Environmental Suitability Analysis for Asian Elephants

in Southern India

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Abstract

A method that uses multivariate analysis of geographic information system data was developed to provide a spatially explicit model of elephant distribution that is applicable when information and digital data is limited. Models with different environmental variables were compared, outputs from classified maps were compared with those outputs using satellite images and the effect of using different training sets were tested. It was observed that using fewer variables resulted in more accurate representation of the real world scenario and that classified images introduce biasness wherefore biasness in outputs using satellite images was reduced. Environmental suitability changes over an eight year period were estimated and it could be concluded that the environmental suitability has not been altered in any significant way in the north-eastern parts of the Nilgiri Biosphere Reserve. The models emphasis on spatial patterns and environmental suitability and contributes to conservation of Asian elephants in Southern India. It provides a basis for more advanced spatial and habitat analysis.

I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work.

Signed …………………………………..

Disclaimer

This document describes work undertaken as part of a programme of study at the International Institute for Geo-information Science and Earth Observation. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Acknowledgement

This thesis could not have come into being without the help of many people in my life. Writing this section therefore gives me a chance to reflect on those who have helped me throughout the research process.

I what to start with acknowledging the Tamil Nadu Forest Department for their help during my field work. At all times I was accompanied by two of their officers. Not only did they identify many plant species and forest types for me, they also led me to remote places and helped me communicate with local people. Their knowledge of the area was of great help and their sharp eyes recognised wildlife including elephants and a tiger in the dense jungle, I would never have seen on my own. I will never forget their friendly faces and great hospitality. My sincere thanks here goes to Wildlife Warden Ashok Uprethi for organising my quarters in the hart of Mudumalai wildlife sanctuary and supplying me with all his available literature. Special thanks also goes and District Forest Officer Sewa Singh for supplying me with field help and information on elephant conflicts.

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Many thanks also goes to my mother, without whom I would never had gone to India. Thank you for always supporting me and giving me the confidence to pursue my dreams. You showed me that everything is possible. Thank you for giving me wings so I can fly.

PLIGHT OF THE INDIAN ELEPHANT

Bygone are the days of grace and glory
What's left to me is a sad story,
I roamed about all your jungles freely
North to South and West to East
Life was happy like an endless feast.
I was worshipped and given reverence,
Pride of kings and symbol of eminence.
I marched over the ranks of your enemies
They ran helter-skelter
Depressed were their armies.
Under your orders
I crushed many of your foes,
Under these very toes
I was your prestige and honour
Loyal to you and your power
And then, what did you to me!
You cut to pieces all my homes
And felled the trees closer to me
Therein –
You made all the dams, reservoirs and barrages,
Cutting off my tribal paths and passages.
In the heart of my playgrounds
You cut across tunnels and canals,
Raised the townships and walls
And, on the grounds I hugely treaded –
All the rail-lines, roads and runways
All the electric lines and highways.
You made them all pass through my shade and shelter
Throwing my home range to wail and welter.
You cut my home range to shreds,
And those great grasslands of mine
You planted them up
With trees of light crown and timber fine
Where could I go?
What could I eat?
You chopped all the bushes
And lopped the trees neat,
Never caring, what fate I to meet.
Miles and miles I used to go
From one river to another
From one ridge to another.
Of all your valleys and hills
From one end to another
Members of my tribe travelled their routes
In numbers big and small.
There was enough food and water
Cover and shelter in seasons all.
My freedom of movement curtailed
You forced me to live in small pockets
Like prisoners and fugitives
You read my acts in your dockets.
I ran short of food resources
I suffered drying up of water resources
Yet your cattle drank and defiled
Whatever was left of water courses
And when out of sheer hunger and thirst
I went to your villages or visited any crops
You made a big issue and fired the shots
Leaving me dead or wounded
Paralysed or grounded.
But this is not the end
The story has a bend
Your great bandits from the south
And those rascals from the north
Are hell-bent to decimate my race.
In great strides and faster pace.
They like my ivory that they sell
There is a market that pays them well
Shall I end here or
Your would listen a little more?
It is about the men of my tribe –
They were the master of lore
What happened to my mahouts
My guardian angels and caretakers –
Are they not a miserable lot?
And in tatters
Lowly paid and hungry
Over worked and sometimes angry
They need your best attention
And in old age, a good pension.
I heard you discuss me
In projects and seminars
Held in great cities and big halls
You ponder and mull over my fate
You probably ask each other
With death and doomsday
When do I have a date?

Mohammad Ahsan

To My Mother,

For her unconditional support and continuous encouragement

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Chapter 1

GENERAL INTRODUCTION

1.1. Introduction

As natural habitats worldwide are being destroyed or converted to other uses, species supported by those habitats are inevitably threatened. The first step towards ensuring the long-term persistence of the elements that comprise biodiversity is to develop the basic information required for their effective management. This information should incorporate data on the distribution, biology and habitat requirements of species in danger. Where those data are available, GIS provides a means of rapidly reviewing the distribution and conservation status of several components of biodiversity. This information can then be used for detailed resource inventory and for decision-making purposes in nature conservation and management. However, even where information is poor or almost non-existent, GIS techniques can be used to predict species distribution patterns based on limited field data (Vogiatzakis 2003).

The Asian Elephant (*Elephas maximus*) represents one of the most seriously endangered species of large mammals in the world. It was recognised as an endangered species in 1975 after the inclusion of its species in Appendix-1 of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) (Bist 2002). Armbruster and Lande (1993) state that Habitat loss and poaching are the two factors most responsible for the African elephant's current decline, and both are a direct product of human population growth. The same can be said of the Asian elephant. Human encroachment on natural habitats is one of the most critical issues facing Asian elephant conservation today. The elephant is threatened by habitat loss and fragmentation as a result of a escalating human population and its aspiration for a better quality of life. Elephant habitats are being cleared for reasons including agricultural development, human settlement, and logging. The elephants in Asia have lost so much of their former habitat that they are often forced to invade the communities that have displaced them, thereby leading to increased conflicts with man (Santiapillai 1997). Conflict between humans and wildlife occurs wherever both co-exist. They are the most severe in the interface between the wildlife range and agricultural land. Most wildlife-human conflict involves crop-raiding animals that consume and destroy food crops and injure or kill people (Chandrashekhar *et al.* 2003). The elephant has become, to the people that live in the vicinity of its habitat, one of the most destructive species of wildlife (Daniel 1996). Proper management is therefore essential to reduce human – elephant conflicts and preserve elephant habitat to ensure the survival of the species.

Elephants are the largest and most impressive of land animals. By virtue of their size and ecology they hold a special significance for conservation. Their requirements in terms of resources and space will most often dwarf those of other species and as such designating protected areas large enough for elephants will certainly include adequate resources and space for all other species that are found in the area. This will most certainly mean the conservation of the biodiversity there (Anon 1995).

Most Asian countries with elephant populations have outdone themselves in striping their country bare of its once vast forest cover. The few large areas remaining that are suitable for elephant conservation, are in fact the last shreds of decent forest cover remaining, so by conserving Indian elephants one will most certainly be saving what little remains of India's forest cover and vital watershed areas (Anon 1995).

Wildlife management involves management of a complete ecosystem. Until recently many conventional techniques involving time consuming and costly field surveys have been applied for collecting data on natural resources. Ground survey methods will always be necessary. However, in many cases tedious fieldwork can be supplemented or partially replaced by remote sensing. In addition, ground methods have limitations as whole areas can not be accessed in one stretch and information collected may not be as accurate as is possible through remote sensing aided by limited ground survey (Kushwaha & Roy 2002). The elephant is a large animal with a big home range. Its habitat crosses many administrative borders, which also complicates fieldwork in many countries.

In wildlife management, Geographic Information Systems (GIS) and Remote sensing (RS) can be used in ecotype analysis, habitat evaluation, gap analysis, monitoring the process of conservation activities, quantifying ecological spatial patterns, connectivity and network analysis and monitoring wildlife populations and more. In this study focus will be given to environmental suitability modeling.

The elephant is deeply rooted within many cultures. Due to its popularity it is a very well studied animal both in Africa and Asia. As the human population is growing and invading undeveloped land elephant habitat is being reduced. It therefore is coherent that elephant - human conflicts are increasing. Many studies throughout Asia and Africa have looked at this problem, using traditional methods such as field observations and on the ground habitat assessment (Sukurmar 1989; Prasad & Reddy 2002; Marak 2002; Srivastava 2002; Chauhan & Chowdhury 2002; Nigam 2002; Singh *et al.* 2002; Tchamba 1996). RS and GIS techniques can provide additional vital support in conservation planning. However, few studies in India have integrated available geographic information derived from GIS and RS with environmental suitability. In this study these techniques will be used to evaluate elephant habitat in parts of the Nilgiri Biosphere Reserve, which is essential to preserve this fragile biosphere reserve.

1.2. GIS and RS Application in Wildlife Habitat Mapping and Modeling

Growing intensity of land use, increasing public interest in biological conservation and legislated requirements for resource impact assessments demand the use of analytical tools for evaluating wildlife response to land management (Flather *et al.* 1992).

