major land use change between the year 2000 and the year 2003 (neither in the time up to the year 2010) in the core zone of the HVTR as suggested by the results of the land use changes assessment. Hence, the time difference did not cause severe problems in the study. The core area has been totally banned since 2003 up to now by threat monitoring and regular patrolling activities. Owing to this, the existing reference land use map (based on the year 2000, Landsat) was able to be used as a training data set in this study.

Species data: Camera trap survey techniques by the researchers of WCS were used to estimate the tiger population in HVTR. So, the tiger presence data for this study are in the form species presence points collected by camera traps as well as GPS points of track and sign data. Camera traps were located based on the tiger detection areas of a short reconnaissance survey. In the study area, the species data sat contained only 5 individuals and all 31 species presence points were not well distributed all over the study area because surveyors were not able to be access all areas for camera-trapping. The success rate of camera trap varies in various habitats. For e.g., capture probability in kaing grass is higher than that in evergreen forest. This is also another major shortcoming for lower detection of species presence points in the evergreen closed forest.

Environmental data: The existing reference land use map was based on pixel-based classification of Landsat imagery of the year 2000, exhibiting lots of scattered white (erroneous) pixels (Salt and Pepper effect). That’s why it could not be directly used for the land use classification, as the Salt and Pepper phenomenon may lead to a reduction in the accuracy of spatial information. Former studies showed that object-oriented image analysis provides the capability of much smoother classification that is crucial in habitat suitability mapping. In this context, object-oriented image analysis was adopted to conduct a segmentation-based land use classification in this study.

The reference data could not provide training areas of secondary forest in the core zone of the HVTR. Therefore, during a field trip, by interview with local villagers and field experts, the historical records of secondary forests in the year 2003 were labeled on the thematic classification map. This data was plotted as polygon in a GIS technique and used as training areas for that land cover category in the classification process.

Training areas for kaing grass, scrubland, and evergreen opened forest with rattan, streambed, agriculture and evergreen opened forest were selected from the reference map. Evergreen closed forest, bamboo and water were directly mapped from the Landsat imagery by using the spectral reflection information from a 5, 4, 3 bands combination (pseudo color band composite including infrared reflection). This was achieved in eCognition and the result was imported into ArcGIS for editing and modification.

5.1.3 Segmentation-based land use classification and accuracy assessment

Altogether 15 land use classes were distinguished by using object-oriented image analysis techniques. The quality of the classification result was quantified an overall accuracy of 79% with a kappa index 0.76. Considering the relatively low spatial resolution of the imagery and the detailed classification scheme with many vegetation types, the achieved accuracy is acceptable. There was also an abundance of challenges to be faced in the classification process (for example, similarity of classes such as agriculture, kaing grass and scrubland, delineation of unclassified pixel clusters by a focal majority process, shifting of the reference raster map to align with the segmentation-based land use map, etc.). According to this, some classes were delineated from the surrounding features, especially in terms of water and streambeds, streambed and kaing grass, rattan and evergreen opened forest with rattan, agriculture and secondary forest.

A confusion matrix (see Table 22 on page 91) was utilized to estimate the accuracy of the segmentation-based land use classification. A closer inspection of the confusion matrix revealed that significant confusion occurred between the classes of rattan and evergreen opened forest. 124 reference pixels of rattan were improperly classified as evergreen opened forest. This matrix lead to a quite low user's accuracy of evergreen opened forest (39%). It is because rattan never appears alone but it grows in association with evergreen opened forest. In the satellite imagery (pseudo color) the evergreen opened forest with rattan appears in magenta color. By contrast, because in the evergreen closed forest, rattan does not contribute to the canopy reflection and hence this type of forest appears in a different way in the satellite imagery.

Another confusion occurred between kaing grass, streambed and agriculture. In HVTR, kaing grass grows along the streambed and many pixels of streambeds were improperly classified as kaing grass. Another challenge was that kaing grass showed a similar reflection pattern like agriculture in the analysis, so that 55 pixels of agriculture were improperly included into the kaing grass, leading to unsatisfactory results for user's accuracy of kaing grass. The remaining unsatisfactory results of user's accuracy occur for the secondary forest class. It is likely to be assumed that its spectral reflection was difficult to differentiate from agriculture because secondary forest was automatically formed after shifting cultivation, resulting in possible mixtures of reflection. That's why the pixels of agriculture were improperly classified as secondary forest, leading to the user's accuracy of secondary forest of only 50%. One scene of satellite imagery was captured in winter (February) and another one was captured in the wet season (October). Mean annual rainfall is more in October than in February. It is therefore strong omission errors and commission errors occurred between streambed and water. It seems the reason that streambed will be water surface in the wet season.

5.1.4 Variable identification

This study is a pioneer study using data from Myanmar to draw a habitat suitability map for tigers. Hence, environmental variables for this study came from literature reviews and expert interviews. Besides, variable had to be determined with regard to tiger ecology. Tigers need home ranges with sufficient large areas of suitable land cover and water surfaces to ensure long-term survival, adequate prey densities, and low disturbance rates from humans. To cover these requirements, three main groups of variables were identified as habitat suitability predictors. These were landscape compositional, topographical and human disturbance variables.

Landscape compositional variables were obligatory in statistical habitat modeling for the tiger. Therefore, 14 land use/ land cover types were identified as important for this study. These were water, streambed, kaing grass, evergreen closed forest, evergreen opened forest, and evergreen opened with rattan forest, bamboo forest, secondary forest, scrubland, agriculture, settlement and road. The area and length of landscape features in a circular analysis window around each landscape cell were quantified as well as the features' distance to each landscape cell to find out preference and avoidance behavior of the tigers with regard to the landscape features in HVTR.

Rivers are distributed all over the HVTR. Access to water sources is essential for tigers and their prey species. River-1(30 m width), river-2 (90 m width) and river-3 (150 m width) were defined and distances to these classes included as variables in the model in order to get more information for future management, through controlling for the gold panning and dynamite fishing along the rivers.

Tigers used streambed and secondary forests as corridors whereas the kaing grass is used as hunting ground (field experience of tiger survey team, HVTR,). They also use kaing grass as a resting site (Khan *et al.,* 2007). Evergreen closed and evergreen open forests comprise 70% of the whole study area, including the most important land cover types for tigers. Rattan, bamboo, scrubland, agriculture and saltlicks were selected as shelter and food resources for the prey species. The remaining landscape variables with regard to road and settlements were selected and confirmed those classes to be unfavorable variables for tigers.

Like protected areas of all over the world, HVTR has been encountered with various types of human intrusion. Minor logging, gold-mining, dynamite fishing, non-timber forest product collection and hunting and poaching were the most common disturbances in the core zone. Variables related to these activities were created and also included into the model to explore human impacts that cause tiger habitat loss and degradation.

Topographical variables were selected by examining tiger preferences for certain elevation and slope situations. Distance measure to each aspect (flat, north, east, south, west) were included to explore the aspect that the tigers mostly prefer in the study area.

5.2 Discussion of Results

5.2.1 Ecological niche factor analysis (ENFA)

5.2.1.1 Score matrix of preliminary the ENFA model

Tigers are habitat generalists and actually occupy large home ranges which represent various land cover types that are still left in the HVTR. Score matrixes of preliminary ENFA results revealed 9 variables to have the highest factor coefficients related to land cover types. Out of them, 6 were related to land cover types (evergreen open forest, evergreen closed forest, evergreen open forests with rattan, streambed, kaing grass, and settlement) and the remaining three to topography variables (dist_south and dist_east and slope). This model allowed to draw the following conclusions on ecological relationships between tigers and EGVs in the HVTR:

- Evergreen open forest area is positively correlated with tiger presence
- **Evergreen closed forest area is negatively correlated with tiger presence**
- Evergreen open with rattan area is negatively correlated with tiger presence
- **Distance to streambed is negatively correlated with tiger presence**
- **Distance to settlement is positively correlated with tiger presence**
- **Kaing grass area is positively correlated with tiger presence**
- **Distance to south aspect is negatively correlated with tiger presence**
- **Distance to east aspect is positively correlated with tiger presence**
- Terrain with little slope is negatively correlated with tiger presence.

As shown is Table 23 on page 94, preliminary modeling results showed that areas of high habitat quality are associated with large areas of evergreen opened forest and kaing grass and terrain with little slopes in the study area.

5.2.1.2 Score matrix of the final ENFA model

The final model included the most important 6 EGVs out of 9 (marked with bold text on the above) based on the highest Boyce index value of that model. These 6 EGVs are composed of:

Evergreen closed forest area: The marginality coefficient of evgclos_area has a value of -0.627, displaying that tigers have negative ecological correlation to these areas. According to this result, it was observed that the tigers seem to escape the dense evergreen closed forest areas of Hukaung's core zone. But, the study area is dominated by many landscape forest types. And the evergreen closed forest areas in the core zone are mainly surrounded by evergreen opened forest.

A test model was carried out by substituting the evergreen open forest for the evergreen closed forest in the analysis; the coefficient of evergreen open forest on the marginality factor shows the highest value (see Table 25. B). This makes clear that tigers are especially linked to the evergreen open forest. But the model also shows a moderate power of prediction with the Boyce Index (BI) =0.55, that is lower than for the final model (BI=0.85

see Table 25. A). In ENFA modeling, a model with the highest BI value should finally be chosen.

Table 25 (A): Final model that displays negative correlation between tigers and evergreen closed forest areas but with a high model predictive power (BI=0.85). (B): Test model with

(A) EGVs	**F.1**	**F.2**		**(B) EGVs**	**F.1**	**F.2**
evgclos_area	**-0,627**	**-0,483**		**evgopen_aera**	**0.65**	**0.34**
streambed_dist	**-0,442**	**0,017**		**streambed_dis**	**-0.43**	**-0.14**
settlem_dist	**0,428**	**-0,861**		**settlem_dist**	**0.42**	**-0.90**
kaing_area	**0,346**	**0,100**		**kaing_aera**	**0.34**	**0.13**
dist_south	**-0,242**	**-0,067**		**dist_south**	**-0.24**	**-0.05**
dist_east	**0,224**	**0,101**		**dist_east**	**0.22**	**0.20**
Boyce Index = 0,847				**Boyce Index= 0,55**		

evgopen_area instead of evgclos_area: though the evergreen open forest area is highly correlated with tigers, it could not be taken as the final model because of its lower model predictive power (BI=0.55).

Throughout the literature, there are also some arguments regarding tiger preferences for dense forest areas. It was observed that tigers preferred areas of dense forest as well as more open spaces (see the Literature Review on page 18).

The findings of this study support the results of Khan *et al.* (2007) and Reza *et al.* (2001) because they also weakly support the tigers' preference for the dense evergreen closed forest areas but strongly support more open areas such as evergreen open forest, streambed and kaing grass.

Due to this, the nature of forests should be taken into account for tiger preferences (i.e., crown density as well as understory). Although former studies mention the crown cover density, no discussions were found about this. Habitat preferences of tigers might be different in different forest types. Karanth and Sunquist (2000) completed a study in moist deciduous forests, Khan *et al.* (2007) in mangrove forests and the WWF, WCS, the University of Montana and key stakeholders from China (2010) in pure deciduous forests. So, the nature of undergrowth in each forest will be different to some extent. This study was based on dense lowland evergreen forest and subtropical moist evergreen forest, characterized by dense and complex patterns with numerous evergreen tree species or by a dense understory. This is why the tigers tend to avoid the evergreen closed forest areas in which some areas are dominated by the regeneration of bamboo and rattan. The preliminary results also showed that the tigers are negatively related with evergreen open forest with rattan.

Another tiger expert, Alan Rabinowitz (2008) wrote that, *"big cats like easy routes of travel such as dirt roads, trails and water ways."* Undoubtedly, the tigers may prefer the forest with less complex understory which can support their movements, feeding and hunting more easily.

This study used the sparse data of species presence points collected between 2002 and 2004 (as in the study of Lynam *et al.,* 2008). Tiger presences were detected from camera traps and track and sign surveys. The remoteness of the study area has hindered to the survey team to get anywhere, including higher mountains and dense evergreen closed areas. That's why the tiger presence points were not well distributed all over the whole study area. There may be undiscovered additional tiger signs to a considerable extent. These are hidden in the dense forests and high mountainous areas and could not be registered for this study. This might be another reason which could affect the conclusions on the tiger's preferences for evergreen closed areas as well as steeper slopes.

Needless to say, the existence of evergreen cloud forests is very important for insuring the tiger's and their prey species long term survival. Because this type of forest can always provide the tigers sufficient prey species, adequate cover and access to water.

Distance to streambed (streambed_dist): This finding is very consistent with former studies. The coefficient value of -0.442 indicates that tigers have a strong association with streambeds. The ecological interpretation for this is that the tigers usually tend to use streambeds as corridors to move throughout the landscape. It also explains that tigers prefer to stay near water. In 2010, the Hukaung tiger survey team also detected tracks of tigers along the Tawang streambed which was included in the River-3 class of this study.

Distance to settlement (settlem_dist): In terms of the variable dist_settlement (0.428), tigers exhibit strong avoidance of man-made landscape structures such as cities and villages. Half of the species specialization comes from factor 2 (48.9%) and on this factor, the variable of distance to settlement contributes very strongly (0.861) and makes the tigers very specialized on the range of conditions they withstand. All presence data points were located rather far away from the human settlement, supporting this finding more reasonably.

Area of kaing grass (kaing_area): Kaing grass contributes to the species marginality being lower. Because the positive coefficient value (0.346) of „Kaing" area shows a positive relationship of the tigers with this land cover class. This is also consistent with the belief of local people and expert knowledge as well as the study of Khan *et al*. (2007). So, tigers in the Hukaung valley may tend to use kaing grass areas as hiding and resting sites as well as hunting grounds. This conclusion is also supported by the findings of Karanth *et al.* (2000) which say that tigers concentrated their hunting efforts on the edges of short-grass clearings (<25m). They found 45 % of kills take place less than 25 m distance from the short-grass areas.

Distance to south/east_aspect (dist_south/dist_east): The appearance of these two topographical variables in the best model affirms that tigers in the HVTR are affected in their habitat choice by terrain properties. It is observed that the population is more nocturnal and prefers southern areas {dist_south:(-0.242)} to obtain shade in day times. They tend to escape the eastern oriented areas {dist_east: (0.224)} where the direct sunlight is incident in the morning. This is consistent with a study by Karanth (2006). In his study, the radio tracked tigers in Nagarahole were most active between 6:00pm and 9:00am and they tend to be rest between 9:00am and 3:00pm.

The global marginality value for the tiger is rather low (see Table 24) in the core zone. On the other hand, the tolerance value is rather high (0.56), meaning the tiger occupies a relatively wide niche within the core area. However, the core area has special characteristics when compared to other regions. If the distribution of EGVs is compared with that of the whole country, like it is done for ibex species in Hirzel *et al.* (2002), the overall marginality and specialization value of the tiger will become higher but the tolerance value will become lower. The global specialization value (1.78) is rather high. A strong contribution to specialization clearly comes from the avoidance of human settlement for settlem_dist (0.86) on factor 2 (explaining 49% of variance). The remaining specialization predicted by the ENFA model is distributed evenly over the other factors with evergreen closed forest area (0.63) on factor 1(21.4% of explained variance), kaing_area (0.63) and dist_east (0.55) on factor 3 (14.5% of explained variance) and streambed_dist (0.5) and dist_south (0.5) on factor 4 (6.9% of explained variance). A combination of all these EGVs affects the tigers to be quite restrictive on the range of the conditions apparent in the study area.

5.2.1.3 Habitat suitability map

The reclassified suitability map (HS map) exhibits 30% (514 km^2) of unsuitable area and 28% (480 km^2) of marginal area. This larger area proportion of suboptimal and pessimal conditions caused by dense bamboo forest, evergreen closed forest with rattan, high altitude areas and man-made areas such as Ledo road, villages, cultivation near the villages and so on.

In this section, the result of the HS map (see Figure 55) will be presented again in order to compare them with the most important variables computed by the ENFA model and to carefully inspect the contribution of each EGV to the habitat selection of tigers.

In comparison of the map of evergreen closed forest area with the HS map, unsuitable areas which fall in the evergreen closed forest can be seen (see example polygons in Fig.55-A). This may be due to the effect of dense undergrowth. Tigers may prefer evergreen forest areas with lower understory for stalking and roaming. For hunting, the tigers may need some spaces that they cannot get in areas with dense undergrowth. Usually tigers and elephants avoid each other (Rabinowithz, 2008). The findings of this study also reveal that the tigers in Hukaung tend to avoid dense bamboo forests where the elephants are mostly inhabited.

It is also observed that streambeds (see polygons in Fig. 55-B) support the suitability of tiger habitat very well. The tigers show the greatest specialization in terms of distance to settlement. The marginal areas in the HS map start about 10 km distance away from the human settlement (see in Fig. 55-C). So, it is clearly true that human settlement may strongly influence the tiger habitats to be unsuitable.

Some kaing grass areas are also shown to be unsuitable. This may be due to the effect of its location very close to the road and settlement. From the expert interviews, it was known that the tiger tracks and signs were never detected in areas of very dense and tall kaing grass. The detections of tiger tracks in the Hukaung Tiger Reserve were in kaing grass areas with moderate density. On the other hand, it was found that even a low value of kaing grass coverage can highly support habitat suitability for tigers (see polygons in Fig. 55-D).