GIS is a powerful set of tools used to collect, store, retrieve, transform and present spatially referenced environmental data from the real world. Although primarily a tool used in landscape ecology, GIS is now used for a wide range of applications for answering questions on the ecology and distribution of individual species and communities (Vogiatzakis 2003). It has been widely used in many fields, such as resources and environmental evaluation and management, and urban as well as rural planning and management. GIS has caught a lot of attention in the field of ecology in recent years. Here it has been used in landscape ecology and ecosystem research, and has gradually extended to the field of individual and behaviour ecology. There are many cases in which GIS has been successfully used in biology conservation (Liu 1997).

GIS can also assist in expanding the use of satellite imagery for delineating wildlife habitat. Broad habitat features detected in satellite images can be refined using GIS models of an animal's habitat requirements such as proximity to human habitation, preferred vegetation, seasonal use areas, and prey species use areas (Prasad *et al.* 1991).

Remote sensing offers methods to assess wildlife habitat at large spatial scales. It is cost effective and allows rapid qualitative and quantitative spatial assessment, ancillary digital data can be incorporated to aid in vegetation classification and model development, and remote sensed data can be used in temporal analyses to document habitat change (Homer *et al.*1993).

RS and GIS techniques have been used extensively in habitat assessment for various wildlife species. In the early days of remote sensing Laperriere *et al.* (1980) generated Vegetative type maps covering approximately 13 million ha of Alaska from Landsat TM images using modified clustering techniques for moose habitat analysis. Later many studies integrated remote sensing with GIS for more specific analysis. Prasad *et al.* (1991) generated thematic layers from maps and satellite images (SPOT) using density slicing, PCA and unsupervised classification to identify potential snow leopard and blue sheep (leopards prey) habitat in a high mountain ecosystem. Homer *et al.* (1993) used Landsat TM data to model structural and compositional attributes of sage grouse winter habitat in Utah with great success.

Zhixi *et al.* (1995) have evaluated Asian elephant habitat in China and demonstrated the potential for integrating RS and sampling into accurate spatial habitat assessment, Buchroithner *et al.* (1996) used RS for brown bear habitat assessment, Rubino and Hess (2003) creased a model for Barred owl habitat using GIS and Woolf *et al.* (2002) modeled bobcat habitat with RS Data, multivariate statistical techniques and GIS. Store and Kangas (2001) integrated multi-criteria analysis and GIS to improve habitat suitability evaluation over a large area and Zhixi *et al.* (1995) based their elephant habitat evaluation on it. Clark *et al.* (1993) and Corsi *et al.* (1999) used Mahalanobis distance statistic as an index to rank habitat suitability in GIS raster maps.

1.3. Research Objectives and Research Questions

The main objective of this study is:

To investigate how the available environmental variables describe environmental suitability for Asian elephant in the parts of Southern India.

The immediate objective of this research is to determine environmental variables useful to represent preferred elephant habitat and incorporating them into a model. Further it will be determined how the results differ between using classified images and raw satellite images for environmental modeling. The last objective is to determine how many variables are necessary to obtain a habitat model using Mahalanobis distance.

Research questions:

1. In which areas do elephants occur?
2. Which environmental variables show the highest correlation with elephant distributions?
3. Is it possible to make a model for suitable habitat with limited data available?
4. What are the limitations and possibilities of using this model? - How can one improve this model?
5. Is there a change in environmental suitability for elephants in Southern India?

1.4. Research Approach

Before understanding which environmental factors are prefer by elephants the spatial distribution of elephants in the study area should be identified. Chapter 2 deals with elephant distribution mapping. Here techniques used to identify areas of higher preference are described. It further describes habitat suitability modeling and the components defining it. In chapter 3 preferred elephant habitats in a 591 km^2 area is modeled using inductive modeling. Mahalanobis Distance is used to derive habitat suitability maps. The influences various environmental variables have on modeling preferred habitat is observed and compared. After creation of the model it is used on a larger area of 13547 km^2 (including Bandipur N.P. and Nagarahole N.P. to the north west of the study area and silent valley N.P to the south as well urban area to the far north, and cultivated areas to the south and west) to observe environmental changes over an eight year period.

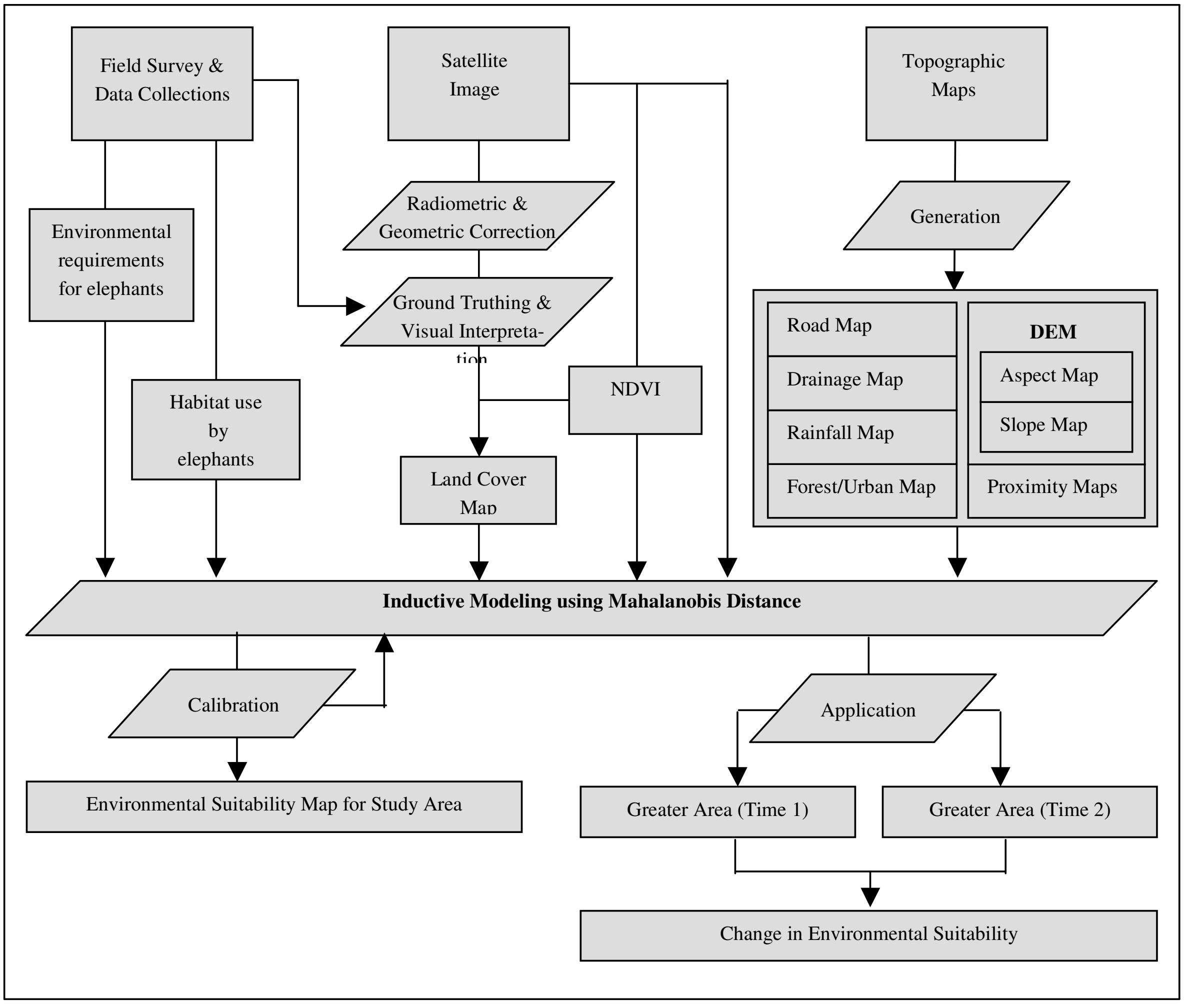

Figure 1.1. Conceptual Framework of thesis research.

1.5. Study Area

The study area covers an area of 591 km^2 and includes Mudumalai Wildlife Sanctuary (W.S.) and National Park (N.P.) as well as its adjoining southern areas (see Figure 1.2.). Mudumalai W.S. is located at the tri-junction of the Tamil Nadu, Karnataka and Kerala states in the Nilgiri District of Tamil Nadu. It is bounded to the north by Bandipur N.P. in Karnataka, and to the west and northwest by Wynad W.S. in Kerala. To the south and east Singara and Sigur Reserve Forests (R.F.) form the boundary. The southwest perimeter of Mudumalai W.S. adjoins private tea and coffee estates, agricultural fields and patta land. The study area lies between 11° 29' and 11° 43' north latitude and 76°20' and 76° 46' east longitude.

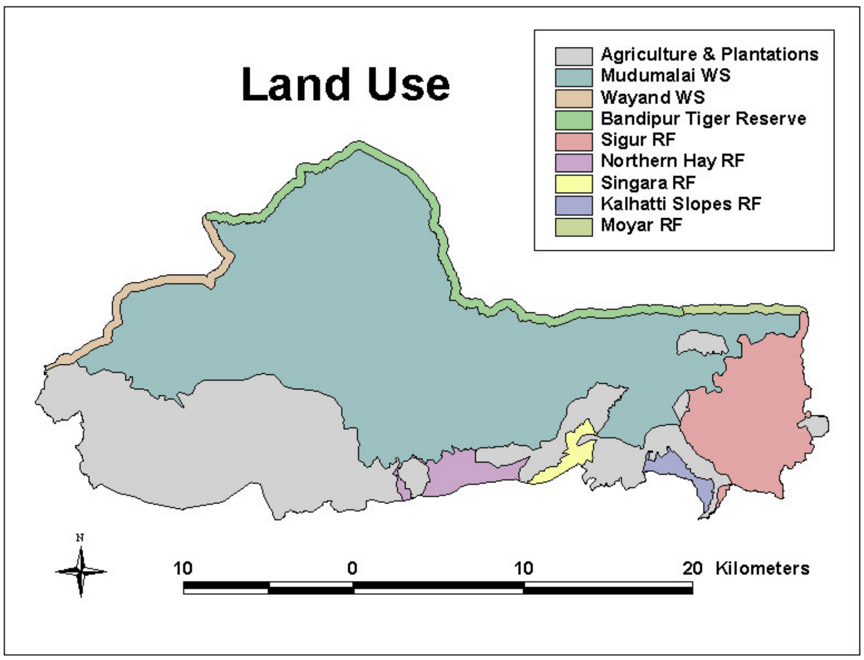

Figure 1.2. Land allocation and land use

The study area lies within the Nilgiri Biosphere Reserve, the first biosphere reserve in India, which was established in 1986. The Nilgiri Biosphere Reserve encompasses six protected areas and surrounding reserve forests. It has a wide variety of forest types from scrub and deciduous forest to tropical evergreen forests and montane grasslands reflecting the gradients in rainfall and topography. In the last few decades, large areas of natural forests were removed for raising commercial crops and establishing tea and coffee plantations, resulting not only in the loss of forest cover but also creating gaps of various sizes between forests in several places. Furthermore, developmental activities in the form of hydroelectric projects, reservoirs and a network of roads have hampered the forest contiguity of protected areas within the Biosphere Reserve and study area. The Nilgiri Biosphere Reserve harbours the largest south Indian population of Asian Elephants today (Sivaganesan and Kumar 1994).

The terrain is undulating with an average elevation of 900 to 1000 m tilting north and eastwards. Mudumalai W.S. is characterised by the frequent occurrence of swamps of various sizes at the foot of the hills. The study area is drained by the Moyar River, the main river system and its tributaries Biderhalla, Benne hole, Doddagatti halla, Imberhalla Kakkanallah, Avarahalla and the Segur River as seen in figure 1.3. Only they are perennial. The Moyar River runs into a gorge after a short distance. The gorge has steep rocky faces on either bank, therefore constricting the animals from reaching the water easily. A number of artificial check dams and water holes have been constructed across seasonal streams and the swamps, which provide adequate water supply to the wild animals (Neelakantan 1988).

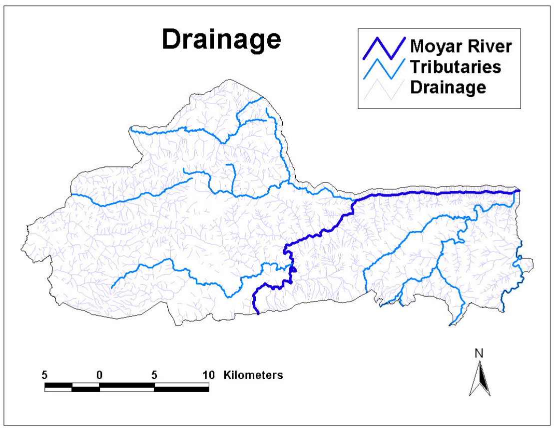

Figure 1.3. Perennial rivers and seasonal drainage

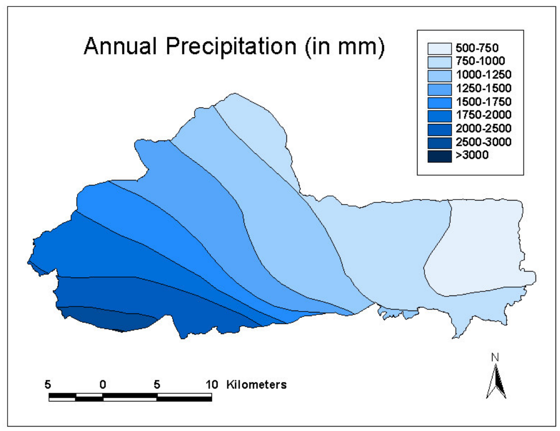

Figure 1.4. Annual Precipitation varies greatly in the study area.

The study area has a long wet season and a short dry season. It receives rainfall from the southwest and northeast monsoon. The southwest monsoon starts by May and ends by August while the northern monsoon starts by September and ends by December. Based on the climate of the study area, the year can be classified into three seasons: Dry season (January to April), first wet season (May to August) and second wet season (September to December) (Desai *et al.* 1999). The rainfall as shown in figure 1.4 has a marked east-west gradient, with the northeast areas getting the least amount of precipitation (500 mm) as it lies in the rain shadow zone and the southwest regions receiving the heaviest rains (up to 3000 mm) (Lengerke 1976). Temperature ranges from 8°C (night) in December to 35°C (day) in April.

The vegetation follows a similar gradient as the rainfall (see figure 1.5.) with Southern high level thorn forest to the east of the sanctuary followed by the Southern tropical dry deciduous in the middle and Southern tropical moist deciduous and semi evergreen containing some moist bamboo brakes to the west. In the far southwest Shola forests are present. Riparian fringing forests are found throughout the area along the rivers (Desai *et al.* 1999).

There are more than 13000 cattle in Masinagudi and adjoining villages, which are maintained for dung. The Avarahallah Reserve Forest in the sanctuary and the adjacent Segur Reserve Forest are open for cattle grazing (Neelakantan 1988).

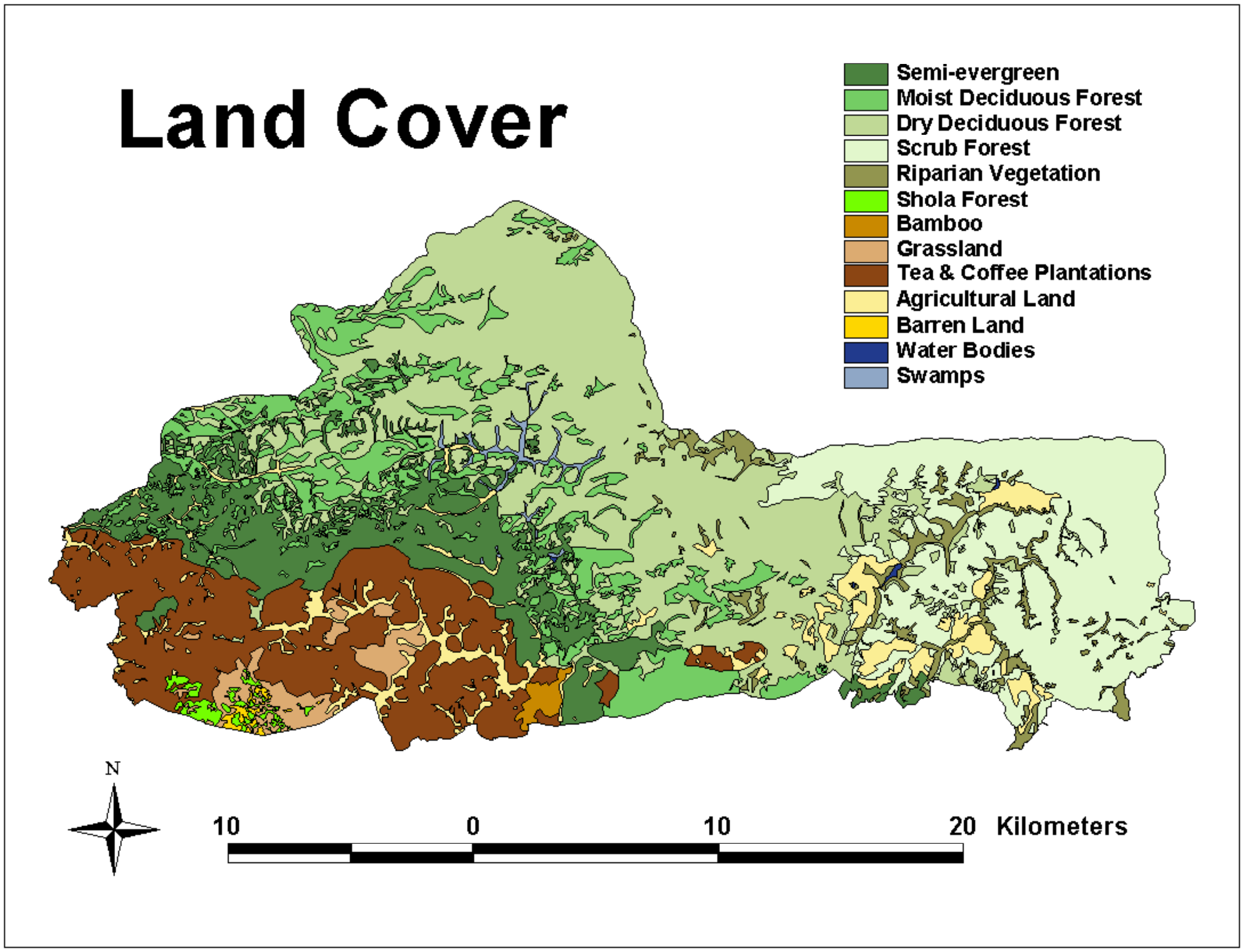

Figure 1.5. Land cover map showing four distinctive natural vegetation types and cultivated areas.