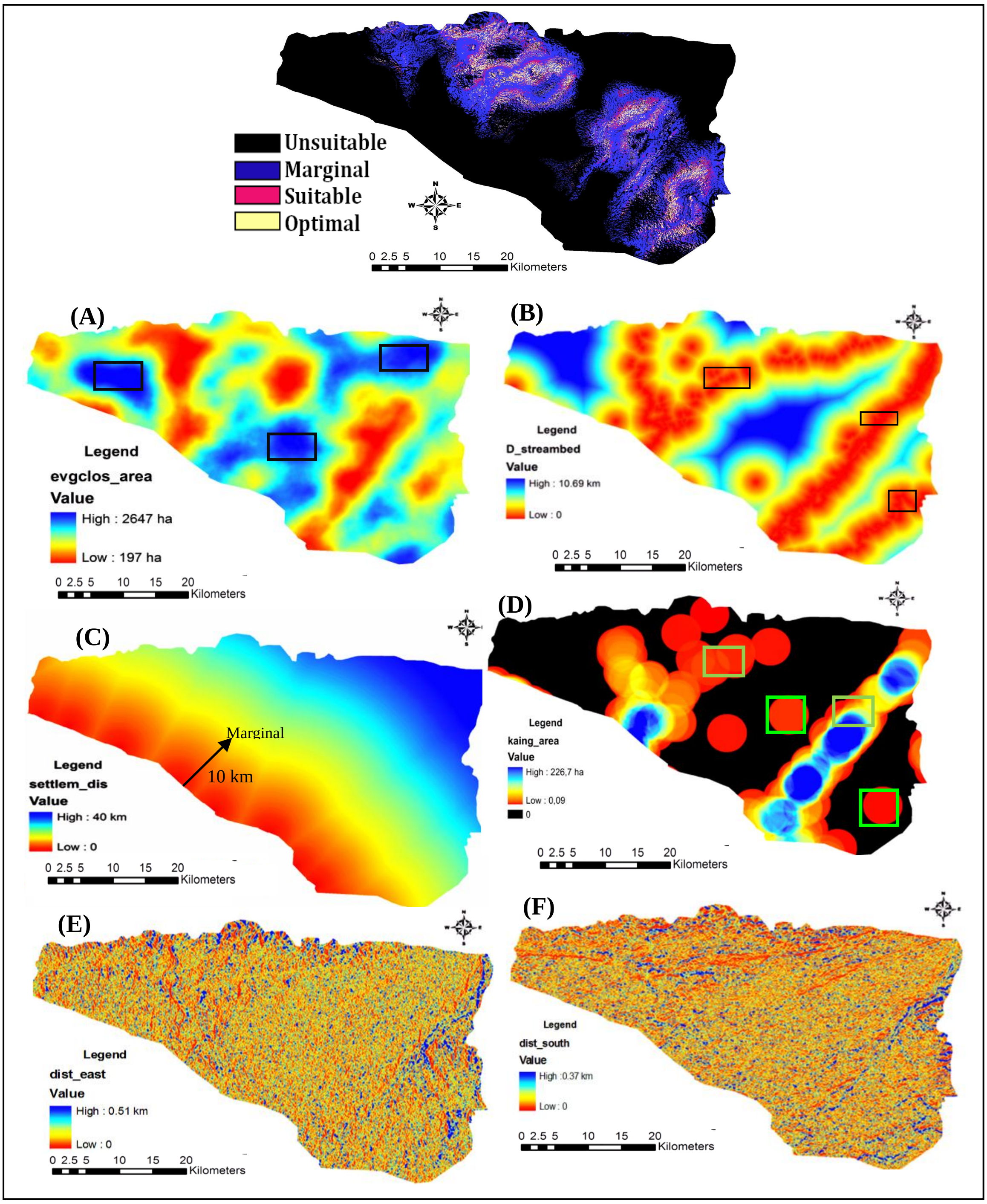


Figure 55: Habitat suitability map (reclassified) is shown in match with maps of the most important EGVs for visual interpretation.

The map comparison also shows that the topographical variables (dist_east and dist_south) have a greater influence on the habitat suitability for tigers. In the maps of distance to east and south aspects (Figure 55-E, F), the blue color shows larger distances from both aspects whereas the red color stands for smaller distance. The results showed that tigers are more associated with close distance to south aspect. But the tigers are negatively correlated with close distance to east aspect. So, the tigers prefer the blue areas of the east aspect map but they avoid that of the south aspect map.

The suitability map also verifies suitable areas of 18% (308 km^2) and optimal areas of 24% (411 km^2) in the study area, meaning in total 42% of the habitat can support the tigers with high or very high quality areas for hunting, shelter etc. By visual interpretation, most of the suitable areas of the HS map are associated with kaing grass and streambeds.

5.2.2 Advantages and limitations of the ENFA model

The advantages of the ENFA model: It does not require absence data, making it a good alternative to use in this study where only presence data was available. The user can immediately interpret the correlations between the environmental variables and the factors in the score matrix. The score matrixes as well as easily derived HS map facilitate the spatial analysis of zones of different habitat quality and the ecological interpretation of the focal species relation to different environmental variables. In addition, with the habitat suitability map, managers are able to more clearly find out the priority areas that are necessary to control and protect. Especially for areas of evergreen closed forest and its cultural role of tiger ecology as predicted by the ENFA model, the results are consistent with expert interviews and literature, making the outcome satisfactory. The study of Hirzel *et al.* (2002) also found the ENFA to be more robust than classical logistic regression with respect to several habitat-occupancy scenarios.

Limitations of the ENFA model: The ENFA approach only characterizes a species' ecological niche relative to a reference area. That means the species marginality, specialization and tolerance values calculated by the ENFA are limited to the extent of the study area. For example, in this study, the tiger would have appeared more marginal and specialized if the reference area of the study was all of Myanmar. The result of relatively high tolerance of tigers in the HVTR for the environmental conditions might be confusing for the readers who do not consider these geographical limitations. Moreover, the analyst has to remove too highly correlated EGVs. When faced with very highly correlated EGVs in the analysis, the ENFA model requires a good knowledge of the focal species' ecology and some knowledge-driven decisions which EGVs to exclude. Presence only models cannot be trusted by extrapolating them to other areas (even to close areas) even though they can accurately predict scenarios for the study area (Hirzel *et al*., 2002).

6 CONCLUSIONS AND RECOMMENDATIONS

Habitat plays a vital role for all wildlife populations; good habitats can support the requirements of tigers for long-term survival. Despite international and national organizations support and funds to conduct tiger conservation efforts in tiger-range countries, their range and numbers are still declining continuously. In Myanmar, one of the tiger habitat ranges, the tiger numbers are becoming smaller in the existing protected areas. Hence, exploring the effective tools which can help for the recovery of prime habitat for endangered tigers becomes a critical issue.

This study utilized quantitative ecological analysis by means of a spatially explicit multivariate habitat suitability analysis, in the context of wildlife quantitative research on landscape level. The use of habitat suitability modeling to identify potential tiger habitats needs time and analysis efforts. However, it is a really effective and profitable strategy of conservation planning. This study identified potential tiger habitat areas by producing a habitat suitability map. The sub-objective to support tiger population conservation has been achieved, because the habitat suitability map which prognoses the spatial distribution of tigers can provide valuable information for the development and implementation of protection measures for the tigers in the reserve.

The result of this study, the assessment of potential tiger habitats in the core zone of the Hukaung Valley Tiger Reserve, has clearly documented the habitat preferences of tigers in that area. The result showed the tigers' avoidance of evergreen closed forest areas. However, the preliminary modeling results revealed areas of high habitat quality which are associated with large areas of evergreen open forest. The tigers' habitats in both models were characterized by kaing grass and close distance to streambeds close to important water resources. Luckily, more than 70% of the study area is occupied by evergreen forests, showing large blocks of potential tiger habitat could be attained for the future.

However, the clashing with human disturbances in the wildlife habitat is inevitable. Human intrusion and hunting intensity increased the decline in tiger numbers in the whole reserve. People have been attracted by available forest lands for cultivation, various forest resources to be exploited including timber, fisheries and rattan production, and especially by gold-mining. Poisoning of waters by means of dynamite fishing and gold panning, and continued exploitation of resources will lead to a degradation of potential tiger habitats.

There are 8 gold mines in the whole Hukaung Valley Tiger Reserve (Kywe, 2006). Bush meat consumption is extremely high due to the intruding mining and non-mining communities, making tiger prey and bush meat species seriously threatened.

The process of developing human settlements along the Ledo road which gradually increases land cultivation around and then exploits the environment is a very common one, which will continue to take place.

The results of this study showed that human settlement along the Ledo road is a major issue of the tiger's specialization within the core area. Although the tiger's presence area is not too different from the rest of the core zone regarding the environmental conditions and it exhibited tolerance towards deviation from optimal habitat, the settlement made the tigers more restricted to the range of conditions they withstand. Tiger distribution points were always located about 10 km far away from human settlements which also showed their sensitivity to human interferences.

Fortunately, there is presently not a major settlement within the inner part of the core area, except the tiger protection base camps. But, it is known that the evidence of dynamite fishing and gold panning, and minor forest product collection is still encountered along the patrol routes. Furthermore, during data collection, distant explosions caused by dynamite fishing were also heard. Moreover, a designated protected area is around the focus of human activities. These points seem vital for any further dealing with human settlements when planning the reserve's management and implementing its management plan. Various specific recommendations could be given based on the study's result.

- It can be said that the core area is still remote and rich in wild fauna and flora up to now. So, this core area should be continuously controlled to minimize threats for the future conservation of the tiger and its prey species.
- The tigers are in close association with evergreen open forests, kaing grass and streambeds (see in Table 25-B on page 107). These landscapes together with continuous areas (e.g., evergreen closed forest and water bodies) and patches of suitable habitats are linked to these EGVs and should be targeted for future conservation and management concerns.

- The final result also showed that tigers avoid locations which are closer to human-settlements which restricts the movement of tigers in the core zone. Hence, the detrimental impacts of future development of human settlement should be minimized around the core zone. In addition, all human interferences within the core zone should be prohibited in order to guarantee sustainability of potential tiger habitats.
- Enhancement of manpower availability and capacity building in order to control the areas more thoroughly and effectively is strongly recommended.
- Develop alternative employment programs for local hunters to reduce their dependence on wildlife, especially in the big Tanaing township located very near to the core area must be a central goal of regional policy and planning.
- To control the bush meat exploitation in the Hukaung Valley Tiger Reserve by means of protein alternatives, public awareness and law enforcement, education and training should be another focus of development activities.
- The amendment of the existing wildlife law (Protection of Wildlife, Wild Plants and Conservation of Natural Areas Law 1994) to comply with the international wildlife laws pertaining to tigers and other endangered species is important. Particularly, the financial punishment issued must be higher.
- Based on the derived habitat suitability map, well designated management zones should be established, including:
    - A core zone of protection that should cover marginal, suitable and optimal ranges until the reserve's east and north boundaries. These areas should be totally banned from all human access and activities especially for hunting.
    - Zones of sustainable utilization (should include unsuitable areas towards settlement).
    - Buffer zones including human settlement (Unsuitable ranges closer to settlement).
- There is a particular need for establishing corridors to ensure the long term survival of existing populations. The corridors are species-ecologically valuable because they help to ensure the connectivity of the remaining habitats. The

corridors can provide the tigers not only shelters to move one location to another but also to re-establish the populations that have been reduced by habitat degradation. For this dealing, habitat suitability map can support in deciding priority areas of corridors even though it could not directly be used to guide corridor design.

- The tigers can occur in unsuitable and marginal areas that are dominated by evergreen closed forest. Tiger survey areas that are within higher mountain ranges around the core zone as well as in remote dense evergreen closed forest are still required. The refinement of the current ENFA model of this study by including these ranges might bring more information allowing for the analysis of habitat conditions also in these additional sites.
- The ENFA model can identify potential areas of high habitat quality and is a promising approach to be applied to other endangered species.
- More ground truth data should be collected in the core area especially regarding secondary forests and scrublands which are limited in this study.
- The current study used a low resolution satellite image-based land use classification map (79% overall accuracy). Additional land use maps should be produced based on high resolution satellite imagery and habitat suitability modeling for the entire reserve should be expended if the budget, sufficient staff and species data can be made available to cover the whole landscape.

7 SUMMARY

This study focuses on drawing a habitat suitability model in order to define the relationships between the spatial distribution of tigers and environmental conditions. Decline in the tiger population due to a combination of habitat loss, human interferences and decreasing prey availability in the Hukaung Valley Tiger Reserve (HVTR) in northern Myanmar was the basic concern for this study. The first two chapters of this thesis cover the general background and problem statement, protection status of tiger and biodiversity, important issues facing the HVTR and a literature review on tiger ecology and habitat suitability modeling is provided. The third chapter specifies methodological steps involved in the study whereas the fourth and the fifth chapters are dedicated to the results presentation and the discussion.

The study mainly concentrates on the core zone of the HVTR that covers an area of 1,713 km^2. The target period for this study is the year 2003 including the end of the year 2002 and the beginning of the year 2004 depending on the available of presence data. The majority of tiger presence locations are in the core zone for this period.

RS and GIS are used as tools to produce independent variables relevant for habitat selection of the tiger. The response variable for the habitat model was the tiger presence, represented by 31 tiger presence points. Independent data are in the form of ecogeographical variables (EGVs) on land use, topography and human-factors.

Segmentation-based land use classification was conducted by means of object-oriented image analysis supported by an existing reference map and other auxiliary data. The classification key was constructed based on feature classes which are expected to be relevant for tiger ecology. Altogether 14 land use classes were identified for the core area. The accuracy assessment of the segmentation based land use classification maps by means of an error matrix showed an overall accuracy 79% of a mean, user’s accuracy 73% of a mean and producer’s accuracy 77% of a mean. From auxiliary data, topographical and human factor variables were derived. Based on species presence data, a Boolean map (1/0) was created to produce the depending data set for the modeling.

The empirical multivariate approach of the Ecological Niche Factor Analysis (ENFA) implemented in the BioMapper software was used to model habitat suitability of the tiger. The ENFA is one of the approaches of presence-only models. The principle of ENFA is to compute a suitability function by comparing environmental variables in the species presence cells ("species distribution") with respective mean values of the entire study area ("global distribution"). It is built on the concept of marginality and specialization of a species. If the species distribution mean differs from the global distribution mean, this is called marginality. Specialization quantifies the difference between the variance of both distributions. The two major outcomes of the FNFA model are a so called score matrix, giving a ranking of EGVs meanings for the habitat choice of the focal species (explanation component of the model) and an area-wide habitat suitability map (prognosis component of the model).

From the literature review and expert interviews, tiger preferences for certain vegetation types as well as its behavior to avoid certain man-made landscape and topographical features were identified. Four major groups of tiger preferences were identified and these were possibly translated into quantitative EGVs by means of radius analyses, regarding area and length of selected landscape elements in the vicinity of focal cells, distance measures and cell-based extraction. Based on tiger's daily movement, 3,000 m radius (2,826 ha inside the circular analysis windows) was used to produce area-related and length-related EGVs. To avoid model overfitting because of the large numbers of EGVs they were categorized into six groups for variable selection. Before using the 36 EGVs in the modeling, all of them were normalized by means of the Box-Cox transformation approach and checked regarding too high correlations. 34 EGVs with only weak correlation, divided into the six variable categories, were further analysed. Separate ENFA runs for each group were conducted and the EGVs with the highest suitability scores were selected and then tested again for their scores in summarizing ENFA runs. Three levels of separate ENFA were performed until the best EGVs were identified. During these analyses, it became clear that the presence of high habitat quality was associated with the presence of large areas of evergreen open forest. Due to low predictive power of the 'full' model with all 9 EGVs, models with all possible combinations of EGVs (each models with at least 6 EGVs) were created to compare the models predictive power. Finally, the model with the highest predictive power was identified. It contained 6 EGVs and revealed the following tiger-environment relationships:

- Tigers avoid higher values of evergreen closed areas (evgclos_area)
- Tigers prefer areas close to streambed (streambed_dist)
- Tigers avoid areas close to settlements (settlem_dist)

- Tigers are associated with kaing grass area (kaing_area)
- Tigers prefer areas close to south aspect (dist_south), and
- Tigers avoid areas close to east aspect (dist_east).

The overall marginality value is 0.5 meaning that the tiger habitat is not too different from the mean available conditions in the core zone. Also the high tolerance value (0.6) explained that tigers are not too picky about their living environment. But the core area has special habitat characteristics when compared to the rest of the study region. The global specialization value was found to be rather high (1.78). This was due to a very strong influence of human settlements in the model which were strongly avoided by the tigers. The habitat suitability (HS) map exhibited 30% of unsuitable areas, 28% of marginal areas and 42% of suitable and optimal areas for the tiger in the core zone. It was observed that the core zone still supports the vegetation cover which the tiger can stalk in. By visual comparison between the HS map and the maps of the most important EGVs, it became clearer that the suitable areas of the HS map are mostly connected to the presence of kaing grass and streambeds. Because of no major land use changes took place within the past 10 years, the HS map contains very useful information for the future conservation management in the study area, even though the map was specifically derived for the year 2003.

The findings of this study are consistent with the literature reviews and expert interviews except for the unexpected finding of a negative relationship of the presence of evergreen closed forest and tiger presence. The characteristics of undergrowth in different forest types will influence the habitat choice of tigers especially regarding closed forests. The tigers in the Hukaung reserve obviously prefer open forest areas to closed forest areas.

Finally, this study strongly recommends a strict monitoring in the core zone in order to minimize threats in the future. It is suggested that three management zones are created in the core zone: a protection zone, a zone of sustainable utilization and a buffer zone. The shape of the zones has to follow the areas of different habitat suitability values from the modeling. The applied model appears to be a very promising method to derive meaningful estimation of habitat suitability. The HS map as one of the major outcomes of the modeling can support wildlife managers in the development and implementation of conservation and protection measures for tigers as well as for other endangered species in the Hukaung reserve.

8 ZUSAMMENFASSUNG

Die vorliegende Arbeit hat die Erstellung eines Habitateignungsmodells zum Inhalt, um die Beziehungen zwischen der räumlichen Verteilung einer Tigerpopulation und den vorherrschenden Umweltbedingungen im Untersuchungsgebiet zu erklären. Die Abnahme der Tigerpopulation im Hukaung Valley Tiger Reserve (HVTR) in Nord-Myanmar, verursacht durch eine Kombination aus Habitatverlust, menschliche Störeinflüsse und abnehmende Beuteverfügbarkeit, war der Grund zur Ausarbeitung dieser Studie. Die ersten beiden Kapitel der Arbeit befassen sich mit dem inhaltlichen Hintergrund und der Problemstellung der Untersuchung, dem Schutzstatus des Tigers, dem Schutz der Biodiversität und weiteren wichtigen Fragestellungen betreffend das HVTR sowie mit der Literaturauswertung zur Ökologie des Tigers und zur Habitateignungsmodellierung. Im dritten Kapitel werden die methodischen Ansätze der Studie erläutert, während das vierte und fünfte Kapitel die erzielten Resultate und die zugehörige Diskussion zum Inhalt haben.