Mudumalai W.S. supports the second highest elephant population in the state. Due to its small area of 321 km^2 it also has the highest elephant density, estimated between 2.19 and 2.39 elephants/ km^2 (Sukumar *et al*. 2002). Elephants are seen in herds and in small group or solitarily in most parts of the study area. The elephants migrate seasonally based on the availability of forage and water. Elephants congregate in the sanctuary from March to October when there is enough food and water. After the grasses mature and seed, many move into the adjoining Segur and Thalamalai Plateau, which have fresh grass growth during the north east monsoon. After the water holes there dry up and food becomes scarce in Jan-Feb, they migrate back to the sanctuary areas. They move along regular fixed paths and there are many such well-marked migratory routes all over the sanctuary (Neelakantan 1988).

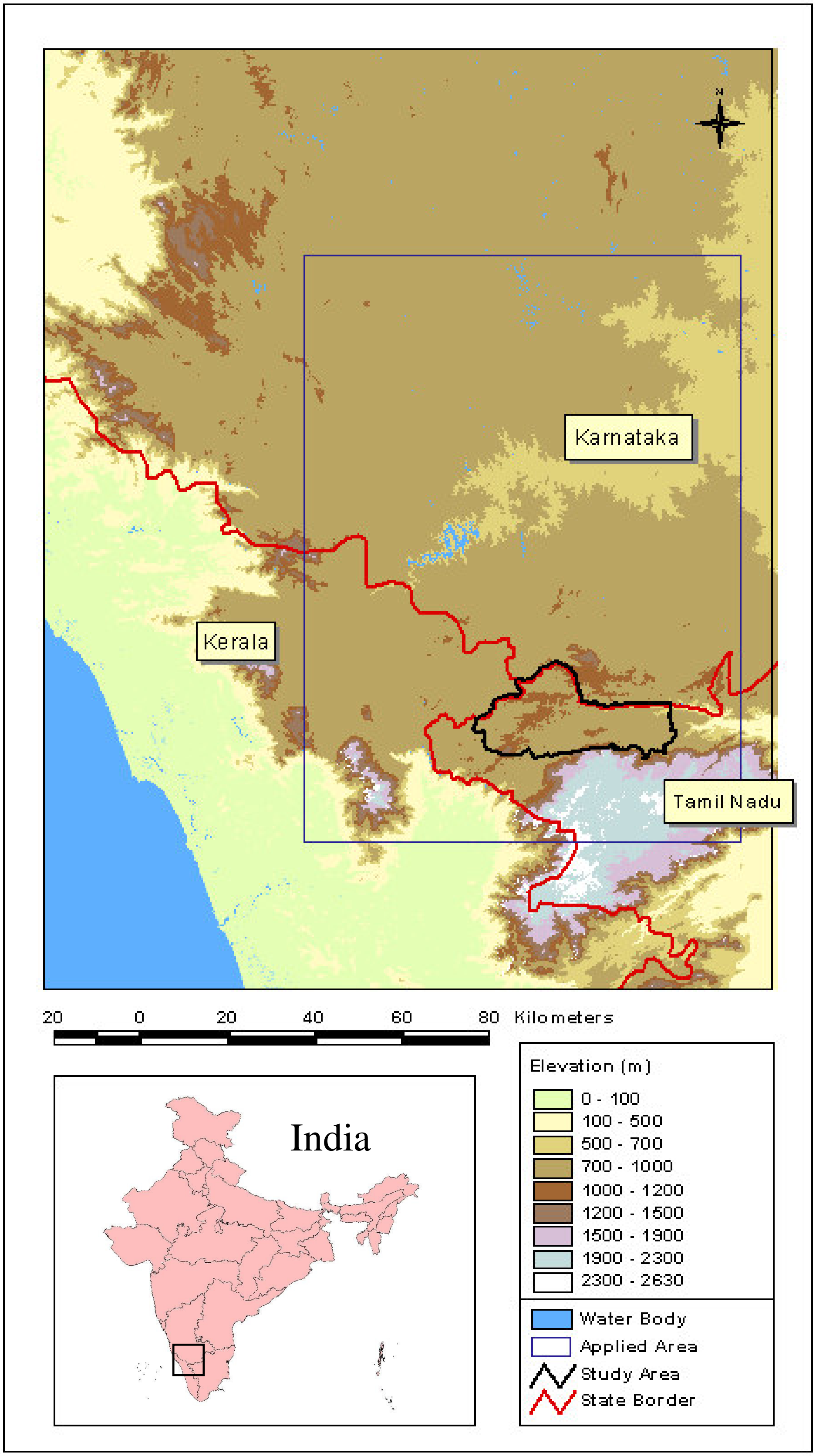

Figure 1.6. Location of the study area (black) and the area the model was applied on (blue) in Southern India.

Chapter 2

HABITAT SUITABILITY MODELING

2.1. Introduction

The rapid development of computers and associated software during the last thirty years has led to the expansion of Geographical Information Systems. Coupled with ecological modeling, GIS can provide significantly increased opportunities for detailed environmental resource inventory and analysis and show considerate promise for extensive use in nature conservation. (Vogiatzakis 2003).

Systematic habitat evaluation, although largely qualitative, was first developed in the 1970's by the U.S. Fish and Wildlife Service. Habitat evaluation is the assassment of the suitability of land (or water) as a habitat for specific wildlife species. To achieve this one needs a model to predict the suitability of land given a particular set of land conditions. Such model is called a habitat (environmental) suitability model (de Leeuw & Albricht 1996).Habitat selection studies have commonly been used for modeling wildlife populations and for gaining a better understanding of these relationships between wildlife and environment. The incentive for modeling relationships between environment and species parameters is based on the belief that animals respond to the environment in an adaptive fashion. This suggests that an animals decisions can be influenced by variation in specific environmental components (Roberts & Morgan 2000).

The evolution of habitat selection models from subjective to empirically derived techniques has resulted in the development of more ecologically valid models of wildlife – habitat relationships. Linking GIS to habitat models has enabled researchers to examine resource selection at broader landscape scales. Projection of these models of habitat conditions through time will be an important aspect of habitat management (Roberts & Morgan 2000).

GIS technology provides the analytical tools to model wildlife – environment relationships that require multivariate calculations on a landscape scale. Multivariate techniques, such as logistic regression and the Mahalanobis distance statistic, in conjunction with GIS technology have been used as modeling tools in habitat selection studies (Clark *et al.* 1993; Roberts & Morgan 2000). GIS and geographically extensive databases have greatly improved the ease with which habitat models can be developed and integrated into ecosystem planning. (Roberts & Morgan 2000).

Effective management of wildlife populations largely depends upon understanding and predicting their environmental needs. Use of multivariate statistics to assess habitat suitability has increased in recent year because the multidimensional nature of habitat limits use of simple univariate statistical techniques. Due to the coarseness of most GIS databases, GIS based habitat models are more effective for species with generalised environmental requirements (Clark *et al.* 1993).

2.2. Models

The rationale behind the GIS approach to species distribution modeling is simple. The GIS database contains a large number of data sets (layers), each of which describe the distribution of a given measurable and mappable environmental variable. The ecological requirements of the species are defined according to the available layers. The combination of these layers and the subsequent identification of the area that meet the species' requirements identify the species distribution range (Corsi *et al.* 2000).

Ecological data sets have two distinct characteristics if compared to other kinds of data. They are multivariate and location specific (Vogiatzakis 2003). Simple univariate statistical techniques may not adequately assess the multidimensional nature of habitats used by wildlife (Clark *et al.* 1993) Although historically ecological modellers have focused on changes in time at single sites or small geographical areas, during the past two decades, they have started to incorporate spatial pattern in the models and apply them in large geographic areas (Vogiatzakis 2003).

The GIS approach to species distribution modeling can be put into practice by using different methods The key point for the implementation of distribution models is the species-environment relationship . Deductive-inductive models, illustrated in figure 2.1, focus on the definition of this species-environment relationship (Corsi *et al.* 2000).