Die Studie konzentriert sich hauptsächlich auf die Kernzone des HVTR, die 1.713 km^2 umfasst. Der Bezugszeitraum dieser Untersuchung ist das Jahr 2003, wobei das Ende des Jahres 2002 sowie der Anfang des Jahres 2004 aus Gründen der eingeschränkten Verfügbarkeit der Artdaten mit eingeschlossen sind. Der Hauptteil der Tiger-Präsenzdaten im HVTR fiel in diesem Zeitrahmen in die erwähnte Kernzone.

Fernerkundung und GIS wurden als Werkzeuge eingesetzt, um unabhängige Variablen mit Relevanz für die Habitatwahl des Tigers abzuleiten. Die Response-Variable des Habitatmodells war die Präsenz der Zielart, wobei 31 Präsenzpositionen des Tigers zur Verfügung standen. Die unabhängigen Daten (ökogeographische Variablen = EGV) lagen in Form von Variablen zur Landnutzung, Topographie und menschlichen Einflussfaktoren vor.

Eine segmentbasierte Landnutzungsklassifizierung wurde durchgeführt, wobei die objektorientierte Analyse der Fernerkundungsdaten unterstützt durch eine bestehende Referenzkarte und weitere Hilfsdaten vollzogen wurde. Der Klassifizierungsschlüssel wurde basierend auf jenen Landnutzungskategorien erstellt, die als potentiell relevant für die Ökologie des Tigers anzusehen waren. Insgesamt 14 Landnutzungen ließen sich für die Kernzone identifizieren. Über eine Genauigkeitsanalyse wurde für die segmentbasierte

Klassifizierung mit Hilfe einer Fehlermatrix eine Gesamtgenauigkeit von 79%, eine mittlere Nutzergenauigkeit von 73% sowie eine mittlere Produzentengenauigkeit von 77% ermitteln. Unterstützt durch die vorliegenden Hilfsdaten konnten die topographischen Variablen sowie die menschlichen Einflussfaktoren abgeleitet werden. Basierend auf den Präsenzdaten des Tigers ließ sich eine Boolesche Karte (1|0) produzieren, um den abhängigen Datensatz für die Modellierung bereitzustellen.

Der empirische multivariate Modellansatz der Ecological Niche Factor Analysis (ENFA), implementiert in der Software Biomapper, wurde zur Modellierung der Habitateignung für den Tiger eingesetzt. Die ENFA stellt einen Vertreter der „Presence-Only-Modelle“ dar. Ihr Prinzip beruht darauf, eine Eignungsfunktion abzuleiten, indem die Werte der Umweltvariablen an den Präsenzpositionen einer Zielart (Species-Verteilung) mit den mittleren Werten der entsprechenden Variablen über das Gesamtgebiet betrachtet (globale Verteilung) verglichen werden. Diese Arbeitsweise der ENFA setzt dabei auf dem Konzept der Marginalität und Spezialisierung einer Art auf. Dabei drückt die Marginalität die Abweichung des Mittelwertes der Species-Verteilung von jenem der globalen Verteilung aus. Die Spezialisierung quantifiziert den Unterschied zwischen den Varianzen der beiden Verteilungen. Die zwei Hauptprodukte der ENFA sind eine sogenannte Score-Matrix, in der eine Rangfolge der Bedeutung der Umweltvariablen für die Habitatwahl der Zielart angegeben wird (Erklärungskomponente des Modells) sowie eine flächendeckende Habitateignungskarte (Prognosekomponente des Modells).

Aus der Literaturrecherche und Experteninterviews ließen sich zahlreiche Präferenzen des Tigers für ausgewählte Vegetationstypen wie auch Angaben zum Meidungsverhalten der Zielart gegenüber bestimmten anthropogenen Landschaftselementen und Strukturen sowie topographischen Landschaftsmerkmalen gewinnen. Vier Hauptgruppen von Präferenzen konnten identifiziert werden, wobei die einzelnen Präferenzen mittels Radiusanalysen zu Fläche und Länge ausgewählter Landschaftselemente, Distanzmaßen und (landschafts)zellbezogenen Extraktionen in quantitative EGV umgesetzt wurden. Ausgehend von einem möglichen täglichen Bewegungsradius des Tigers wurden die Analyseradien mit 3.000 m (= 2.826 ha Kreisfläche) veranschlagt und so die flächen- und längenbezogenen EGV berechnet. Um vor dem Hintergrund einer großen Zahl an EGV eine Überanpassung des Modells zu vermeiden, wurden die Umweltvariablen in 6 Gruppen kategorisiert. Vor ihrer Verwendung im Modell wurden alle 36 EGV mittels Box-Cox-

Transformationen normalisiert und auf gegenseitige Korrelationen überprüft. Es konnten 34 unkorrelierte bzw. nur leicht korrelierte EGV, eingeteilt in die 6 Variablengruppen, weiter analysiert werden. Separate ENFA-Läufe wurden vollzogen und im Zuge einer Variablenselektion diejenigen EGV mit den höchsten Eignungs-Scores identifiziert. Die einflussreichsten EGV wurden in zusammenfassenden ENFA-Läufen wiederum auf ihre Scores getestet, bis eine Gruppe von 9 EGV als wichtigste Variablen aus der Selektion resultierte. Hierbei zeigte sich, dass Flächen hoher Habitateignung mit dem Vorhandensein von großen Flächen immergrünen aufgelichteten Waldes zusammenhingen. Da das „volle Modell" mit sämtlichen 9 EGV eine nur geringe Vorhersagegüte aufwies, wurden Modelle mit sämtlichen möglichen Kombinationen aus den Untermengen der 9 EGV gebildet, wobei jeweils mindestens 5 EGV in ein Modell eingingen. Das Modell mit der höchsten Vorhersagekraft enthielt 6 EGV und zeigte folgende Umweltbeziehungen des Tigers auf:

- Tiger meiden Bereiche mit großen Anteilen geschlossenen immergrünen Waldes (evgclos_area)
- Tiger präferieren Bereiche nahe Flussbetten (streambed_dist)
- Tiger meiden Bereiche in der Nähe menschlicher Siedlungen (settlem_dist)
- Tiger halten sich bevorzugt in Bereichen mit großen Anteilen hohen Grases (Kaing-Gras) auf (kaing_area)
- Tiger präferieren Bereiche mit südwärts ausgerichteten Geländeneigungen (dist_south)
- Tiger meiden Bereiche mit ostwärts ausgerichteten Geländeneigungen (dist_east)

Die Gesamtmarginalität des Tigers lag bei 0,5, was eine nicht allzu starke Abweichung der Habitatbedingungen von den mittleren Bedingungen in der Kernzone des HVTR ausdrückte. Auch der hohe Toleranzwert von 0,6 zeigte, dass der Tiger keine sehr speziellen Anforderungen an seinen Lebensraum stellte. Allerdings galt es hierbei zu berücksichtigen, dass die Kernzone insgesamt sich hinsichtlich ihrer Habitatcharakteristika deutlich von der umgebenden Region abhebt. Die Gesamtspezialisierung lag mit 1,78 verhältnismäßig hoch, was durch den sehr großen Einfluss der menschlichen Siedlungen im Modell verursacht wurde, die vom Tiger stark gemieden werden. Die Habitateignungskarte wies 30% der Kernzone als ungeeignet, 28% als marginal geeignet und 42% als geeignet bis optimal für den Tiger aus. Es zeigte sich ferner, dass die

Kernzone (noch) diejenige Vegetationsbedeckung bietet, die der Tiger für seine auf dem verdeckten Anschleichen beruhende Jagd benötigt. Aus dem visuellen Abgleich der Habitateignungskarte und den Einzelkarten der 6 wichtigsten EGV ergab sich, dass geeignete Bereiche vorwiegend mit dem Vorhandensein von ausreichend großen Flächen an Kaing-Gras und nahegelegenen Flussbetten verknüpft waren. Da sich die Landnutzung in der Kernzone auch innerhalb der vergangenen 10 Jahre kaum verändert hat, stellt die Habitateignungskarte, auch wenn sie nur die Bedingungen im Jahr 2003 widerspiegelt, wichtige Information für das zukünftige Arten(schutz)-Management im Untersuchungsgebiet bereit.

Die Erkenntnisse der vorliegenden Studie stimmen mit den Ergebnissen der Literaturrecherche und Experteninterviews weitgehend überein. Eine Ausnahme bildet die gefundene negative Beziehung von Tigerpräsenz und dem Vorhandensein großer Flächen immergrünen dichten Waldes. Eine wichtige Rolle dürfte in diesem Zusammenhang der Unterwuchs spielen, der die Habitatwahl des Tigers mit Bezug auf den dichten Wald beeinflusst. Offensichtlich ziehen die Tiger der Population im Hukaung-Reservat aufgelichtete Waldbereiche dem dichten Wald vor.

Es geht aus dieser Untersuchung hervor, dass dem strengen Monitoring der Kernzone zur Verminderung von Habitatbeeinträchtigungen eine große Bedeutung für die Zukunft zukommt. Es wird eine Zonierung in drei Schutzkategorien vorgeschlagen: streng geschützte Bereiche, Zonen mit nachhaltiger Nutzung sowie Pufferzonen. Die Verläufe der Zonen sollten sich an den Bereichen unterschiedlicher Habitatgütewerte aus der Modellierung orientieren. Das hier angewandte Habitatmodell zeigt sich als vielversprechende Methode, um zu aussagekräftigen Einschätzungen der Lebensraumqualität zu gelangen. Die Habitateignungskarte als eines der Hauptresultate der Modellierung kann die Wildtier-Manager im Hukaung-Reservat in der Entwicklung und Umsetzung von Erhaltungs- und Schutzmaßnahmen für den Tiger wie auch für weitere geschützte Arten unterstützen.

9 ANSWERS TO THE RESEARCH QUESTIONS

The intermediate and final ENFA models answered the following research questions:

Research question 1: Has there been any previous analysis which is suitable for building a habitat suitability model for the tiger in case of small number of presence points/missing absence data? Has a selected model been proven to be a suitable approach for tiger habitat suitability analysis?

Indicators: Review habitat suitability models based on only presence-only data.

Answer: Yes. As recommended by Hirzel *et al. (*2002), the ENFA model of BioMapper4 software was used for this study of presence only data of small sample points. ENFA has been proven to be a suitable approach for tiger habitat suitability analysis by producing two outputs: 1) Score matrix (ecological interpretation), and 2) A Habitat suitability map (prognosis).

The score matrix predicted by the ENFA answers the research questions 2, 3 and 4 as follows:

Research question 2: What are the habitat preferences of tigers regarding vegetation features? Are there any habitats which are favoured by tigers in the study area?

Indicators: Tiger presence in/close to vegetation types (closed evergreen forest, open evergreen open forest, Kaing grass, bamboo, rattan, etc.)

Answer: Yes. The habitats that are favoured by tigers in the study area are characterized by low densities of evergreen closed forest, high frequency of evergreen open forest, streambeds and kaing grass.

Research question 3: Is there any ecological relationship between topographical variables and the tiger habitat preferences?

Indicators: Tiger presence at different slopes, elevations, and aspects (flat/north/east/south/west).

Yes. ENFA predicted that there is an ecological relationship between tigers and topographical variables especially with regard to the aspect of the terrain. Tigers favour going closer to south aspect, but they prefer staying away from east aspect and terrain little slope percentages.

Research question 4: Have there been any human disturbances to the tiger's habitat in the core zone?

Indicators: Amount/ distance of different human interferences to tiger presence in the core zone (dynamite fishing, settlement, gold-mining, logging, etc.)

Answer: Yes. The result showed that human-settlement is the most dominant factor for the tiger's specialization in the study area. The remaining human threats such as dynamite fishing, gold-panning, non-timber forest product collection verified to be not too extreme in terms of threatening tiger locations in the core zone.

10 REFERENCES

Baatz, M., Schape, A. 2000. Multiresolution segmentation: an optimization approach for high quality multi-scale image segmentation: XII Angewandte Geographische Informationsverarbeitung.

Baudy, R. E. 1968. Report on the Sieberian tiger. Published by the author, Center Hill, Florida: pp. 1-6.

BBCNews. 2010. Available from: http://news.bbc.co.uk/earth/hi/earth_news/newsid_8998000/8998042.stm. Assessed on: 16 /05/2012.

Begon, M., J. L. Harper, and C. R. Townsend. 1996. Ecology: Individuals, Populations and Communities. *3rd ed. Blackwell Science*, Oxford, UK.

Blaschke, T., Lang, S., Lorup, E. and Brown, D. W. 2000. Object-oriented Image Processing in an integrated GIS/Remote Sensing Environment and Perspectives for Environmental Applications. In *Enviromental Information for Planning, Politics and the Public*, Cremers, A. and Greve, K., Marburg: metropolis-Verlag, pp 555–570.

Boyce, M. S., Vernier, P. R., Nielsen, S.E., Schmiegelow, F. K. A. 2002. Evaluating resource selection functions. *Ecol. Model*. 157, 281–300.

Bradley, B., Fleishman, E. 2008. Can remote sensing of land cover improve species distribution modelling? *Journal of Biogeography*, 35**:** pp. 1158-1159.

Brain, J. H., Glenn. D. W., Michael, L. C. 2010. Habitat suitability and conservation of the Giant Gartersnake (*Thamnophis gigas*) in the Sacramento Valley of California. *Copeia*, No.4: pp. 591-599.

Braunisch, V., Bollmann, K., Graf, R. F., Hirzel, A. H. 2008. Living on the edge – modelling habitat suitability for species at the edge of their fundamental niche. *Ecological Modelling* (214): pp.153–167.

Broton, S.L., Thuiller, W., Araujo, M. B., Hirzel, A. H. 2004. Presence-absence versus presence-only modeling methods for predicting bird habitat suitability. *Ecography* 27: pp. 437-448.

Bryan, T. L., Metaxas, A .2007. Predicting suitable habitat for deep-water gorgonian corals on the Atlantic and Pacific Continental Margins of North America. *Mar Ecol Prog Se*r 330: pp.113–126.

Buschmann, A. 2011. Bruthabitatmodellierung für den Rotmilan (Milvus milvus) im EU-Vogelschutzgebiet ‚Unteres Einchsfeld' eine fernerkundungsgestützte Studie unter spezieller Berücksichtigung der Landschaftsstruktur. PhD thesis, Georg-August University Goettingen: pp.1-383.

Calenge, C., Darmon, G., Basille, M., Loison, A., Jullien, J. M. 2008. The factorial decomposition of the Mahalanobis distances in habitat selection studies. *Ecology*, 89(2): pp.555–566.

Cañadas, A., R. Sagarminaga, R. de Stephanis, E. Urquiola and P.S. Hammond. 2005. Habitat selection models as a conservation tool: proposal of marine protected areas for cetaceans in Southern Spain. Aquatic Conservation: *Marine and Freshwater Ecosystems* 15: pp.495-521.

Card, D. 1982. Using known map category marginal frequencies to improve estimates of thematic map accuracy. *Photogrammetric Engineering and Remote Sensing*. 48(3): pp. 431-439.

Chhabra, A., Geist, H. J., Houghton, R. A., Haberl, H., Braimoh, A. K., Vlek, P. I. 2006. Multiple impacts of land-use/cover change. In: Lambin, E.F., Geist, H.J. (Eds.), Land-use and Land-cover Change. Local Processes and Global Impacts. *Springer-Verlag,* Berlin: pp. 71–116.

Christie, S. 2006. NGO investment in tiger conservation units, 1998–2003. Pages 116–119 in Sanderson E, et al., eds. Setting Priorities for the Conservation and Recovery of Wild Tigers: 2005–2015. The Technical Assessment. Washington (DC): WC S,WWF, Smithsonian, and NFWFSTF.

Christie, S. and Walter, O. 2000. European and Australian studbook for tigers (*Panthera tigris*), vol. 6. Zoological Society of London, London.

Chundawat, R. S., Gogate, N., Johnsingh, A. J. T. 1999. Tigers in Panna: preliminary results from an Indian tropical dry forest. In Riding the Tiger: Tiger Conservation in Human-Dominated Landscapes (eds J. Seidensticker, S. Christie & P. Jackson), pp. 123–129. Cambridge University Press, Cambridge, UK.

Clark, C. R. 1990. Remote sensing scales related to the frequency of natural variation: an example from paleo-rice-flow in Canada. *IEEE Trans. Geosci. Remote Sens.* 28(4): pp.503-508.

Clark, J. D., J. E. Dunn, and K. G. Smith. 1993. A multivariate model of female black bear habitat use for a geographic information system. *Journal of Wildlife Management* 57: pp. 519–526.

Cody, M. L. 1985. Habitat selection in birds: the roles of habitat structure, competitors and productivity. *Bioscience* 31: pp.107-113.

Congalton, R. G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment* 37: pp. 35-46.

Congalton, R. G., Green, K. 1999. Assessing the accuracy of remotely sensed data: principles and practices. Boca Raton, FL: *Lewis Publishers*: Pp.1-137.

Corbett Fun Resort. 2012. Available from: http://www.corbettfunresort.com/Tigers.php. Assessed on: 12/05/2012.

Dalsted, K. 2011. Remote Sensing and GIS Techniques for the Detection, Surveillance and Management of Invasive Species. GIS Applications in Agriculture, Volume Three. Edited by Sharon A . Clay. CRC Press 2011: pp. 1–8

De Kok, R., Schneider, T., Ammer, U. A. 1999. Object-based Classification and Applications in the Alpine Forest. International Archives of Photogrammetry and Remote Sensing, 32, (Part 7-4-3 W6). Valladolid, Spain.

Decoursey, D. G. 1992. Developing models with more detail: do more algorithms give more truth? *Weed Technol.* 6: pp. 709–715.

Definiens. 2003. eCognition Version 3. User guide.

Dirzo, R., Raven, P. H. 2003. Global state of biodiversity and loss. *Annu. Rev. Environ. Resour*. 28: pp.137–167

Dobby, E. H. G. 1964. Southeast Asia, University of London Press Ltd, Warwick Square, London.

Dormann, C.F., Blaschke, T., Lausch, A., Schröder, B., Söndgeranth, D. (Hrsg.). 2004. Habitatmodelle-Methodik, Anwendung, Nutzen. Tagungsband zum Workshop vom 8.-10. Oktober 2003 am UFZ Leipzig. UFZ-Berichte 9/2004.

Eastmen J. R. (2006) Idrisi Andes. Guide to GIS and Image Processing. Manual Version 15.*Clarke Labs. Clarke University*, Worcester, MA, USA.

Edgaonkar, A. 2008. Ecology of the Leopard (*Panthera pardus*) in Bori Wildlife Sanctuary and Satpura National Park, India. University of Florida. PhD thesis: pp. 1-134.

Elith, J. et al. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29: pp. 129_151.

ESD. 2012. Available from: http://www.esd.ornl.gov/programs/SERDP/EcoModels/habmodel.html. Assessed on 27/04/ 2012.

Farmer, A. H., M. J. Armbruster, J. W. Terrell, R. L. Schroeder. 1982. Habitat models for land use planning: assumptions and strategies for development. Transactions of the North American *Wildlife and Nature Conference* 47: pp.47-46. Hilborn, R,M. Mangel. 1997. The ecological detective. Princeton University Press, Princeton, N.J.

Fielding, A. H., Bell, J. F. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environ.Conserv.* 24: pp. 38–49.

Flanders, D., Hall-Beyer, M., Pereveryoff, J. 2003. Preliminary evaluation of eCognition object-based software for cut block delineation and feature extraction.

Forest Department, Food and Agricultural Organization of the United Nations. 2010. Global Forest Resource Assessment, Country Report, Myanmar. FRA 2010/41. Rome.

Franklin N, Sriyanto B, Siswomartono D, Manansang J, Tilson R. 1999. Last of the Indonesian tigers: a cause for optimism. In: Seidensticker J, Christie S, Jackson P (eds) Riding the tiger: tiger conservation in human dominated landscapes. Cambridge Uni-versity Press, Cambridge, pp 130–147.

Freer, R. A. 2004. The Spatial Ecology of the Güiña (*Oncifelis guigna*) in Southern Chile. Department of Biological Sciences, University of Druham, UK. PhD thesis: pp.1-219.

Galparsoro, I., Borja, A., Bald, J., Liria, P., Chust, G. 2009. Predicting suitable habitat for the European lobster (*Homarus gammarus*), on the Basque continental shelf (Bay of Biscay), using Ecological-Niche Factor Analysis: *ecological modeling* 220: pp. 556–567

Georg B. Shaller. 1967. The Deer and the Tiger. The Study of Wildlife in India. University of Chicago Press. LTD., London: pp.1-361.

Gorte, B.1998. Probabilistic Segmentation of Remotely Sensed Images. ITC Publication Series No. 63, Enschede, ITC Publication

Griffiths, M. 1996 in Sunquist, M., Karanth, K.U., Sunquist, F. 1999. Ecology, behavior and resilience of the tigers and its conservation needs. pp. 5-18 of Riding the tiger, 1999.

Griffiths, M. 1996. Avalilable from: http:\\ www.5tigers.org/griffiths.htm;

Grinnell, J. 1917. The niche relationship of the californian Trasher. *Auk*.34: pp.427-433.

GTI. 2009. Global Tiger Initiative. Saving Wild Tigers: A report from the Global Tiger Workshop on October 27-30, 2009. Kathmandu, Nepal: pp.1-17.

Guisan, A., Zimmermann, N. E. 2000. Predictive habitat distribution models in ecology. *Ecological Modelling;* 135: pp. 147–186.

http:\\ www.5tigers.org/intrphva.htm. Assessed on: 07/05/2012.

Hall, C. A. S. and J. Day. 1977. Systems and models: Terms and basic principles. In Ecosystem modeling in theory and practice, ed. C.A.S. *Hall and J.W.Day*: pp. 6-36. New York Wiley Interscience.

Hatcher, L., Stepanski, E. J. 1994. A Step by Step Approach to Using the SAS System for Univerate and Multivariate Statistics, Cary, NC: SAS Institute Inc.,pp. 1-552.

Hay, S. I., Packer, M. J., Rogers, D. J. 1997. The impact of remote sensing on the study and control of invertebrate intermediate host and vectors for disease. *Intl. J. Remote Sensing 18*, 2899–2930.

Hemley, G., and J. A. Mills. 1999. The beginning of the end of tigers in trade? *in* J. Seidensticker, S. Christie, and P. Jackson, editors. Riding the Tiger: Tiger conservation in human dominated landscapes. Cambridge University Press, Cambridge, UK.

Henrik, S., Humphreysb, E., Garthec, S., Geitnerd, K., Gremillete, D., Hamerb, K. C., Hennickef, J., Parnerg, H., Wanlessh, S. 2008. Application of habitat suitability modelling to tracking data of marine animals as a means of analyzing their feeding habitats. *Ecological modelling* 212: pp. 504-512.

Hewett, J. 1938. Jungle trails in Northern India. London. (quoted after Mazák, V. 1981).

Higgins, S. I., D. M. Richardson, M. C. Richard, and T. H. Trinder-Smith. 1999. Predicting the landscape-scale distribution of alien plants and their threat to plant diversity. *Conservation Biology* 13: pp. 303–313.

Hirzel, A. H. 2004. Biomapper 3. User's Manual. Lausanne. Switzerland.

Hirzel, A. H. 2005. Presentations on ENFA principles and various habitat suitability algorithms. Presented in Portland (Oregon, USA). Last updated: 22/11/2006. Available from: http://www2.unil.ch/biomapper/Presentations.html. Assessed on: 12/05/2012.

Hirzel, A. H. 2006. Presentation on evaluation of presence-only models with the continuous Boyce index and cross-validation. Presented at a workshop at the Castle of Rauischholzhausen. Last updated 22/11/2006. Available from: http://www2.unil.ch/biomapper/Presentations.html. Assessed on: 12/05/2012.

Hirzel, A. H., Arlettaz, R. 2003. Modelling habitat suitability for complex species distributions by the environmental-distance geometric mean. *Environ. Manage*. 32, 614–623.

Hirzel, A. H., Braunisch, V., Bollmann, K., Graf, R.F. 2008. Living on the edge Modelling habitat suitability for species at the edge of their fundamental niche. Ecological Modelling, on line.

Hirzel, A. H., Guisan, A. 2002. Which is the optimal sampling strategy for habitat suitability modeling. *Ecological modelling* 157: pp. 331-341.

Hirzel, A. H., Hausser, J., Chessel, D. and Perrin, N. 2002. Ecological Niche Factor Analysis: how to compute habitat-suitability maps without absence data. *Ecology*, 83 (7): pp. 2027-2036.

Hirzel, A. H., Hausser, J., Perrin, N. 2004. Biomapper 3.1. Lab. of Conservation Biology, Department of Ecology and Evolution, University of Lausanne. URL: http://www.unil.ch/biomapper. Assessed on: 12/05/2012.

Hirzel, A. H., Helfer, V., M´ etral, F. 2001. Assessing habitat-suitability models with a virtual species. *Ecological Modeling* 145: pp.111–121.

Hirzel, A. H., Lay, G.L., Helfer, V., Randin, C., Guisan, A. 2006. Evaluating the ability of habitat suitability models to predict species presence. Ecological Modelling 199: pp. 142-152.

Hirzel, A. H., Posse, B., Oggier, P.-A., Glenz, Y.C., Arlettaz, R. 2004. Ecological requirements of a reintroduced species, with implications for release policy: the bearded vulture recolonizing the Alps. *J. Appl. Ecol.* 41: pp. 1103–1116.

Huck, M., Jedrzejeswski, W., Borowik, T., Milosz-Cielma, M., Schmidt, K., Jedrzejeswska, B., Nowak, S. & Myslajek, R. 2010. Habitat suitability, corridors and dispersal barriers for large carnivores in Poland. *Acta Theriologica*, 55(2): pp. 177-192.

Huges, A. 2009. Expert Driven Habitat Suitability Modeling for the Magellanic Woodpecker in Karukinka National Park Tierra del Fuegl, Chile. M.Sc thesis: pp. 1-59.

Hutchinson, G. E. 1957. Concluding Remarks. *Cold Spring Harbor Symp Quantitative Biol*., 22: pp. 416-427.

Imam, E., Kushwaha, S., & Singh, A. (2009) Evaluation of Suitable Tiger Habitat in Chandoli National Park, India, Using Multiple Logistic Regression. *Ecological Modelling* 220 (24): pp. 3621–3629.

IUCN. 2011. IUCN Red List of Threatened Species. Version 2011.2. Available from: <www.iucnredlist.org>. Assessed on**:** 13/04/2102.

IUCN. 2012. Available from: http://www.iucn.org/what/tpas/biodiversity/about/. Assessed on: 12/05/2012.

Johnsingh, A. J. T. 1983. Large mammalian prey-predators in Bandipur. J. Bombay Nat. *Hist. Soc.* 80(1): pp.1-57.

Johnson, R., Temple, S. 1986. Assessing habitat quality for birds nesting in fragmented tallgrass prairies. In: Verner, J., Morrison, M., Ralph, J. (Eds.), Wildlife 2000. Modelling Habitat Relationships of Terrestrial Vertebrates: pp. 245–249.

Johnston, R. J. 1999. Geography and GIS. In *Geographical Information Systems. Volume 1: Principles and Technical Issues*, 1, edited by Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W. (New York: John Wiley & Sons): pp. 39-47.

Jongman, R. H. G., C. J. F. ter Braak, and O. F. R. Van Tongeren. 1987. Data analysis in community and landscape ecology. Cambridge University Press, Cambridge, UK. Kery, M. 2000. Ecology of small populations. Dissertation. University of Zürich, Zürich, Switzerland.

Joseph D. Clark. 1998. A female black bear denning habitat modeling using a Geographic Information Systmen. *Ursus* 10: pp. 181-185.

Kanagaraj, R., Wiegand, T., Kramer-Schadt, S., Anwar, M. and Goyal, S. P. 2010. Assessing habitat suitability for tiger in the fragmented Terai Arc landscape of India and Nepal. – *Ecography* 33:

Karanth, K. U. 1993. Predator-prey relationships among large mammals of Nagarahole National Park, (India). PhD thesis, Mangalore University, Mangalore, India.

Karanth, K. U. 2001. *Tigers.* Scotland, U.K: Colin Baxter Photography in Damania, R., Stringer, R., Karanth, K.U., Sinth, B. 2003. The economics of protecting tiger populations: Linking household behavior to poaching and prey depletion. *Land Economics* 79 (2): pp- 198-216

Karanth, K. U. 2006. The Way of the tiger. Voyageur Press: pp.1-132.

Karanth, K. U., Nichols, J. D. 1998. Estimation of tiger densities in India using photographic captures and recaptures. *Ecology 79*: pp. 2852-2862.

Karanth K. U., Nichols, J. D. 2000. Ecological status and conservation of tigers in India. Final technical report to the US Fish and Wildlife Service (Division of International Conservation), Washington DC, Wildlife Conservation Society, New York. Centre for Wildlife Studies, Bangalore, India

Karanth, K. U. , Nichols, J. D. 2002. Monitoring tigers and their prey. Centre for Wildlife Studies, Bangalore, India.

Karanth, K. U., Nichols, J. D., Kumar, N.S., Link, W.A., Hines, J.E. 2004. Tigers and their prey: predicting carnivore densities from prey abundance. *Proc Natl Acad Sci* USA 101: pp. 4854–4858. doi: 10.1073/pnas.0306210101

Karanth, K. U., Nichols, J. D, Kumar, N., N., Hines, J. E. 2006. Assessing tiger population dynamics using photographic capture-recapture sampling. *Ecology*, 8, pp.2925-2937.

Karanth, K. U., Sunquist, M. E. 1992. Population structure, density and biomass of large herbivores in the tropical forests of Nagarahole, India. *J. trop. Ecol*. 8: pp. 21-35.

Karanth, K. U., Sunquist, M. E. 1995. Prey selection by tiger, leopard and dhole in tropical forests. *J. Anim. Ecol.* 64: pp. 439-450.

Karanth, K. U., Sunquist. M. E. 2000. Behavioural correlates of predation by tiger (*Panthera tigris*), leopard (*Panthera pardus*) and dhole (*Cuon alpinus*) in Nagarahole, India.The Zoological Society of London Printed in the United Kingdom. *J. Zool*., Lond. 250: pp. 255-265

Karmode, C. W. D. 1964. Some aspects of silviculture in Burma. Forest Department, Central Press, Yangoon.

Kerley, L. L., Goodrich, J. M., Miquelle, D. G., Smirnov, E. N., Quigley, H. B. and Hornocker, M. G. 2002. Effects of roads and human disturbance on Amur tigers. *Conserv. Biol.* 16(1): pp. 97-108.

Khan, M. M. H. 2004. Ecology and conservation of the Bengal Tiger in the Sundarbans Mangrove Forest of Bangladesh.

Khan, M. M. H., Chivers, D.J. 2007. Habitat preferences of tigers Panthera tigris in the Sundarbans East Wildlife Sancturary, Bangladesh, and management recommendations. *Oryx* Vol 41 (4): pp. 463-468.

Kliskey, A. D., Lofroth, E. C., Thompson, W. A., Brown, S., Schreier, H. (1999). Simulating and evaluating alternative resource-use strategies using GIS-based habitat suitability indices. *Landscape and Urban Planning* 45: pp.163-175.

Koeln, G.T., Cowardin, L. M., Strong, L. L. 1994. Geographic information systems. Pages 540-566 in T.A. Bookhout, ed. Research and management techniques for wildlife and habitats. Fifth ed. The Wildlife Society, Bethesda, Md.

Korzukhin, M. D., Ter-Mikaelian, M. T., Wagner, R. G. 1996. Process versus empirical models: which approach for forest ecosystem management? Can. *J. For. Res*. 26: pp. 879–887.

Krebs, C. J. 1994. Ecology. HarperCollins College Publischers, New York.

Kushwaha, S. P. S., Khan, A., Habib, B., Quadri, A., Singh, A. 2004. Evaluation of sambar and muntjac habitats using geostatistical modelling. Curr. Sci. 86 (10): pp. 390–1400.

Kywe, T. Z. 2006. Impact of current land use practices and developments in the Hukaung Valley Tiger Reserve, northern Myanmar. MSc thesis: pp.1-71.

Lam, N. S.-N., Quattrochi, D. A. 1992. On the isssues of scales, resolution and fractal analysis in the mapping sciences. *Prof. Geogr* 44 (1): pp. 88-98.

Larson, M. A., W. D. Dijak, F. R. Thompson, III & J. J. Millspaugh.2003. Landscape-level habitat suitability models for twelve wildlife species in Southern Missouri. General Technical Report NC_233. St. Paul, MN: U.S. Dept of Agriculture, Forest Service, North Central Research Station. Pp. 1-51.

Latt, K. T. 2011. Community-based natural resource management. A case study of Hukaung Valley Tiger Rerserve, Myanmar. MBA. Yangon Institute of Economics: pp. 1-62.

Latt , K. T., Win, Z. & Lynam, A. 2004. Establishment of GIS data base for identifying potential tiger habitat in the Hukaung Valley Tiger Reserve by using remote sensing and GIS techniques. WCS (Myanmar Programme).

Lapoint, E., Conard, K., et al. 2007. Tiger Conservation. It's time to think outside the box. IMWC World Conservation Trust: pp.1-15. Available from: http://www.iwmc.org/PDF/IWMCtiger.pdf. Assessed on: 24/04/2012.

Leary, R. A. 1985. Interaction Theory in Forest Ecology and Management. Nijhoff, Dordrecht, The Netherlands.

Legendre, L., and P. Legendre. 1998. Numerical ecology. Second English edition. Elsevier Science BV, Amsterdam, The Netherlands.

Levins, R. 1966. The strategy of model building in population ecology. Am. Sci. 54: pp. 421–431.

Lewis, H. G., Brown, M. 2001. A generalized confusion matrix for assessing area estimates from remotely sensed data. INT.J. Remote Sensing, 2001, vol. 22, no. 16: pp. 3223–3235.

Livingston, S. A., C. S. Todd, W. B. Krohn, and R. B. Owen. 1990. Habitat models for nesting bald eagles in Maine. *Journal of Wildlife Management* 54:pp. 644–657.

Lynam, A. J. 2003. A National Tiger Action Plan for the Union of Myanmar.. Myanmar Forest Department and Wildlife Conservation Society, Yangon. Pp.1-57

Lynam, A. J., Khaing, S. T., Zaw, K. M. 2006. Developing a National Tiger Action plan for the Union of Myanmar. *Environmental Management* Vol.37, No.1: pp. 30-39.

Lynam, A. J., Rabinowitz, A., Myint, T., Maung, M., Latt, K. T., Po, S. H. T. 2008. Estimating abundance with sparse data: tigers in northern Myanmar. *Popul Ecol* 51:pp. 115–121 DOI 10.1007/s10144-008-0093

Macdonald, D. (2001) The New Encyclopedia of Mammals. Oxford University Press, Oxford.

MacKenzie, D. I., Lachman, G.B., Droege, S., Royle, J. A., Langtimm, C. A. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83: pp. 2248-2255.

Manel, S., J. M. Dias, S. T. Buckton, S. J. Ormerod. 1999. Alternative methods for predicting species distribution: an illustration with Himalayan river birds. *Journal of Applied Ecology* 36: pp.734–747.

Maruska, E. J. 1987. White tiger: Phantom or freak? In: Tigers of the World: The Biology, Biopolitics, Management and Conservation of an Endangered Species, eds. R. L. Tilson and U. S. Seal, Noyes Publ.: Park Ridge, NJ: pp.372-379.

Marzluff, J. M., Millspaugh, J. J., Ceder, K. R., Oliver, C. D., Withey, J., McArther, J. B., et al. 2002. Modeling changes in wildlife habitat and timber revenues in response to forest management. *Forest Science* 48: pp.191-202.

Mazák, V. 1965. *Der Tiger Panthera tigris Linnaeus 1758*. Volume 356 of Die Neue Brehm-Bücherei. A. Ziemsen, Wittenberg Lutterstadt.

Mazák, V. 1981. Mammalian species. Published by the American Society of Mammalogists. No. 152: pp. 1-8

Mather, P.1999. *Computer Processing of Remotely Sensed Images*, Chichester, Wiley.