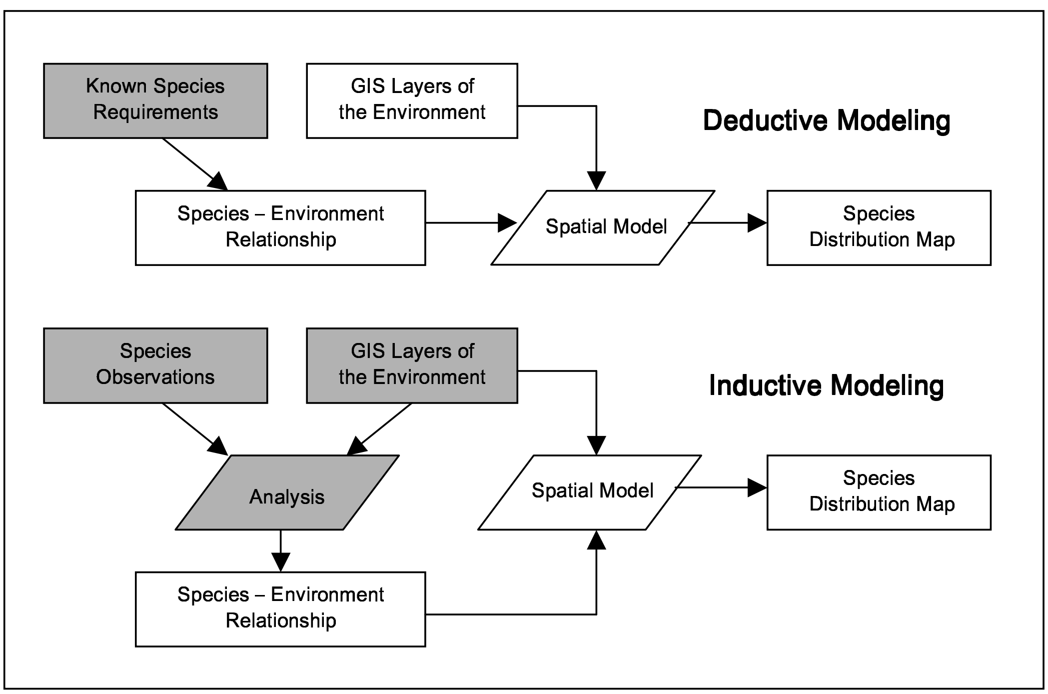

Figure 2.1. Framework of deductive and inductive modeling

Deductive or theoretical approaches are based on accepted theories on relationships between phenomena (Vogiatzakis 2003). It uses known species ecological requirements to extrapolate suitable areas from the environmental variable layers available in the GIS database. Once the preferences are identified overlay operation are used to merge the different environmental layers to yield the combined effect of all environmental variables (Corsi *et al.* 2000). Deductive modeling has some severe drawbacks in wildlife ecology as for many species knowledge of habitat requirements simply does not exist. For limited number of species models have been developed for one particular area, however the validity elsewhere remains unknown (de Leeuw & Albricht 1996). Inductive modeling has been advertised to overcome these problems (de Leeuw & Albricht 1996). Inductive or empirical approaches are based on the analysis of field collected data. Thus prediction is induced from empirical observations (Vogiatzakis 2003). Therefore when the species-environment relationships are not known, like in this study, the inductive approach is used to derive the ecological requirements of the species from locations in which the species occurs (Corsi *et al.* 2000; Omullo 1996). A species' ecological signature can be derived from the characterisation of these locations, which is used to extrapolate the distribution model (Corsi *et al.* 2000). Here modeling goes from the specific case (field data) towards a generalisation (de Leeuw & Albricht 1996).

Inductive and deductive models can further be classified, according to the kind of analysis performed to derive the species-environmental relationship, into descriptive or analytical. Descriptive models either use the specialists' a priori knowledge (deductive-descriptive) or simply overlay of known location of the species with associated environmental variable layers (inductive-descriptive) to define the species-environment relationship. Models that fall into the analytical group introduce variability. They tend to estimate the relative importance of different environmental layers. In the case of deductive-analytical models variability in terms of different opinions of experts are introduced or that the species observation data are analysed in a way that takes into account the range of acceptability of all environmental variables measured, their confidence limits, and their correlation. Inductive - analytical techniques rely on samples of locations that are analysed and combined using statistical procedure (Corsi *et al.* 2000). This study uses an inductive analytical approach.

2.3. Radio-tracking

Radio tracking is the technique of determining information about an animal through the use of radio signals from a device carried by the animal. "Telemetry" is the transmission of information through the atmosphere usually by radio waves, so radio-tracking involves telemetry, and there is much overlap between the two concepts (Mech & Barber 2002).

In 1960 very small radio transmitters were attached to a cottontail rabbit and a mallard duck, in Illinois, USA. This was the genesis of radio telemetry for wildlife research and management, now a widely practiced technique (Cochran *et al.* 2002). Radio tracking brought two new advantages to wildlife research: the ability to identify individual animals and the ability to locate each animal when desired. These advantages have led to the wide application of radio tracking since the first complete workable system was designed. Radio tracking has since been used to study animals as varied as fish, toads, snakes, crayfish, dolphins, manatees, tigers and elephants in most major countries (Mech & Barber 2002).

The radio-tracking technique is so revolutionary that there is no other wildlife research technique that comes close to approximating its many benefits. Before radio tracking, the study of animal movements depended on live trapping and tagging animals and then hoping to recapture them somewhere else. A refinement was the use of visual markers such as color-coded collars that allowed observers to identify individuals from afar. The crudeness and biases inherent in this method are obvious, but the technique is the next best to radio tracking for this kind of study (Mech & Barber 2002).

Advances in radio-tracking since Cochran and Lord's first system according to Mech and Barber (2002) include refinements of conventional, or very high frequency (VHF), telemetry as well as entirely new systems such as satellite telemetry and GPS radio-tracking. Improvements in conventional VHF telemetry now enable researchers to determine, for examples, whether an animal is active (feeding, walking, running) or resting, and the time spent in mortality from death until the transmitter is recovered. Microphone-containing transmitters allow researchers to listen to a creature's vocalizations and ambient sounds. In addition to more straightforward applications such as movement/home range analysis and mortality studies, radio telemetry has proved useful in examining many diverse topics including disease transmission, scent marking, predation and co-evolution, vocalisations, socioecology and breeding behaviors, sleep characteristics, physiological studies of heart rate, respiration rate, body temperature, and nest egg condition (Mech & Barber 2002).

Traditional very high frequency (VHF) radio telemetry systems have been used as early as the 1970s to track the movements of the long-ranging and highly mobile elephant (Foley 2002). Telemetry provides an exceptionally useful tool in elephant research and management. Despite the appeal of radio - collaring the resulting data must be used with caution, as the data are for one animal only (in case of a female elephant, the data can also be representative of her other group members)

2.4. Elephant Distribution Assessment

2.4.1. Environmental Variables for Elephant Distribution

Although highly specialized in some parts of their anatomy, elephants are relatively unspecialised ecologically. They are able to occupy a wide variety of habitats, from sea level to montane and from desert to tropical rain forest (Wheelock. 1980). According to Wheelock (1980), elephants, when given the chance, move naturally on response to availability of water, food and shade.

Circumstantial evidence obtained by Leuthold and Sale (1973) suggests that food is the primary proximal factor governing movements and distribution of elephants. Sukumar (1989) agrees by stating that the movement of elephants in the study area are largely in conformity with expectations of optimal foraging theory. Food availability, in turn, is determined largely by the spatial and temporal pattern of rainfall (Leuthold & Sale 1973). The study conducted by Leuthold and Sale (1973) further showed a definite relationship between elephant movements and the pattern of localised rainfall, but it was not clear if they move as a direct response to rain in a distant location or due to the rapid growth of vegetation after rain. Sukumar (1989) adds that elephant movements are also governed by spatial distribution and temporal availability of water.

Wheelock (1980) stated that in restricted habitats, researchers have been unable to find convincing evidence of any regular seasonal movements greater than 15 km. Major seasonal patterns can no longer be an important feature of elephant behaviour due to concentration of the animals in reserves and parks. The elephants are forced to congregate in marshes during the dry season. Their movements are related to rains but do not follow an annual cycle. Wheelock (1980) further believes that there is a strong correlation between elephant distribution and sodium availability.

Zhixi *et al.* (1995) also took into account slope steepness, aspect and human activity in evaluating Asian elephant habitat. Hoare and du Toit (1999) found that elephant and human coexistence occurs at various levels of human density and that only beyond a curtain threshold elephant populations disappear.

2.4.2. Elephant Distribution

The recent elephant distribution is determined largely by man, without regard for the preference of the animal. Consequently, populations are under varying degrees of stress. During this century, the elephant have been steadily concentrated into areas unsuited to human occupation. (Wheelock. 1980).

Census operations carried out during 1997-2001 indicate the presence of over 28000 elephants in India. Elephants are found in five distinctive geographical zones. These being North-eastern India (c. 9200), Eastern India (c. 2400), Northern India (c. 1600), Southern India (c. 14800) and the Andaman and Nicobar Islands (c. 50). The later population originates from domestic elephants that were released (Bist 2002). The South Indian elephant populations do not occur in one continues range, as can be seen in figure 2.2., but rather is distributed throughout numerous forest, some of which are joined by narrow corridors.