Meng, L., Fang, J., Lou, S., Zhang, W . 2009. Study on Image Segment Based Land Use Classification and Mapping, School of Remote Sensing and Information Engineering.

Mertzanis, G., Kallimanis, A., Kanellopoulos, N., Sgardelis, S., Tragos, A., Aravidis, I. 2008. Brown bear (Ursus arctos L.) habitat use patterns in two regions of northern Pindos, Greece – management implications. *Journal of Natural History* 42(5): pp. 301-315.

Michael A. Larson, William D. Dijak, Frank R. Thompson, III, and Joshua J. Millspaugh, 2003. Landscape-level Habitat Suitability Models for Twelve Wildlife Species In Southern Missouri.

Morris, D. W., D. L. Davidson. 2000. Optimally foraging mice match patch use with habitat differences in fitness. *Ecology* 81 (8): pp. 2061-2066.

Morrison, M. L., L. S. Hall. 1998. Responses of mice to fluctuating habitat quality.I. Patterns from a long-term observational study. *Southwestern Naturalist* 43: pp. 123-36.

Morrison, M. L., Marcot, B. G., Mannan, R. W. 2006. Wildlife-habitat relationships: Concepts and Application. Third Edition. Island Press, London.

MyanmarTimes Journal . 2011. Available from: http://www.mmtimes.com/2011/news/587/news58719.html. Assessed on: 11/05/2012.

Myers, N, Mittermeier, RA, Mittermeier, CG, da Fonseca, GAB, Kent, J. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

Nathan G. Swenson. 2007. The past and future influence of geographic information systems on hybrid zone, phylogeographic and speciation research. *Journal of Evolution Biology*. doi:10.1111/j.1420-9101.2007.01487.x. pp. 421-434.

National Commission for Environmental Affairs (NCEA) Government of the Union of Myanmar, Ministry of Forestry, 2009. Fourth National Report to the United Nations Convention on Biological Diversity. Nay Pyi Taw: pp. 1-83.

Nowell K, Jackson P. 1996. North Africa and Southwest Asia, Cheetah. In: Nowell K, Jackson P, editors. Wild cats: Status survey and conservation action plan. Gland, Switzerland: IUCN/SSC Cat Specialist Group; pp- 41-44.

Opdam, P., Foppen, R., Vos, C. 2001. Bridging the gap between ecology and spatial planning in landscape ecology. *Landscape Ecology*16: pp. 767-779.

Otis, D. L., Burnham, K. P., White, G. C., Anderson, D. R.1978. Statistical inference from capture data on closed animal populations. *Wildl Monogr* 62:1–35

Özesmi, S. L., U. Özesmi. 1999. An artificial neural network approach to spatial habitat modelling with interspecific interaction. *Ecological Modelling* 116: pp.15–31.

Palma, L., Beja, P., Rodrigues, M. 1999. The use of sighting data to analyse Iberian lynx habitat and distribution. *Journal of Applied Ecology,* 36: pp. 812–824.

Pausas, J., Braithwaite, M., Austin, M. 1995. Modelling habitat quality for arboreal marsupials in the South Coastal forests of New South Wales, Australia. For. *Ecol. Manage* 78: pp. 39–49

Pearce, J. L., and M. S. Boyce. 2006. Modelling distribution and abundance with presence-only data. *Journal of Applied Ecology* 43: pp.405–412.

Peeters, E. T. H., and J. J. P. Gardeniers. 1998. Logistic regression as a tool for defining habitat requirements of two common gammarids. *Freshwater Biology* 39: pp.605–615.

Prater, S. H. 1971. The Book of Indian Animals. Bombay Natural History Society and Oxford University Press, Mumbai: pp. 324-328.

Pickett, S. T. A., Kolasa, G., Jones, C. G. 1994. Ecological Understanding: the Nature of Theory and the Theory of Nature. Academic Press, New York.

Podchong. S. 2009. An Assessment of Wildlife Habitat and Human Threats for Wildlife Conservation and Protected Areas Management: A Case Study in Phu Khieo Wildlife Sancturary in Chaiyaphum Province, North-east Thailand (PhD thesis).

Pollok, C., Thom, W. S. 1900. Wild Sports of Burma and Assam. Hurst and Blackett,

Limited, London.

Rabinowitz, A., G. B. Schaller and U. Uga. 1995. A survey to assess the status of Sumatran rhinoceros and other large mammal species in Tamanthi Wildlife Sanctuary, Myanmar.*ORYX* 29: pp. 123-128.

Rabinowitz, A. 1998. Status of the tiger in North Myanmar. Tigerpaper 25:15-19.

Rabinowitz, A. 2008. Life in the Valley of Death. The Fight to Save Tigers in a Land of Guns, Gold and Greed. *OISLANDPRESS*, Washington: pp-1-230.

Rahman, M. R., Saha, S. K. 2008. Multi-resolution segmentation for object-based classification and accuracy assessment of land use/land cover classification using remotely sensed data. *Journal of the Indian Society of Remote Sensing* 36: pp.189-201.

Refaeilzadeh P., Tang L., and Liu H. 2008. Cross Validation. Arizona State University. Comp. by: BVijayalakshmiGalleys0000875816: pp. 1-6.

Reutter, B. A., Helfer, V., Hirzel, A. H., Vogel, P. 2003. Modelling habitat-suitability on the base of museum collections: an example with three sympatric Apodemus species *from* the Alps. *Journal of Biogeography* 30: pp. 581–590.

Rexstad E., Burnham, K. P. 1991. User's guide for interactive program CAPTURE abundance estimation of closed animal populations, Colorado State University. Fort Collins, Colorado.

Reza, A. H. M. A., Feeroz, M. M., Islam, M. A. 2001. Habitat preference of the Bengal tiger, Panthera tigris tigris, in the Sundarbans. *Bangladesh Journal of Life Sciences* 13: pp. 215–217.

Ricketts, T., Imhoff, M. 2003. Biodiversity, urban areas, and agriculture: locating priority ecoregions for conservation. *Conservation Ecology* 8: pp. 1-15.

Sanderson, E., J. Forrest, C. Loucks, J. Ginsberg, E. Dinerstein, J. Seidensticker, P. Leimgruber, M. Songer, A. Heydlauff, T. O'Brien, G. Bryja, S. Klenzendorf, E. Wikramanayake. 2006. *Setting Priorities for the Conservation and Recovery of Wild Tigers: 2005-2015. The Technical Assessment.* WCS, WWF, Smithsonian, and NFWF-STF, New YorkWashington, D.C.

Sankhala, K. S. 1967. Breeding behaviour of the tiger in Rajasthan. *Int. Zoo Yearb.* 7: pp.133-147.

Santos X., Brito J. C., Sillero N., Pelguezuelos J. M., Llorente A., Fahd S., Parellada X. 2006. Inferring habitat-suitability areas with ecological modelling techniques and GIS: A contribution to assess the conservation status of Vipera latastei. *Biological Conservation* 130: pp. 416-425.

Sattler, T., Bontadina, F., Hirzel, A. H., Arlettaz, R. 2007. Ecological niche modelling of two cryptic bat species calls for a reassessment of their conservation status. British Ecological Society, *Journal of Applied Ecology* : pp 1-12.

Schaller, G. B. 1967. The Deer and the Tiger: A Study of Wildlife in India. University Chicago Press, Chicago.

Schamberger, M. L., L. J. O'Neil.1986. Concepts and constraints of habitat model testing. In Verner, J., M.L. Moorison, C.J.Ralph (eds.). Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. The University of Wiscosin Press, Madison, WI. Pp. 5-10.

Schneider, D. C.1994. Quantitative Ecology Spatial and Temporal Scaling. Academic Press: pp. 1-395.

Seidensticker, J., Christie, S. and Jackson, P. 1999. Riding the Tiger: Tiger Conservation in Human-Dominated Landscapes.P.1-383. Cambridge University Press, Cambridge, UK.

Seidensticker, J., McDougal, C. 1993. Tiger predatory behavior, ecology and conservation. *Symposium of the Zoological Society of London 65*: pp.105-125

Sharpe, P. J. A. 1990. Forest modeling approaches: compromises between generality and precision. In: Dixon, R.K., Meldahl, R.S., Ruark, G.A., Warren, W.G. (Eds.), Process Modeling of Forest Growth Responses to Environmental Stress. Timber Press, Portland, OR, pp. 180–190.

Sharpe, P. J. A., Rykiel, E. J., Jr. 1991. Modeling integrated response of plants to multiple stress. In: Mooney, H.A., Winner, W.E., Pell, E.J. (Eds.), Response of Plants to Multiple Stress. Academic Press, San Diego, CA; pp. 205–224.

Singh, R., Joshi, P. K., Kumar, M., Dash, P. P., Joshi, B. D. 2009. Development of tiger habitat suitability model using geospatial tools- a case study in Achankmar Wildlife Sanctuary (AMWLS), Chhattisgarh India. *Environ Monit Assess 155:* pp. 555-567.

Smith, J. L. D. 1984. Dispersal, communication and conservation strategies for the tiger (*Panthera tigris*) in Royal Chitwan National Park, Nepal. PhD dissertation, University of Minnesota, St. Paul.

Smith,J. L. D.1993. The role of dispersal in structuring the Chitwan tiger population. *Behaviour* 124: pp. 65-95

Smith, J. L. D. and McDougal, C. 1991. The contribution of variance in lifetime reproduction to effective population size in tigers. *Conserv. Biol.* 5(4): pp. 484-490.

Spitz, F., and S. Lek. 1999. Environmental impact prediction using neural network modelling: an example in wildlife damage. *Journal of Applied Ecology* 36: pp. 317–326.

Stith, B. M., and N. S. Kumar. 2002. Spatial distributions of tigers and prey: mapping and the use of GIS. Pages 51–59 in K. U. Karanth and J. D. Nichols, editors. Monitoring tigers and their prey. A manual for wildlife managers, researchers, and conservationists. Centre for Wildlife Studies, Bangalore, India.

Story, M., and Congalton, R. 1986. Accuracy assessment: auser's perspective, *Photogramm. Eng. Remote Sens.*52(3): pp. 397-399.

Sunquist, M. E. 1981. Social organization of tigers (*Panthera tigris*) in Royal Chitwan National Park, Nepal. *Smithsonian Contrib. Zool*.336: pp.1-98.

Sunquist, M. E., Karanth, K. U., Sunquist, F.1999. Ecology, behavior and resilience of the tiger and its conservation needs.

Sunquist, M. E & Sunquist, F. C. 2002. *Wild Cats of the World.* University of Chicago Press, Chicago, USA: pp. 345-372.

Tamang, K. M. 1993. Wildlife management plan for the Sundarbans reserved forest. Report of the FAO/UNDP project (no. BGD/84/056) entitled 'Integrated Resource Development of the Sundarbans Reserved Forest'. Pp.1-113.

ter Braak, C. J. F., and C. W. N. Looman. 1987. Regression. Pages 29–77 *in* R. H. G. Jongman, C. J. F. ter Braak, and O. F. R. Van Tongeren, editors. Data analysis in community and landscape ecology. Cambridge University Press, Cambridge, UK.

Thant, N. M. L. 2006. Direct and indirect impacts of anthropogenic activities of the survival of tiger (*Panthera tigris*) with special consideration of gold mining in the Hukaung Valley Tiger Reserve, Northern Myanmar. M.Sc thesis, Yezin: pp. 1-58.

Tigers in Crisis. 2012. Available from: http://tigersincrisis.com/bengal_tiger.htm. Assessed on: 30/04/2012.

Tittensor, D. P., Baco, A. R., Brewin, P. E., Clark, M. R., Consalvey, M., Hall-Spencer, J., Rowden, A. A., Schlacher, T., Stocks, K. I., Rogers, A. D. 2009. Predicting global habitat suitability for stony corals on seamounts. *Journal of Biogeography*, 36: pp. 1111–1128.

Travel World. 2012. Available from: http://travelnewsworld.blogspot.com/2010/08/re-worlds-largest-tiger-reserve-created.html. Assessed on: 01/05/2012.

Trocmé, M., Cahill, S., de Vries, J. G., Farrall, H., Folkeson, L., Fry. G., Hichs, C., Peymen, J. (eds.). 2002. COST 341. Habitat Fragmentation due to Transportation Infrastructure. The European Review. Office for Official Publications of the European Communities. Luxemburg: pp. 1-253 .

Turner, M.-G., Arthaud, G. J., Engstrom, R. T., Hejl, S. J., Liu, J. G., Loeb, S., McKelvey, K. 1995. Usefulness of spatially explicit population models in land management. *Ecological Applications* , 5: pp. 12-16.

Turner, M.-G., Dale, V. H., Gardner, R. H. 1989. Predicting across scales: theory development and testing. Landscape Ecol. 3: pp. 245-252.

Turner, M.-G., Gardner R. H. and O'Neill R. V. 2001. Landscape Ecology in Theory and Practice: Pattern and Process. Springerverlag, New York, New York, USA.

Turner, S. J., O' Neill, R. V., Conley, M. R., Humphries, H. C. 1991. Pattern and scale: Statistics for landscape ecology. In Quantitative Methods in Landscape Ecology (Turner, M.-G. and Gardner, R.H. Eds). Spring Verlag, New York: pp. 19-49.

U.S. Fish and Wildlife Service. 1980. Habitat evaluation procedures (HEP). Division of Ecological Services Manual 102. Washington, DC: U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service. 1981. Standards for the development of habitat suitability index models for use in the habitat evaluation procedure. Division of Ecological Services Manual 103. Washington, DC: U.S. Fish and Wildlife Service.

Walston, J., Robinson, J. G., Bennett, E. L., Breitenmoser, U., da Fonseca G. A. B., Goodrich, J., Gumal, M., Hunter, L., Johnson, A., Karanth, K. U., Leader-Williams, N., MacKinnon, K., Miquelle, D., Pattanavibool, A., Poole, C., Rabinowitz, A., Smith, J. L. D., Stokes, E. J., Stuart, S. N., Vongkhamheng, C. and Wibisono, H. 2010. Bringing the Tiger Back from the Brink-The Six Percent Solution. *PLoS Biology* 8(9): e1000485.

Wentzel, J., Stephens, J. C., Johnson, W., Menotti-Raymond, M., Slattery, J. P., Yukhi, N., Carrington, M., Quigley, H. B., Miquelle, D. G., Tilson, R., Manasang, J., Brady, J., Zhi, L., Wenshi, P., Shi-Qiang, H., Johnston, L., Sunquist, M., Karanth, K. U., O'Brien, S. J. 1999. Subspecies of tigers: Molecular assessment using "voucher specimens" of geographically traceable individuals. Pages 40-49 In Riding the Tiger: Tiger Conservation in Human Dominated Landscapes (Editors: J. Seidensticker, S. Christie and P. Jackson). Cambridge University Press.

White, G. C., Anderson, D. R., Burnham, K. P., Otis, D. L.1982. Capture-recapture and removal methods for sampling in closed populations. LA 8787-NERP Los Alamos National Laboratory. Los Alamos, USA: pp.1- 235.

Wikramanayake, J., Dinerstein, E., Loucks, C., Ginsberg, E., et al. 2007. The Fate of Wild Tigers. *Bioscience* 57(6): pp. 508-514.

Wildlife Sancturary. 2012. Available from: http://www.oocities.org/samandkarleigh/WildlifeSactuary.html. Assessed on: 16/04/ 2012.

Williams, A. K. 2003. The influence of probability of detection when modeling species occurrence using GIS and survey data [Virginia]: *Virginia Polytechnic Institute and State University*: pp. 1-146.

Wissel, C. 1992. Aims and limits of ecological modeling exemplified by island theory. *Ecol. Model*. 63: pp.1–12.

Woodward, F. I. 1987. Climate and Plant Distribution. Cambridge University Press, Cambridge: pp. 1-174.

World Wildlfe. 2012. Available from: http://www.worldwildlife.org/species/finder/tigers/ecology.html. Assessed on: 04 /05/ 2012.

WWF. 2002. Conserving tigers in the wild: A WWF framework and strategy for action 2002-2010. Species programme, World Wildlife Fund International, Gland.

WWF.2012. Available from: http://wwf.panda.org/what_we_do/endangered_species/tigers/about_tigers/breeding_family/. Assessed on: 26/04/ 2012.

WWF, Save Tigers Now. 2012. Available from: http://www.savetigersnow.org/solutions. Assessed on: 03/05/2012.

WWF, WCS, Northeast Normal University, KORA, The University of Montana and support of Chinese stakeholders. 2010. Technical report on the identification of potential tiger habitat in the Changbaishan ecosystem, Northeast China: pp. 1-85.

Xuezhi, W. 2008. Application of ecological - niche factor analysis in habitat assessment of giant pandas. *Acta Ecologica SINICA*. Vol 28, Issue 2: pp. 821-828.

Zarri, A. A, Rahmani, A. R., Singh, A., Kushwaha, S. P. S. 2008. Habitat suitability assessment for the endangered Nilgiri Laughingthrush: A multiple logistic regression approach. Current Science 94 (11): pp. 1487-1494.

11 Appendices

Appendix I. Plants found in the Hukaung Valley

No.	Common name	Scientific name	Remarks
1	Gangaw	*Mesuaferrea*	
2	Kyilan	*Shorea assamica*	
3	Kanaso	*Heritiera fomes*	
4	Gwe	*Spondias pinnata*	
5	Kanyin	*Dipterocarpus turbinatus*	
6	Ma-u-lettan-she	*Anthocephalus cadamba*	
7	Ma-u-lettan-to	-	
8	Sagawa	*Michelia champaca*	
9	Saga-phyu	*Michelia doltsopa*	
10	Kalaung ni	*Dysoxylum binectariferum*	
11	Thitkado	*Cedrela toona*	
12	Sagat	*Quercus spicata*	
13	Mani-awga	*Carallia brachiata*	
14	Taw-kyetmauk	*Euphoria longana*	
15	Thapan	*Ficus glomerata*	
16	Phet-waing	*Macaranga denticulata*	
17	Taung-htan	*Livistona speciosa*	
18	Taung-tama	*Cedrela multijuga*	
19	Cherry-bo	*Betula alnoides*	
20	Thabye	*Syzygium cumini*	
21	Letpan	*Salmalia malabarica*	
22	Pangar	*Terminalia chebula*	
23	Zibyu	*Emblica officinalis*	
24	Htauk-kyink	*Terminalia alata*	
25	Thitkyabo	*Cinnamomum zeylanicum*	
26	Laukya-byu	*Schima noronhae*	
27	Seiknan	*Phoebe lanceolata*	
28	Akyaw	*Aquilaria agallocha*	
29	Taw-thayet	*Mangifera caloneura*	
30	Thitsein	*Terminalia belerica*	
31	Thabyu	*Dillenia indica*	
32	Maibau	*Alnus nepalensis*	
33	Ngu-shwe	*Cassia fistula*	
34	Tamarind	*Tamarindus indica*	
35	Taw-kunthi	*Areca trianara*	
36	Thitmin	*Podocarpus wallichianus*	
37	Myauk-ngo	*Duabanga grandiflora*	Thit-kazaw
38	Metlin	*Garcinia paniculata*	
39	Thitsi	*Melanorrhoea usitata*	

Appendix I (cont.)

Bamboos found in the Hukaung Valley

No.	Common name	12 Scientific name	Remarks
1	Wanet	*Dendrocalamus longispathus*	
2	Wabo	*Dendrocalamus brandisii*	
3	Tin-wa	*Cephalostachyum pergracile*	
4	Wabo-myet-san gye	*Dendrocalamus hamiltonii*	
5	Wa-nwe	*Dinochloam clellanldi*	
6	Wa-kha	*Pseudostachyum wakha*	
7	Shwe-wa	*Bambusa vulgaris*	

Rattan found in the Hukaung Valley

No.	Common name	13 Scientific name	Remarks
1	Yamata	*Calamus latifolius / palustris*	
2	Ye-kyein	*Calamus floribundus*	
3	Kyein-ni	*Calamus guruba*	
4	Kadin	*Calamus wailong*	
5	Kyet-u	*Calamus spathus*	
6	Taung-kyein	*Calamus doriaei*	
		Calamus tenius	
		Calamus flagellum	
		Wallichia densiflora	
		Pinanga spp.	
		Calamus gracilis	
		Plectocomia spp.	
		Arenga spp.	
		Calamus erectus	
		Calamus acanthospathus	
		Salacca spp.	
		Livistona jenkinsiana	
		Calamus henryanus	

Appendix II. Wild animals found in the Hukaung Valley Tiger Reserve

No	Common name	Scientific name	IUCN	CITES	Myanmar
1	Tiger	*Panthera tigris*	EN	I	TP
2	Leopard	*Panthera pardus*	UV	I	TP
3	Golden cat	*Felis temmincki*			
4	Large indian cevit	*Viverricula zibetha*	-	III	TP
5	Marbled cat	*Felis marmorata*	DD	I	TP
6	Common palm cevit	*Paradoxurus hermaphroditus*	UV	III	TP
7	Small indian cevit	*Viverricula indica*	-	III	TP
8	Hog badger	*Arctonyx collaris*	-	-	-
9	Asiatic jackal	*Canis aureus*	-	-	-
10	Crab-eating mangoose	*Herpestes urva*	-	III	-
11	Barking deer	*Muntiacus muntjak*	-	-	-
12	Yellow-throated marten	*Martes flavigula*	-	III	-
13	Sambar deer	*Cervus unicolar*			
14	Wild boar	*Sus scrofa*	-	-	-
15	Asiatic wild dog	*Cuon alpinus*	UV	II	P
16	Serow	*Capricornis sumatrensis*	-	I	CP
17	Goral	*Naemorhedus goral*	LR,nt	I	CP
18	Jungle cat	*Felis chaus*	-	II	P
19	Gayal	*Bos gaurus frontalis*	-	-	-
20	Gaur	*Bos gaurus*	-	I	CP
21	Brush-tailed porcupine	*Atherurus macrourus*			
22	Malayan porcupine	*Hystrix brachyura*			
23	Common otter	*Lutra lutra*	UV	I	CP
24	Leaf deer	*Muntiacus putaonesis*	-	-	-
25	Hoolock gibbon	*Hylobates hoolock*	-	I	CP
26	Slow loris	*Nycticebus coucang*	-	II	P
27	Stump-tailed macacaque	*Macaca arctoides*			
28	Himalayan black bear	*Selenarctos thibetanus*	UV	I	P
29	Malayan sun bear	*Helarctos malayanus*	LR,nt	I	CP
30	Leopard cat	*Felis bengalensis*			
31	The chinese pangolin	*Manis pantadactyla*	LR/nt	II	CP
32	Elephant	*Elephas maximus*	EN	I	CP
33	Clouded leopard	*Neofelis nebulosa*	-	I	CP

Appendix III. Questionnaires to assess threats to wildlife and their habitats

Topographic map must be provided to the interviewees to answer the following questions.

1. Hunting areas

No	Local name of hunting place	Estimate distance from village (mile)	Compass bearing from village (degree)	Intensity	Remarks
1					
2					
3					

1 = heavy 2 = medium 3 = low

2. Shifting cultivation area

No	Local name of Shifting cultivation area	Estimate distance from village (mile)	Compass bearing from village (degree)	Intensity	Remarks
1					
2					
3					

1 = heavy 2 = medium 3 = low

3. Commercial forest products extraction

No	Name of forest product	Local name of Forest products extraction area	Estimate distance from village (mile)	Compass bearing from village (degree)	Intensity	Remarks
1						
2						
3						

1 = heavy 2 = medium 3 = low

4. Minor forest products extraction area

No	Name of minor forest product	Local name of minor forest products extraction area	Estimate distance from village (mile)	Compass bearing from village (degree)	Intensity	Remarks
1						
2						
3						

1 = heavy 2 = medium 3 = low

Appendix III. (cont.) Questionnaires to assess threats to wildlife and their habitats

5. Gold-mining

No	Type of mine	Local name of mining area	Estimate distance from village (mile)	Compass bearing from village (degree)	Intensity	Remarks
1						
2						
3						

1 = heavy 2 = medium 3 = low

6. Dynamite Fishing activities

No	Local name of Dynamite Fishing area	Estimate distance from village (mile)	Compass bearing from village (degree)	Intensity	Remarks
1					
2					
3					

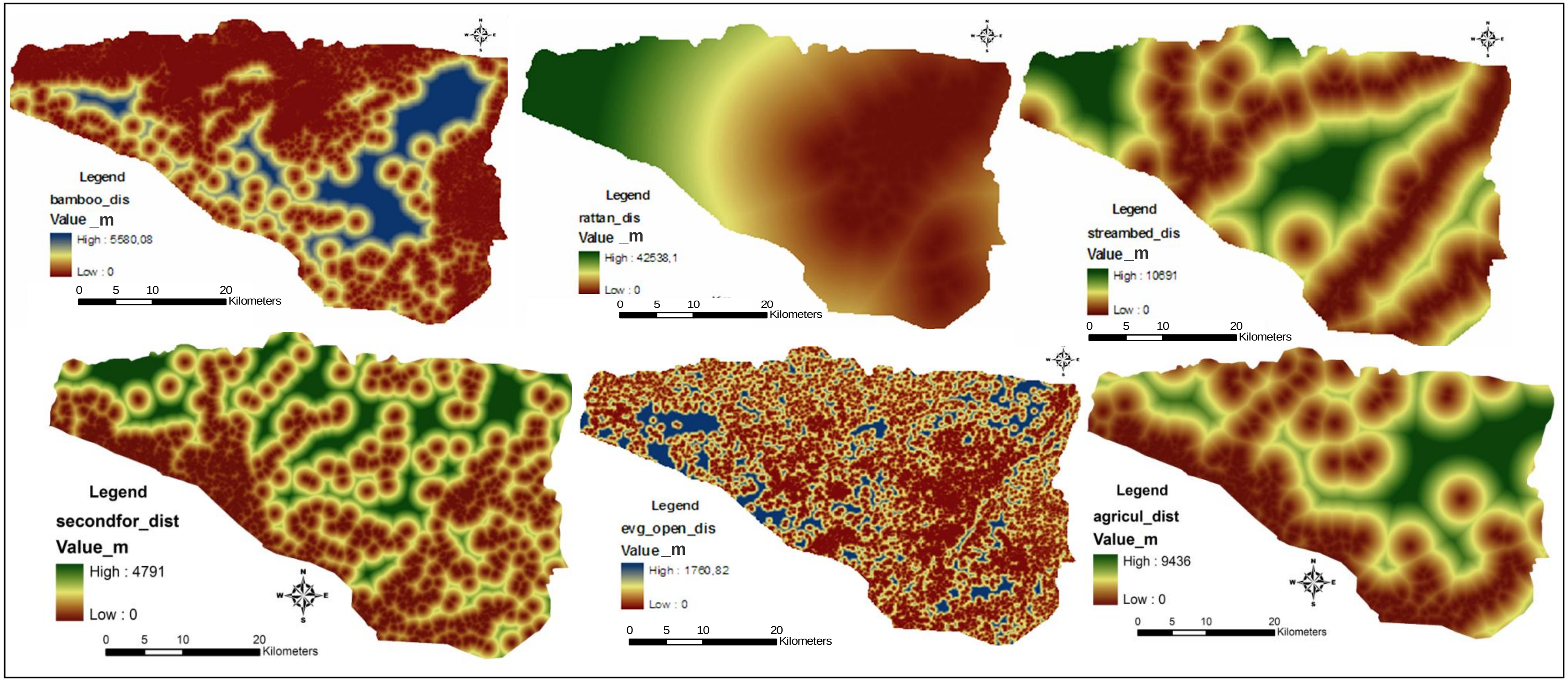
1 = heavy 2 = medium 3 = low

7. Wild forest fire occurrences in the last five years

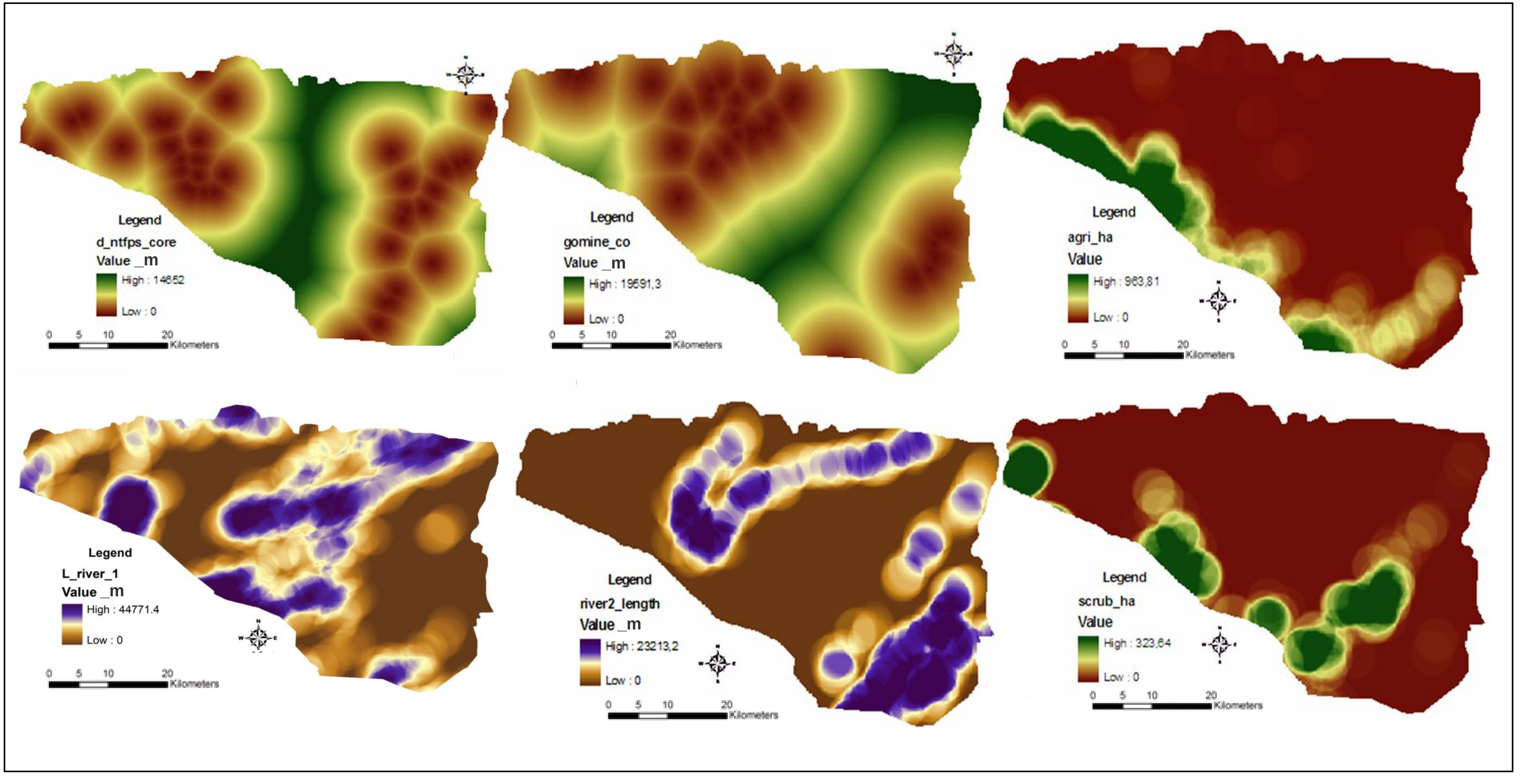
No	Local name of forest fire occurrences area	Estimate distance from village (mile)	Compass bearing from village (degree)	Intensity	Remarks
1					
2					
3.					

1 = heavy 2 = medium 3=low

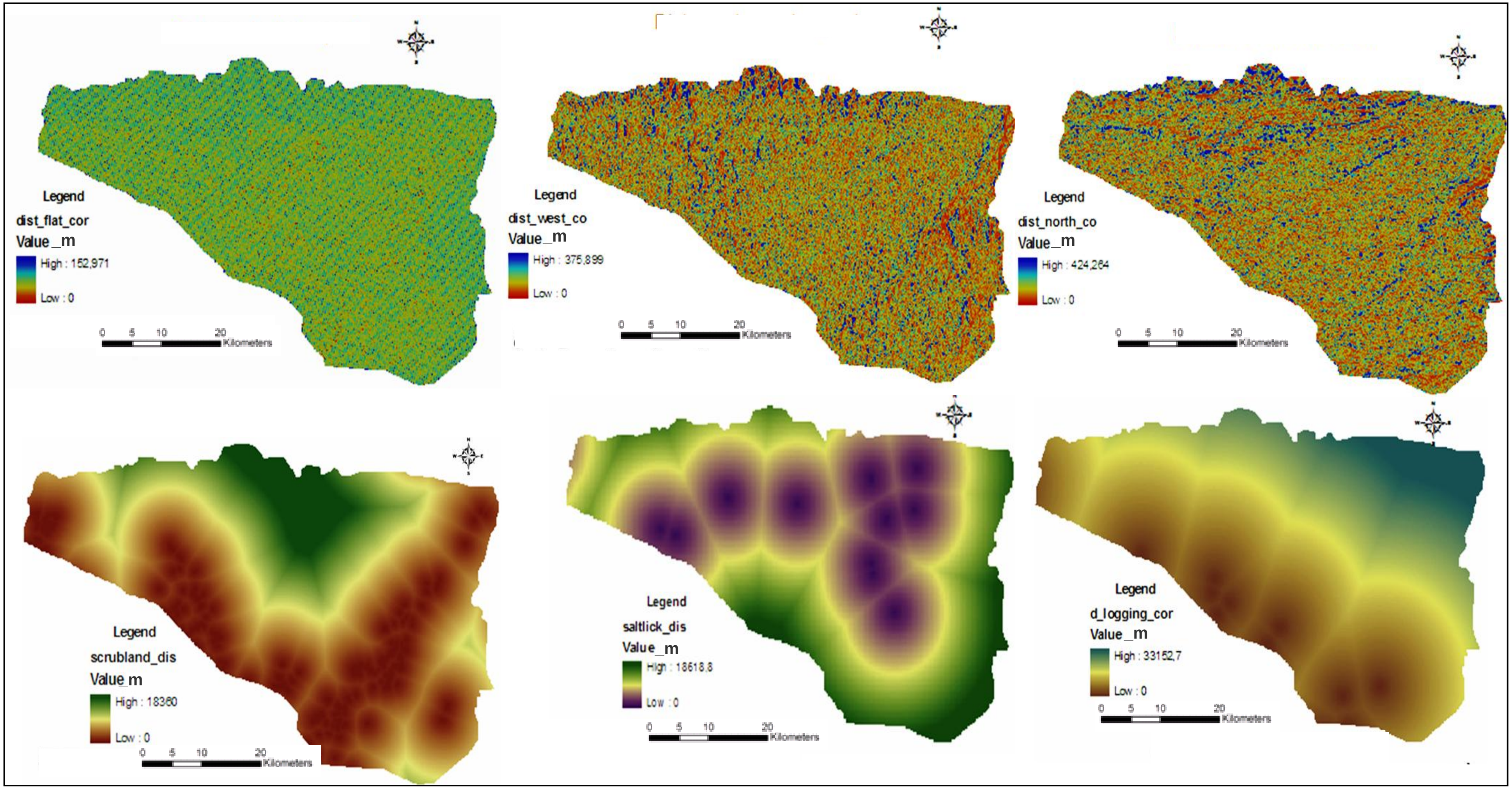
Appendix IV: Ecogeographical variable maps