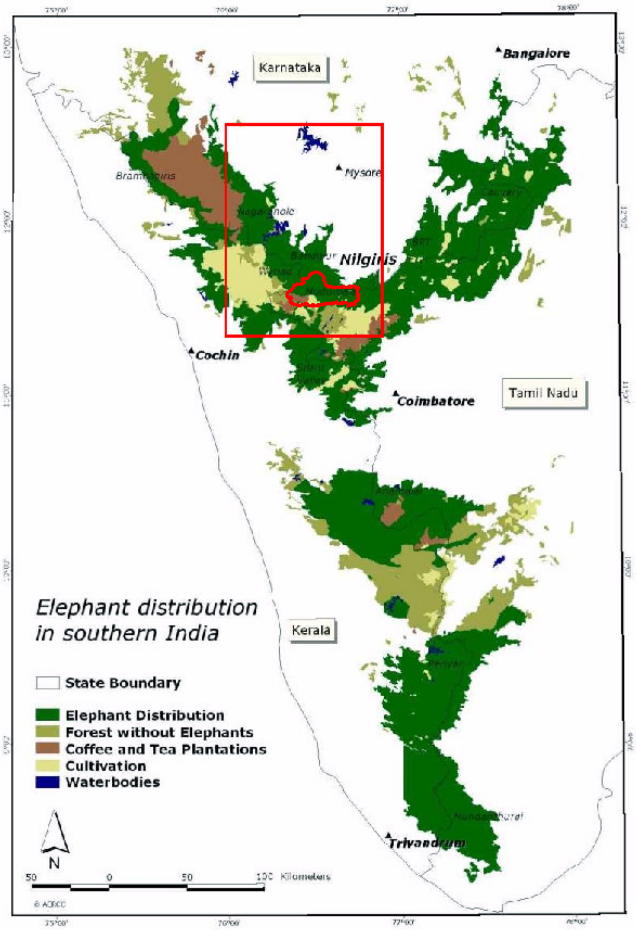

Figure 2.2. Elephant distribution in Southern India. The smaller read outline shows the study area and the bigger the applied area. Source: Indian Institute of Science Website.

Wildlife habitat managers require detailed information pertaining to the distribution and abundance of species to help understand their ecology (Yamada *et al.* 2003). Many methods have been developed to obtain the knowledge of spatial distribution of species. These methods range from simple animal sighting to more sophisticate radio- telemetry tracking. Elephant distributions in the study area is partly derived from literature: two studies conducted by the Bombay Natural History Society (BNHS) using radio tracking and colour collaring were utilised. In addition local people were questioned for elephant occurrences outside the home range area during fieldwork to determine elephant distributions.

2.4.3. Home Range Estimation

Home range can be defined as the area that comprises an animals established home, which is traversed by it in its normal activities of food-gathering, mating and caring for young and includes the area covered in normal daily activities (Sanderson 1966). Habitat selection can be regarded as hierarchical orders. First-order selection is the selection of a geographical area, second-order selection is the proportion of habitats that make up an animal's home range, and third-order selection is the use of habitat within the home range (Clark *et al.* 1993).
The first study (Anon 1989) focusing on second order selection was conducted by the BNHS from 1980 to 1987 to determine elephant distributions. Here elephant movement patterns were determined through resighting of 119 elephants. Colour collars were used for better identification of two individuals but were of limited success as they were either torn off or covered with mud. Home ranges ofthree known elephants (one male and two females) were plotted and can be seen in figure 2.3. Sukumar (1989) states that home range sizes determined by radio-tracking are usually larger that those revealed by visual identification. This can be observed when comparing this study with a second study that followed four years later.

The previous study was followed by a more accurate 3,5 year long (Feb. 1991- Sep. 1994) radio tracking study of five elephants (Anon 1995). Here second and third order selection was studied. Using conventional radio collars to track elephants and research their movement helps understand elephant needs. Elephants require lots of space to roam, and this is becoming harder and harder for them to find. Through radio tracking one can gain insights on how elephants make decisions and this helps to predict the impact that any ecological change might have on elephants and the biodiversity of an area. The objective of the study was to determine the home range of elephants, ascertain what implication it had for management and to deal with the question of viable populations in term of integrity. In addition to these aspects the study also looked at the problem of crop raiding by elephants.

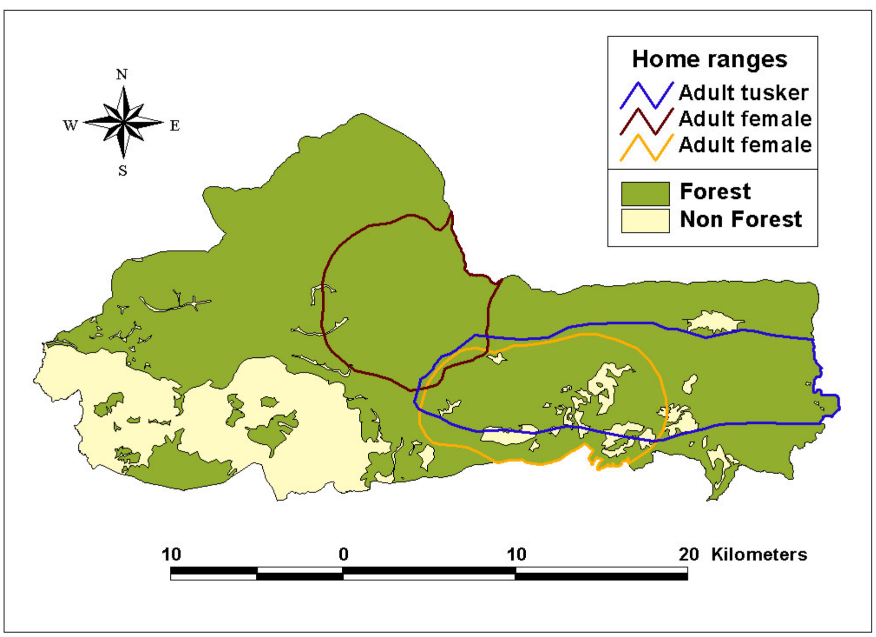

Figure. 2.3. Estimated home range of three known elephants within the study area

To determine the home range size of clans and adult males , adult females from 3 clans (Priyanka, Harini and Wendy) and 2 adult males (Salim Ali and Admiral) were radio collard. Completely assembled radio collars from Telonics Inc. U.S.A. were used for collaring the elephants. The radio tracking was done using H antennas and receivers from the same manufacturer. Efforts were made to confirm locations by homing and only when it was extremely difficult to do so, was the triangulation method used. Homing consists of following a signal toward its greatest strength until the researcher sees the animal or otherwise estimates its location when sufficiently near, wereas triangulation involves obtaining two signal bearings from different locations (preferably at angles of about 90° to one another) which then cross at the animal. When more than two bearings are plotted, the bearings form an error polygon on a map. This polygon theoretically contains the animal's location (Mech & Barber 2002).

A minimum of eight locations were confirmed per month for all the radio collard elephants except for Wendy when the elephant was present at the southern most extreme of her range. Here a minimum of two locations per month as well as additional information from the villages was collected.

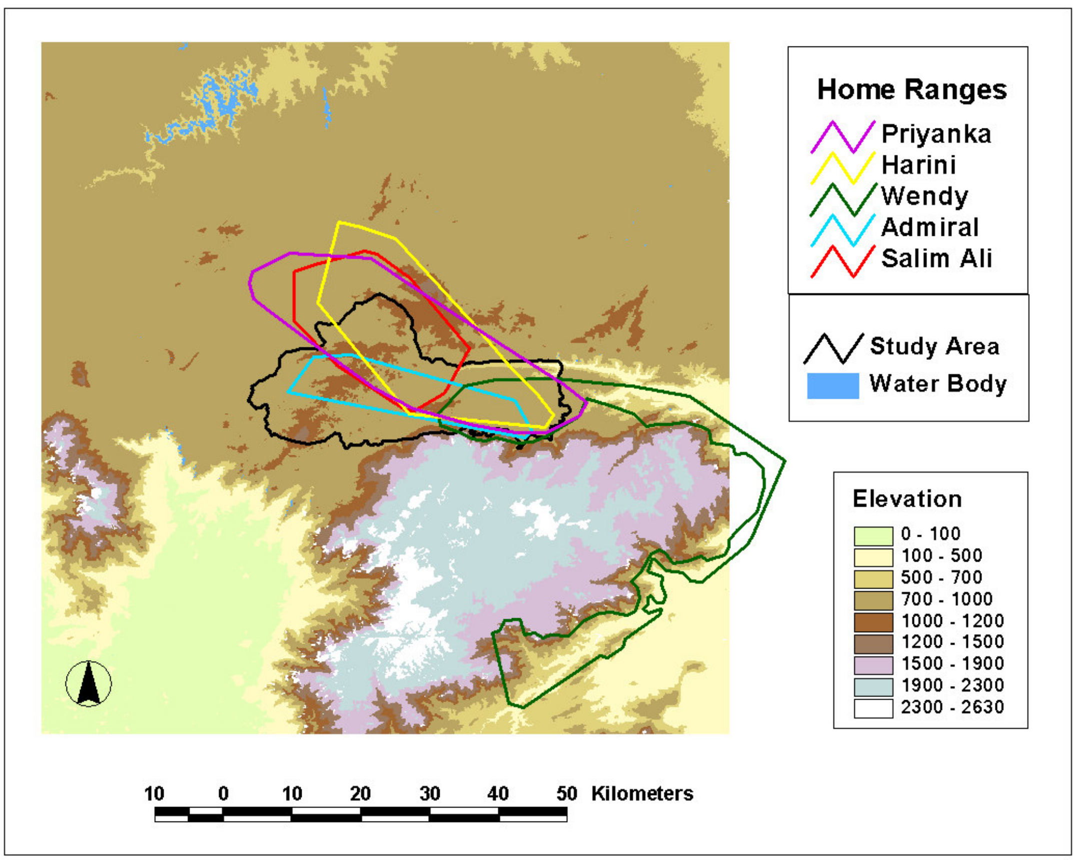

Figure 2.4. Home ranges of five radio tracked elephants

Priyanka, Harini and Wendys clan were tracked for 42, 38, 40 month respectively, while the males Salim Ali and Admiral were tracked for 15 and 22 months respectively. During this period they were located at 564, 539, 127, 114 and 257 days respectively. The locations were plotted on a 1:50 000 topographic map and home ranges were calculated using the Minimum Convex Polygon Method. The