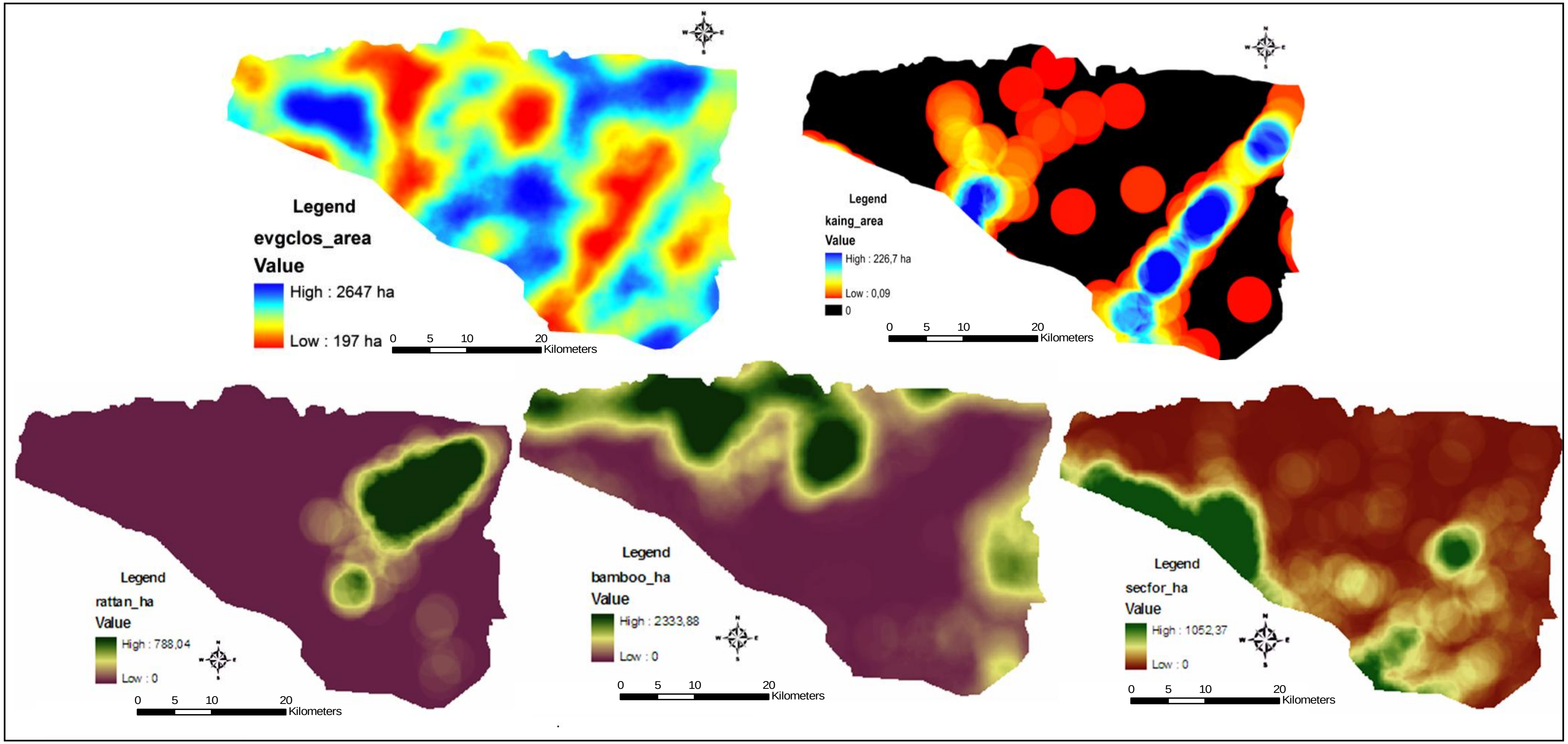
Appendix IV (cont.): Ecogeographical variable maps



Appendix IV (cont.): Ecogeographical variable maps



Appendix IV (cont.): Ecogeographical variable maps



Appendix V. A general form of SAS program to perform normality of all EGVs. The following is an example of syntax used for distance to agriculture (agri_dist).

```
data agri_dist;
      infile
      'G:\egvs_categorization\comsumable_features\openland\ascii\agri_dis
.txt' firstobs=7 lrecl=1000000;
      input value @@;
      if value ne -9999;
run;

proc univariate data= agri_dist normal plot;
      var value;
run;

proc gchart data= agri_dist;
      vbar value;
run;

proc capability data= agri_dist;
      ppplot value / normal;
run;

proc capability data= agri_dist;
      qqplot value / normal;
run;

proc capability data= agri_dist;
      histogram value / normal;
run;
```

Appendix VI: Test for normality of EGVs with Kolmgorov-Smirnov in SAS procedures

No.	EGVs name	Test-Kolmgorov-Smirnov	
		Statistic (D)	*p*-value
1.	Bamboo_area	0.44569	Pr > D <0.0100
2.	Bamboo_dist	0.34301	Pr > D <0.0100
3.	Everclos_area	0.02720	Pr > D <0.0100
4.	Everclos_dist	0.35008	Pr > D <0.0100
5.	Everopen_area	0.10132	Pr > D <0.0100
6.	Everopen_dist	0.26167	Pr > D <0.0100
7.	Rattan_area	0.51082	Pr > D <0.0100
8.	Rattan_dist	0.35658	Pr > D <0.0100
9.	Secfor_area	0.38507	Pr > D <0.0100
10.	Secfor_dist	0.23926	Pr > D <0.0100
11.	Comhunt_dist	0.20104	Pr > D <0.0100
12.	Saltlick_dist	0.11580	Pr > D <0.0100
13.	Agri_area	0.49263	Pr > D <0.0100
14.	Agri_dist	0.26549	Pr > D <0.0100
15.	Kaing_area	0.51806	Pr > D <0.0100
16.	Kaing_dist	0.22290	Pr > D <0.0100
17.	Scrubl_area	0.51562	Pr > D <0.0100
18.	Scrubl_dist	0.28848	Pr > D <0.0100
19.	Streamb_area	0.51748	Pr > D <0.0100
20.	Streamb_dist	0.26424	Pr > D <0.0100
21.	River3_length	0.51322	Pr > D <0.0100
22.	River2_length	0.52007	Pr > D <0.0100
23.	River1_length	0.53278	Pr > D <0.0100
24.	Dist_flat	0.33177	Pr > D <0.0100
25.	Dist_north	0.25492	Pr > D <0.0100
26.	Dist_east	0.26170	Pr > D <0.0100
27.	Dist_south	0.26214	Pr > D <0.0100
28.	Dist_west	0.26327	Pr > D <0.0100
29.	Elevation	0.10949	Pr > D <0.0100
30.	Slope	0.50289	Pr > D <0.0100
31.	Settlement_dist	0.11990	Pr > D <0.0100
32.	Logging_dist	0.11405	Pr > D <0.0100
33.	NTFPs_dist	0.15474	Pr > D <0.0100
34.	Goldmining_dist	0.15966	Pr > D <0.0100
35.	Road_dist	0.17578	Pr > D <0.0100
36.	Dynfishing_dist	0.17040	Pr > D <0.0100

Appendix VII. The structure of EGVs categorization and calculation of their scores

LEVEL-1: 6 groups

I. Forest with distance measures of EGVs: Winners: Saltlicks, evergreen opened forest with rattan, evergreen opened forest

Specialization	26.8	22.6	16.4	1.4	11.3	8.9	Total Spec.	Marginality	Total
EGVs	1	2	3	4	5	6			
Saltlicks	**0.57**	**0.13**	**0.44**	**0.20**	**0.49**	**0.35**	**46.33**	**57.10**	**103.43**
rattan_dis	**0.57**	**0.36**	**0.10**	**0.17**	**0.45**	**0.57**	**35.48**	**56.90**	**92.38**
evopen_dis	**0.41**	**0.34**	**0.81**	**0.14**	**0.48**	**0.17**	**38.97**	**40.50**	**79.47**
evclos_dis	0.43	0.68	0.08	0.46	0.45	0.05	34.39	42.70	77.09
bambo_dis	0.06	0.46	0.10	0.41	0.35	0.70	24.32	5.90	30.22
Secforest_dis	0.02	0.24	0.36	0.73	0.06	0.21	15.51	2.30	17.81

II. Forest with areas measures of EGVs: Winners: Evergreen closed forest, evergreen opened with rattan, evergreen opened forest

Specialization	37	34.1	12	10.6	6.5	Total Spec.	Marginality	Total
EGVs	1	2	3	4	5			
evgclos_area	**0.59**	**0.49**	**0.46**	**0.47**	**0.21**	**50.23**	**59.00**	**109.23**
rattan_area	**0.51**	**0.76**	**0.36**	**0.37**	**0.23**	**54.59**	**51.00**	**105.59**
evgopen_area	**0.63**	**0.18**	**0.18**	**0.74**	**0.05**	**39.33**	**62.50**	**101.83**
secforest_hac	0.03	0.32	0.73	0.19	0.34	24.79	2.80	27.59
bamboo_area	0.01	0.23	0.30	0.26	0.89	20.32	1.10	21.42

III. Open land with distance measures of EGVs: Winners: Kaing grass, streambed

Specialization	28.6	44.3	19.2	8	Total Spec.	Marginality	Total
EGVs	1	2	3	4			
kaing_dis	**0.64**	**0.76**	**0.48**	**0.01**	**61.25**	**64.10**	**125.35**
streambed_dis	**0.63**	**0.54**	**0.77**	**0.06**	**57.41**	**63.40**	**120.81**
scrubland_dis	0.34	0.17	0.31	0.68	28.51	34.10	62.61
agriculure_dis	0.27	0.32	0.28	0.74	33.20	26.80	60.00

IV. Open land with area measures of EGVs: Winners: Kaing grass, streambed and river2

Specialization	25.80	40,7	16	7.5	4.6	3.4	2	Total Spec.	Marginality	Total
EGVs	1	2	3	4	5	6	7			
kaing_ha	**0.53**	**0.30**	**0.44**	**0.34**	**0.22**	**0.72**	**0.30**	**39.46**	**53.10**	**92.56**
streambed_ha	**0.54**	**0.28**	**0.03**	**0.47**	**0.63**	**0.59**	**0.21**	**34.53**	**53.80**	**88.33**
river2_len	**0.47**	**0.48**	**0.15**	**0.35**	**0.51**	**0.29**	**0.25**	**40.46**	**47.20**	**87.66**
agri_hac	0.42	0.38	0.22	0.35	0.06	0.11	0.56	34.09	41.80	75.89
scrubland_hac	0.16	0.53	0.60	0.10	0.09	0.12	0.56	38.10	16.10	54.20
river3_len	0.03	0.42	0.60	0.14	0.42	0.15	0.24	31.23	2.50	33.73
river1_len	0.06	0.04	0.13	0.63	0.32	0.10	0.35	12.44	6.20	18.64

Appendix VII (cont.). The structure of EGVs categorization and calculation of their scores

V. Human-factors EGVs: Winners: Settlement, Common hunting places

Specialization	**61.4**	**15.4**	**11.2**	**9.6**	**2.4**	**Total Spec.**	**Marginality**	**Total**
EGVs	1	2	3	4	5			
settlem_dis	**0.64**	**0.25**	**0.14**	**0.68**	**0.39**	**52.29**	**64.40**	**116.69**
comhunt_dis	**0.61**	**0.06**	**0.19**	**0.55**	**0.21**	**45.97**	**60.60**	**106.57**
goldmine_dis	0.44	0.40	0.38	0.22	0.62	40.78	43.70	84.48
ntfps_dis	0.14	0.36	0.56	0.18	0.62	23.65	13.90	37.55
dyfishing_dis	0.08	0.81	0.70	0.39	0.18	29.59	8.40	37.99

VI. Topographical EGVs: Winners: Distance to east aspect, elevation and south aspect

Specialization	**15.2**	**43.0**	**15.7**	**11.1**	**5.7**	**5.0**	**4.4**	**Total Spec.**	**Marginality**	**Total**
EGVs	1	2	3	4	5	6	7			
dist_east	**0.49**	**0.39**	**0.25**	**0.48**	**0.56**	**0.44**	**0.24**	**39.96**	**48.90**	**88.86**
elevation	**0.28**	**0.83**	**0.12**	**0.29**	**0.22**	**0.11**	**0.11**	**47.19**	**27.80**	**74.99**
dist_south	**0.53**	**0.02**	**0.25**	**0.03**	**0.45**	**0.59**	**0.49**	**20.65**	**52.90**	**73.55**
slope	0.48	0.09	0.08	0.59	0.09	0.44	0.22	22.82	48.40	71.22
dist_west	0.33	0.26	0.59	0.18	0.46	0.33	0.46	33.81	32.90	66.71
dist_flat	0.24	0.28	0.39	0.39	0.45	0.00	0.49	30.97	24.30	55.27
dist_north	0.06	0.05	0.59	0.39	0.09	0.40	0.45	21.36	5.90	27.26

LEVEL-2: 2 groups

I. EGVs with area measures: Winners: Evergreen opened forest, evergreen opened with rattan, evergreen closed forest

Specialization	**25.20**	**41.10**	**14.40**	**7.30**	**6.80**	**5.10**	**Total Spec.**	**Marginality**	**Total**
EGVs	1	2	3	4	5	6			
evgopen_area	**0.55**	**0.32**	**0.47**	**0.64**	**0.19**	**0.12**	**40.09**	**54.80**	**94.89**
rattan_area	**0.45**	**0.59**	**0.27**	**0.11**	**0.23**	**0.34**	**43.66**	**44.80**	**88.46**
evgclos_area	**0.52**	**0.24**	**0.01**	**0.61**	**0.09**	**0.35**	**29.99**	**51.80**	**81.79**
streambed_ha	0.29	0.51	0.21	0.35	0.69	0.61	41.62	29.00	70.62
kaing_ha	0.29	0.30	0.66	0.05	0.59	0.22	34.54	28.60	63.14
river2_len	0.25	0.38	0.48	0.30	0.29	0.57	35.71	25.40	61.11

Appendix VII (cont.). The structure of EGVs categorization and calculation of their scores

II. EGVs with distance measures: Winners: Kaing grass, saltlicks, settlement

Specialization	**32.70**	**25.90**	**21.90**	**7.60**	**5.40**	**3.50**	**2.90**	**Total Spec.**	**Marginality**	**Total**
EGVs	1	2	3	4	5	6	7			
kaing_dis	**0.37**	**0.53**	**0.70**	**0.05**	**0.09**	**0.34**	**0.14**	**43.39**	**36.70**	**80.09**
settlem_dis	**0.35**	**0.78**	**0.42**	**0.26**	**0.07**	**0.03**	**0.39**	**42.20**	**35.20**	**77.40**
saltlicks	**0.45**	**0.08**	**0.23**	**0.48**	**0.37**	**0.50**	**0.04**	**29.22**	**44.70**	**73.92**
rattan_dis	0.45	0.28	0.06	0.05	0.13	0.11	0.85	27.07	44.60	71.67
Streambed_dis	0.36	0.12	0.48	0.39	0.20	0.66	0.13	32.30	36.30	68.60
comhunt_dis	0.33	0.10	0.11	0.70	0.31	0.37	0.29	24.93	33.10	58.03
evgopen_dis	0.32	0.00	0.19	0.25	0.84	0.23	0.09	22.16	31.80	53.96

LEVEL-3: 2 groups

I. EGVs of Forest: Winners: Evergreen opened forest area, evergreen opened with rattan area, evergreen closed forest area

Specialization	**12**	**42.6**	**23.5**	**6.9**	**6.5**	**4.5**	**3.9**	**Total Spec.**	**Marginality**	**Total**
EGVs	1	2	3	4	5	6	7			
evgopen_area	**0.53**	**0.59**	**0.38**	**0.05**	**0.12**	**0.61**	**0.37**	**45.60**	**52.60**	**98.20**
rattan_area	**0.43**	**0.63**	**0.07**	**0.33**	**0.51**	**0.23**	**0.30**	**41.41**	**43.00**	**84.41**
evgclos_area	**0.50**	**0.27**	**0.48**	**0.04**	**0.28**	**0.38**	**0.49**	**34.58**	**49.70**	**84.28**
saltlicks	0.43	0.38	0.39	0.03	0.35	0.32	0.41	36.05	43.20	79.25
comhunt_dis	0.32	0.03	0.51	0.63	0.07	0.48	0.08	24.40	31.90	56.30
secforest_dis	0.02	0.20	0.33	0.65	0.56	0.02	0.11	24.96	1.80	26.76
bambo_dis	0.05	0.04	0.32	0.25	0.46	0.31	0.58	17.83	4.50	22.33

II. EGVs of Open Land: Winners: Distance to streambed, settlement and kaing grass area

Specialization	**45**	**29.6**	**9.5**	**8.1**	**5.3**	**2.4**	**Total Spec.**	**Marginality**	**Total**
EGVs	1	2	3	4	5	6			
streambed_dis	**0.52**	**0.21**	**0.39**	**0.61**	**0.24**	**0.26**	**40.04**	**51.90**	**91.94**
settlem_dis	**0.50**	**0.05**	**0.70**	**0.29**	**0.22**	**0.34**	**34.99**	**50.30**	**85.29**
kaing_area	**0.41**	**0.60**	**0.16**	**0.50**	**0.47**	**0.19**	**44.40**	**40.70**	**85.10**
river2_len	0.36	0.55	0.03	0.49	0.75	0.05	40.98	36.20	77.18
agri_area	0.32	0.54	0.56	0.06	0.00	0.39	37.27	32.00	69.27
scrubland_dis	0.28	0.00	0.15	0.22	0.34	0.79	19.49	28.00	47.49

Appendix VII. Cont. The structure of EGVs categorization and calculation of their scores

Preliminary model: Analyzed by the winners of level 2 and topographical EGVs

In this analysis there is very high correlation between settlement and elevation. Among topographical EGVs, slope holds a higher score next to the elevation. So, it was included into the intermediate analysis instead of elevation.