Minimum Convex Polygon Method was first described in 1947 and is the most widely used method to delineate home ranges. It has also been called the minimum area method or convex-polygon method. In this method, the outermost locations are connected by a convex polygon, and everything within the polygon is considered to be the animal's home range (Springer 2003).

It was found that the elephants showed very strong fidelity to the home ranges as they used the same areas during the same seasons. Only Wendy shifted her home range after one year and remained at its new range for at least two consecutive years. The five home ranges are illustrated in figure 2.4.

2.4.4. Participatory Rural Appraisal (PRA)

Twenty villages throughout the study area were visited in July 2003. These villages were located inside and outside of protected areas (see figure 2.5). Local people were interviewed to inquire about elephant occurrences. The information was needed to verify elephant distributions and to obtain knowledge of what attracted elephants to those areas.

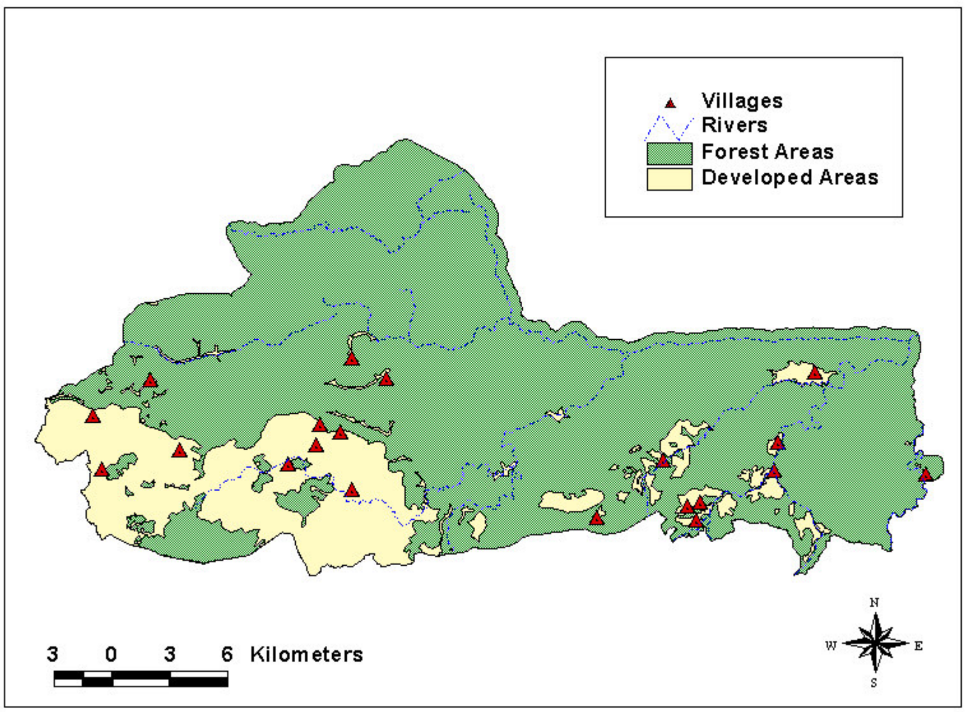

Figure 2.5. Villages visited for elephant distribution verification

A questionnaire was formulated to get more insight into the elephant problem in the villages. One or sometimes a group of locals were questioned. To determine the reliability of the localite general questions about him or her were stated first. It was asked how long he or she had lived in the village and what his or her occupation was. The knowledge of the size of the village and the crops grown there was also acquired. It was asked if farmers had problems with wild animals specifically elephants. Time of the year and frequency of elephant sightings were asked. Lastly a description of the damage elephant cause in the villages was requested. Here it was asked if the elephant damage crops by trampling them when moving through the fields or by eating them.

The results of the questionnaire showed that elephants were seen in all villages. They were seen more often in those villages surrounded by forest. Damage was the severest in the three villages within Mudumalai W.S.. Relocation of 2 of these villages located in the centre of Mudumalai WS are being planned. The villages in the eastern parts of the study area surrounded by scrub forest also reported many elephant sightings and high crop damage. Most villages or crop fields in this area were fenced in by electrical fences in the last 2 years due to the elephant problem. Crop raiding had been severely reduced or totally eradicated in those areas now. In some areas power fluctuation would still allow elephants to enter and raid fields at times.

In most incidences it was said that elephants come during the crop seasons to raid the crops. The crops they consumed the most was paddy (rice), bananas, raggi, and arkan-nut. They would also break coconut trees and eat mango and jackfruit from usually solitary trees grown in the study area.

Most people interviewed had been living in the village for there whole life and their families had been established there for many generations. They were all either farmers or labourers in the respective villages.

Chapter 3

MODELING ELEPHANT HABITAT

3.1. Introduction

This chapter will assess the possibilities to model the suitable elephant habitat based on remotely sensed images, 1:50 000 topographic maps and eight known elephant home ranges. The model then is applied on a lager unknown area to observe environmental suitability changes for elephants over an eight year period.

3.2. Material and Methods

3.2.1. Digital Data Generation

A 8. December 2000, IRS ID Liss3 scene, obtained from the National Remote Sensing Agency, Hyderabad, formed the base layer of the GIS. It has a spatial resolution of 23.5 x 23.5 m (a pixel) and consists of four spectral bands. Light reflectance for each pixel is measured in each of the four bands and assigned a digital value from zero to 255. All bands (see table 3.1) were used for analysis. A second satellite image from a 19. February 1993, IRS 1A Liss I scene with a spatial resolution of 70.5 x 70.5 m was visually interpreted to see if larger land cover changes had taken place.

Table 3.1. Liss I and Liss III sensor characteristics

Liss I	Liss III	Spectral Bands	Wavelength Range
Band 1	ABSENT	Visual Blue	0.45-0.52 µm
Band 2	Band 1	Visible Green	0.52-0.59 µm
Band 3	Band 2	Visible Red	0.62-0.68 µm
Band 4	Band 3	Near Infrared (NIR)	0.77-0.86µm
ABSENT	Band 4	Short Wave Infrared (SWIR)	1.55-1.70 µm.

The satellite image was georeferenced to UTM, WGS 84 zone 43, using the Earth Resource Data Analysis System (ERDAS Imagine Inc., Atlanta, Ga.) after which the study area was subset from the raw IRS digital data.

To arrive at terrain features and vegetation type from the satellite image some enhancement techniques were used. Radiometric corrections were applied to the IRS image using the dark pixel subtraction technique. In this techniques the NIR pixel values of dark pixels usually representing water bodies are observed and then subtracted from the entire image to remove the effect of haze. The SWIR band was removed during Radiometric corrections as it has a coarser resolution of 70.5m.

To delineate vegetation the normalized different vegetation index (NDVI) was computed using the band ratio technique. The NDVI is a common remotely sensed measure of vegetation quality and quantity (Foley 2002) and is determined by vegetation density and greenness (Ernest 1997). The NDVI is calculated by dividing the difference between band 2 and 3 with the sum of the two bands:

$$NDVI = NIR - Visual\ Red / NIR + Visual\ Red$$

Generally, higher NDVI values signify greater vegetation vigour and dense vegetation cover.

Two classification methods were conducted. First unsupervised classification (a clustering methods that is used to group pixel spectral signatures into similar classes) was conducted on the IRS image using ERDAS Imagine. Then Visual interpretation was performed using all images, the raw image, the radiometric corrected image and the NDVI image. Previous classifications conducted by the Indian Space research organisation, Bangalore, as well as ground truth data was also consulted. During visual interpretation on screen digitisation of 13 land cover classes was performed at a scale of 1:1250 using ArcView and ArcGIS generating a polygon coverage

Constrained by the limited digital data available all thematic layers (elevation, contours, drainage, rainfall and roads) of the study area had to be generated. This was done with the help of satellite images, 1:50 000 topographic maps and literature of previous studies conducted. 1:50 000 topographic maps of the study area were mosaiced and georeferenced. Thematic data of the study area were digitised and entered into ArcView/ArcGIS. Contour intervals were set at 15.24 m. Rainfall contours and elephant home ranges were digitised from maps created by Lengerke (1976) and Anon (1989 ;1995) respectively. Using the ArcView extension Animal Movements 400 random points were generated within the home ranges. The number of points generated per home range were proportional to the home range size. This method assumes that more random points are chosen in overlapping home range areas. These random points were later used to generate environmental suitable areas.