	Marginality	Factors of specialization							
	Fac1	Fac2	Fac3	Fac4	Fac.5	Fac.6	Fac.7	Fac.8	Fac.9
EGVs	16.60%	42.40%	11.80%	8.40%	7.60%	4.90%	3.70%	2.60%	2%
evgopen_area	0.497	0.146	0.030	-0.115	**-0.356**	0.648	-0.434	0.215	0.429
evgclos_dist	-0.470	-0.400	0.069	0.429	0.057	0.507	-0.229	-0.042	0.422
evgopen_rattan_area	-0.406	0.102	0.314	0.018	-0.690	0.241	0.015	-0.221	0.572
streambed_dis	-0.331	-0.041	0.441	-0.296	-0.009	-0.060	0.416	0.751	-
settlem_dis	0.320	**-0.883**	0.317	0.111	-0.495	0.056	0.092	0.021	0.344
kaing_ha	0.259	0.032	0.563	0.354	0.248	-0.403	0.124	0.424	0.273
dist_south	-0.181	-0.058	0.263	0.130	-0.136	-0.064	-0.595	0.043	-
dist_east	0.167	0.050	**0.456**	-0.296	0.154	0.261	0.046	-0.390	-
slope	-0.166	-0.141	-0.086	-0.688	0.211	-0.156	-0.454	0.069	0.167
Marginality:	**0.691**								
Specialization:	**1.705**								
Tolerance (1/S):	**0.586**								

Appendix VIII. All possible combinations of the best EGVs out of 9 EGVs

Notes on the evaluations of the various models finals

Window size=20

No.	With 8 EGVs (9)	Name	Factors Maps
1.	12345678	8EGVs_1	5Maps_94%
2.	12345679	8EGVs_2	5Maps_95%
3.	12345689	8EGVs_3	5Maps_93%
4.	12345789	8EGVs_4	5Maps_95%
5.	12346789	8EGVs_5	5Maps_95%
6.	12356789	8EGVs_6(BI=0,442)	5Maps_95%
7.	12456789	8EGVs_7(BI=0,724)	5Maps_94%
8.	13456789	8EGVs_8	5Maps_95%
9.	23456789	8EGVs_9	5Maps_95%

EGVs codes
1=dist_east
2=dist_south
3=evgclos_area
4=evgopen_rattan_area
5=evgopen_area
6=kaing_area
7=settlemen_dist
8=slope
9=streambed_dist

4 partitions

No.	With 7 EGVs (36)	Name	FactorsMap	No.	With 7 EGVs (36)	Name	FactorsMap
1.	1234567	7EGVs_1	4Maps_93%	19.	1245789	7EGVs_19	4Maps_92%
2.	1234568	7EGVs_2	4Maps_90%	20.	(BI=0,787) **1246789**	7EGVs_20	4Maps_93%
3.	1234569	7EGVs_3	4Maps_90%	21.	1256789	7EGVs_21	4Maps_93%
4.	1234578	7EGVs_4	4Maps_93%	22.	1345678	7EGVs_22	4Maps_93%
5.	1234579	7EGVs_5	4Maps_94%	23.	1345679	7EGVs_23	4Maps_94%
6.	1234589	7EGVs_6	4Maps_91%	24.	1345689	7EGVs_24	4Maps_91%
7.	**(BI=0,756 1234678**	7EGVs_7	4Maps_93%	25.	1345789	7EGVs_25	4Maps_93%
8.	1234679	7EGVs_8	4Maps_94%	26.	1346789	7EGVs_26	4Maps_93%
9.	1234689	7EGVs_9	4Maps_90%	27.	1356789	7EGVs_27	4Maps_94%
10.	1234789	7EGVs_10	4Maps_93%	28.	1456789	7EGVs_28	4Maps_92%
11.	**(BI=0,554)1235678**	7EGVs_11	4Maps_93%	29.	2345678	7EGVs_29	4Maps_93%
12.	1235679	7EGVs_12	4Maps_94%	30.	2345679	7EGVs_30	4Maps_94%
13.	1235689	7EGVs_13	4Maps_90%	31.	2345689	7EGVs_31	4Maps_91%
14.	1235789	7EGVs_14	4Maps_94%	32.	2345789	7EGVs_32	4Maps_94%
15.	1236789	7EGVs_15	4Maps_94%	33.	2346789	7EGVs_33	4Maps_94%
16.	1245678	7EGVs_16	4Maps_91%	34.	(BI=0,688) **2356789**	7EGVs_34	4Maps_94%
17.	1245679	7EGVs_17	4Maps_92%	35.	2456789	7EGVs_35	4Maps_93%
18.	1245689	7EGVs_18	4Maps_91%	36.	3456789	7EGVs_36	4Maps_93%

3 partitions

Appendix VIII (cont.). Possible combination of 6 EGVs out of 9 EGVS=84

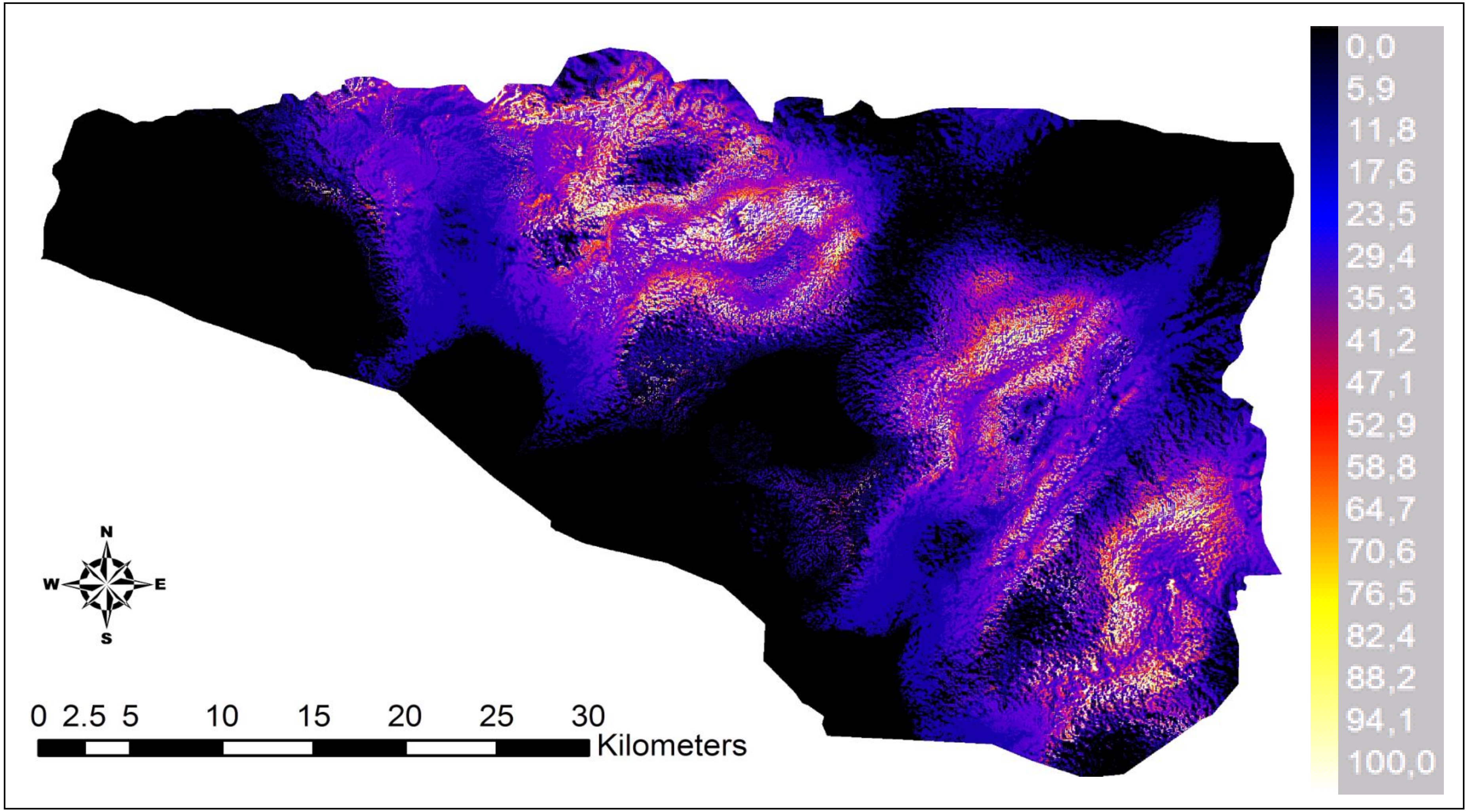
No.	6 EGVs	Name	FactorsMap	BI	No.	6 EGVs	Name	FactorsMap	BI
1.	123456	6EGVs_1	4Maps_93%	0.299	43.	134679	6EGVs_43	4Maps_96%	-0.04
2.	123457	6EGVs_2	4Maps_96%	0.558	44.	134689	6EGVs_44	4Maps_93%	0.103
3.	123458	6EGVs_3	4Maps_93%	0.423	45.	134789	6EGVs_45	4Maps_95%	0.382
4.	123459	6EGVs_4	4Maps_93%	0.34	46.	135678	6EGVs_46	4Maps_95%	0.364
5.	123467	6EGVs_5	4Maps_95%	0.35	47.	135679	6EGVs_47	4Maps_95%	-0.08
6.	123468	6EGVs_6	4Maps_92%	0.133	48.	135689	6EGVs_48	4Maps_92%	-0.08
7.	123469	6EGVs_7	4Maps_93%	0.351	49.	135789	6EGVs_49	4Maps_96%	-0.20
8.	123478	6EGVs_8	4Maps_95%	0.559	50.	136789	6EGVs_50	4Maps_96%	0.34
9.	123479	6EGVs_9	4Maps_96%	0.0493	51.	145678	6EGVs_51	4Maps_94%	0.24
10.	123489	6EGVs_10	4Maps_91%	-0.114	52.	145679	6EGVs_52	4Maps_95%	0.54
11.	123567	6EGVs_11	4Maps_95%	0.327	53.	145689	6EGVs_53	4Maps_94%	0.31
12.	123568	6EGVs_12	4Maps_92%	0.196	54.	145789	6EGVs_54	4Maps_95%	0.30
13.	123569	6EGVs_13	4Maps_92%	-0.161	55.	146789	6EGVs_55	4Maps_95%	0.107
14.	123578	6EGVs_14	4Maps_95%	-0.184	56.	156789	6EGVs_56	4Maps_95%	-0.02
15.	123579	6EGVs_15	4Maps_95%	-0.187	57.	234567	6EGVs_57	4Maps_96%	0.65
16.	123589	6EGVs_16	4Maps_91%	-0.369	58.	234568	6EGVs_58	4Maps_93%	0.26
17.	123678	6EGVs_17	4Maps_95%	0.574	59.	234569	6EGVs_59	4Maps_93%	0.21
18.	123679	6EGVs_18	4Maps_96%	0.847	60.	234578	6EGVs_60	4Maps_96%	0.49
19.	123689	6EGVs_19	4Maps_92%	0.101	61.	234579	6EGVs_61	4Maps_96%	0.59
20.	123789	6EGVs_20	4Maps_95%	0.374	62.	234589	6EGVs_62	4Maps_93%	0.20
21.	124567	6EGVs_21	4Maps_94%	0.454	63.	234678	6EGVs_63	4Maps_95%	0.50
22.	124568	6EGVs_22	4Maps_93%	0.495	64.	234679	6EGVs_64	4Maps_96%	0.28
23.	124569	6EGVs_23	4Maps_93%	0.0049	65.	234689	6EGVs_65	4Maps_92%	0.39
24.	124578	6EGVs_24	4Maps_94%	-0.031	66.	234789	6EGVs_66	4Maps_96%	-0.24
25.	124579	6EGVs_25	4Maps_95%	0.233	67.	235678	6EGVs_67	4Maps_96%	0.20
26.	124589	6EGVs_26	4Maps_93%	0.104	68.	235679	6EGVs_68	4Maps_96%	0.24
27.	124678	6EGVs_27	4Maps_94%	0.213	69.	235689	6EGVs_69	4Maps_92%	0.29
28.	124679	6EGVs_28	4Maps_95%	0.472	70.	235789	6EGVs_70	4Maps_95%	0.02
29.	124689	6EGVs_29	4Maps_93%	0.0334	71.	236789	6EGVs_71	4Maps_96%	0.61
30.	124789	6EGVs_30	4Maps_94%	0.156	72.	245678	6EGVs_72	4Maps_94%	0.21
31.	125678	6EGVs_31	4Maps_94%	0.0943	73.	245679	6EGVs_73	4Maps_95%	0.48
32.	125679	6EGVs_32	4Maps_95%	0.533	74.	245689	6EGVs_74	4Maps_93%	0.52
33.	125689	6EGVs_33	4Maps_92%	0.527	75.	245789	6EGVs_75	4Maps_94%	0.14
34.	125789	6EGVs_34	4Maps_94%	0.398	76.	246789	6EGVs_76	4Maps_95%	0.49
35.	126789	6EGVs_35	4Maps_95%	0.746	77.	256789	6EGVs_77	4Maps_95%	0.39
36.	134567	6EGVs_36	4Maps_95%	-0.218	78.	345678	6EGVs_78	4Maps_95%	0.25
37.	134568	6EGVs_37	4Maps_93%	0.165	79.	345679	6EGVs_79	4Maps_96%	0.13
38.	134569	6EGVs_38	4Maps_93%	0.113	80.	345689	6EGVs_80	4Maps_94%	0.38
39.	134578	6EGVs_39	4Maps_95%	0.0413	81.	345789	6EGVs_81	4Maps_96%	0.04
40.	134579	6EGVs_40	4Maps_96%	-0.389	82.	346789	6EGVs_82	4Maps_96%	0.05
41.	134589	6EGVs_41	4Maps_94%	-0.377	83.	356789	6EGVs_83	4Maps_96%	0.10
42.	134678	6EGVs_42	4Maps_95%	0.113	84.	456789	6EGVs_84	4Maps_95%	0.14

Partition=3, Window size= 20

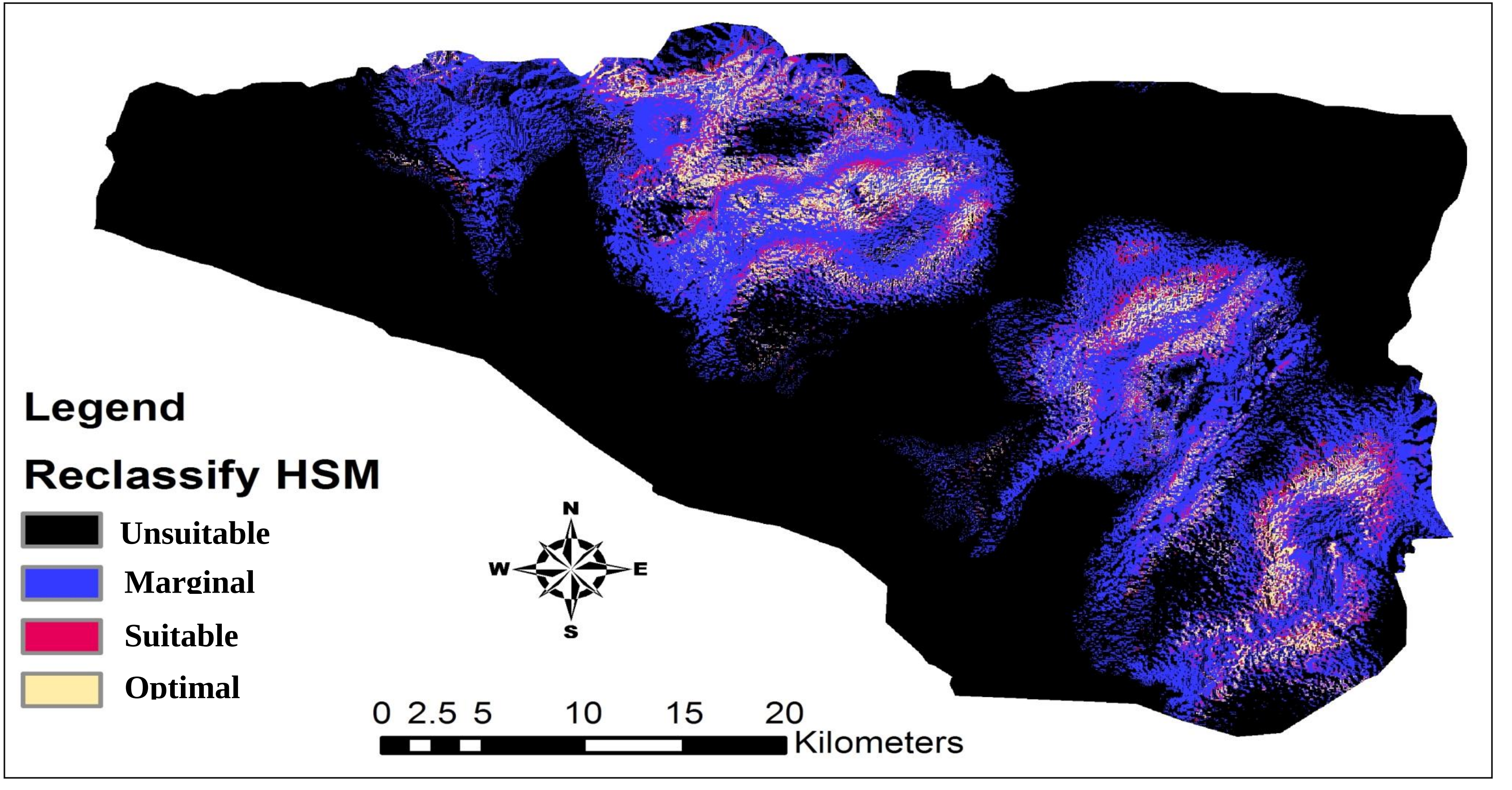
EGVs code:

1= dist_east, 2=dist_south, 3=evgclos_area, 4=evgopen_rattan_area 5=evgopen_area, 6=kaing_area**,** 7=settlemen_dist, 8=slope, 9=strembed_dis

Appendix IX: Habitat Suitability Map of the study area computed from ENFA. Cell size is 30*30 m. (A larger format version)



Appendix X: HS map after the reclassification process based on the HS range (A large format version)



CURRICULUM VITAE

Personal data:

Name	Tin Zar Kywe
Nationality	Myanmar
Date of Birth	15-4-1977
Place of Birth	Dawei Township, Myanmar
Family Status	Married to Moe Aung

Education

1983-1987	Elementary school, Kanyone, Dawei, Myanmar
1988-1995	Middle and high school, No.1.Basic Education High School, Dawei, Myanmar
1996-2002	Degree: Bachelor of Science in University of Forestry, Yezin, Myanmar
2004-2006	Degree: Master of Science in University of Forestry, Yezin, Myanmar
2009-2012	PhD studies, Faculty of Forest Sciences and Forest Ecology, Chair of Forest Inventory and Remote Sensing, University of Göttingen, Germany
04-09. 2009	German Language Course at Speak + Write, Marburg, Germany

Work experience:

2002-2008	Range Officer, Nature and Wildlife Conservation Division, Forest Department, Myanmar
2008-2011	Range Officer, Taung Dwin Gyi Township Forest Office, Magwe Division, Myanmar
2011 to current	Staff Officer, Forest Research Institute, Yezin, Nay Pyi Taw, Myanmar