A forest map and an urban area map were generated from the land cover map. These were converted to a distance to urban area and distance to forest area continuous raster map. Distance to road and distance to river maps were generated from their primary layers. A DEM was generated from the contours and elevation map. The DEM was further processed to a slope and aspect map. The rainfall contours were interpolated to a continuous raster layer. The eight home ranges were overlaid and overlapping areas were identified. This completed the primary and secondary layer creation.

A site visit to the study area was conducted in July 2003 to verify the preliminary results of GIS and remote sensing analysis. GIS map products and hard copies of the satellite image were carried into the field for ground truthing.

3.2.2. Data Processing

The overall area of elephant presence was characterised by subdividing it according to the number of overlaps of individual home ranges. For each category (areas with only one home range, areas containing two home ranges etc.) the area characteristic was analysed using the available environmental variables (slope, aspect, rainfall, distance from river, distance from roads, distance from forest and distance from urban areas.). This analysis was then used to select the environmental variables to feed into the ecological distance model.

Thematic layers containing the following environmental variables, land cover, rainfall, distance to rivers, distance to forests and distance to urban areas, were transformed into 100 m cell sized grid formats.

The area of different preference were characterised by performing simple overlay operations with the five thematic layers and calculating basic statistics. Percentage of cover was calculated for each class of the land cover map and the mean was calculated for the remaining continuous variables. To extend the results based on these training sets to the entire study area map algebra focal functions were used. Each raster was processed by assuming that each pixel was the centre of a hypothetical preferred area and by assigning to that pixel the same statistics used to characterise the training set. Each was calculated within a window of a 10 pixel radius. A 1 km radius gives an area of 316 ha which is close to 150% of the size of the most preferred area, were seven of the eight elephants were found. It is suggested that the focal area should optimally have the size of an average home range for habitat suitability modeling. As the average home ranges of the elephants in the area was 431km^2 (calculated from five elephants), which is an area covering 73% of the study area, this was not a feasible approach. The 316 ha window therefore represents an area a little larger than the proposed third-order selection.

3.2.3. Data Analysis

The processed grids were then used for further analysis. To find the ecological distance from the elephants optimal environmental conditions Mahalanobis distance was used.

The Mahalanobis distance is a very useful way of determining the similarity of a set of values from an unknown sample to a set of values measured from a collection of known samples. The Mahalanobis distance statistic is an abstract quantity representing a squared distance between two points in an abstract multidimensional space (see figure 3.1.). One of the main reasons the Mahalanobis distance method is used is that it is very sensitive to inter-variable changes in the training data. In addition, since the Mahalanobis distance is measured in terms of standard deviations from the mean of the training samples, the reported matching values give a

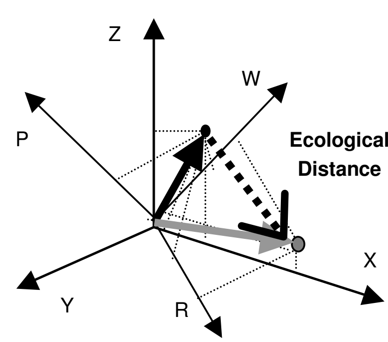

Figure 3.1. Graphical display of Mahalanobis Distance

statistical measure of how well the spectrum of the unknown sample matches the original training spectra.

As visual inspection is not a viable method for real world discriminant analysis applications. a mathematical equation is needed to measure nearness of the unknown point to the mean point of a group. Mahalanobis distance is computed in the following way:

$$D^2_t(x) = (x - m_t)S^{-1}_t(x - m_t)'$$

Were
D_t is the generalised squared distance of each pixel from the *t* group of observed localities (known training set),
S_t represents the within-group covariance matrix,
m_t is the vector of the means of the variables of the *t* group and
x is the vector containing the values of the environmental variables observed at location x (Corsi *et al.* 1999).

The result of using this algorithm with GIS is a single raster with the value of ecological distance from the species' "optimal" conditions, the higher the distance, the less suitable the pixel's ecological conditions.

Various thematic layer combinations were tried for the study area using Mahalanobis Distance and their results were compared to observe which environmental variables are more essential during environmental suitability modeling. Furthermore the results obtained directly from satellite images and those received from the land cover maps were compared as to find out which one closer represents the real world situation.

Lastly the model was applied on a much larger area using a slope map generated from a 90 m resolution DEM released by NASA and NIMA from the Shuttle Radar Topography Mission as well as the two satellite images (IRS 1D Liss 3, 2000 satellite and IRS 1A Liss 1, 1993 satellite). Results of the two time periods were then compared. NDVI and different band combinations were also tried.

3.2.4. Output Comparison

Continuous surfaces can be interpreted in many ways, therefore output layers can easily be displayed to show any desired result by grading the distance values in categories after ones liking. This of course is not a scientific approach and should be prevented at any cost. It is also important to display different outputs in such a way that they can be compared with each other to give sensible and correct results. The approach taken here was the following. For each output the mean and the first to eighth standard deviation of the area within the training set (area with seven home ranges, area with five+ home ranges or areas representing the random points) was computed. The entire output image then was sliced using the following intervals shown in table 3.2.

These intervals were chosen according to the Gaussian distribution represented in figure 3.2. Pixel values falling within the first standard deviation represent the most abundant 68% of the values, pixel values within the second standard deviation represent 95% of the most abundant values and excluded

Table 3.2. Intervals chosen for data representation

Interval	From	To
1	0	mean
2	mean	Mean + Std. Dev.
3	Mean + Std. Dev.	Mean + 2. Std. Dev.
4	Mean + 2. Std. Dev.	Mean + 4. Std. Dev.
5	Mean + 4. Std. Dev.	Mean + 8. Std. Dev.
6	Mean + 8. Std. Dev.	end

5% of the data which was being represented least, whereas the third and consecutive standard deviations excluded less than 0.3 percent of the least represented pixel values.

This categorisation was chosen as the Gaussian distribution is most commonly observed and it is the starting point for modeling many natural processes. It usually is found in events that are the aggregation of many smaller, but independent random events. This theorem tells us that sums of random variables are approximately normally distributed if the number of observations is large. Even when a distribution may not be exactly normal, it may still be convenient to assume that a normal distribution is a good approximation. In this case many statistical procedures can still be used.

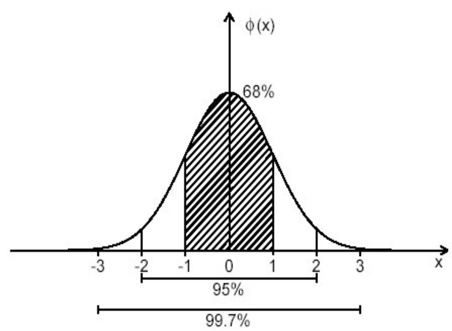

Figure 3.2. Gaussen distribution showing the mean and the first, second and third standard deviation.

3.3. Results and Discussion

The IRS ID Liss III image from 2000 was visually compared to that of the IRS 1A Liss I image from 1993. Land cover changes could not be observed. As the Liss III image was more advanced with a higher resolution it was used as the base image for further research.

Two classifications were conducted on the satellite data. The unsupervised classification was of poor quality as many areas were misclassified. Pixels of different classes were grouped into one. Results obtained by visual interpretation gave more accurate results. This classified image showed an accuracy of 63.5% derived from 63 GCP. Most GCP's were recorded in the Dry Deciduous forest or agricultural fields. During classification urban area and agricultural land were grouped into one class, as they were not distinctive classes. One class (riparian vegetation) was not considered while conducting ground truthing, instead the surrounding vegetation type was recorded. This accounted for four misclassifications. Six further misclassified points were found within 100m of its respected class. Errors here could have derived due to the inaccuracy of the hand held Garmin, 12 Channel GPS. When discarding these 10 points the classification showed an accuracy of 75.5%. Most classification errors were found in the transitions zones between Semi-evergreen, Moist Deciduous, Dry Deciduous and Scrub forest. During Fieldwork ground classification of the vegetation type in the transitional areas was a difficult task and misclassifications on ground should also be considered as a good possibility as the vegetation types gradually flowed into each other and distinctive boundaries could not be observed. During visual interpretation previous land classifications of the area were also taken into account. The output of the visual interpretation was used for further studies.

After subdividing the overall area of elephant presence into the number of overlaps of individual home ranges (see figure 3.2), seven categories could be identified. These ranged from areas inhabited only by one elephants to an area that was used by seven of the eight known elephants. According to the area characteristic (range of environmental variables) of these area categories one could observe that aspect had no influence on elephant distribution and hence habitat preference of the animal. Distance to roads showed a strong correlation with distance to rivers as the Moyar River (main water source) ran along side a main road. Therefore aspect and distance to road were discharged from further studies.

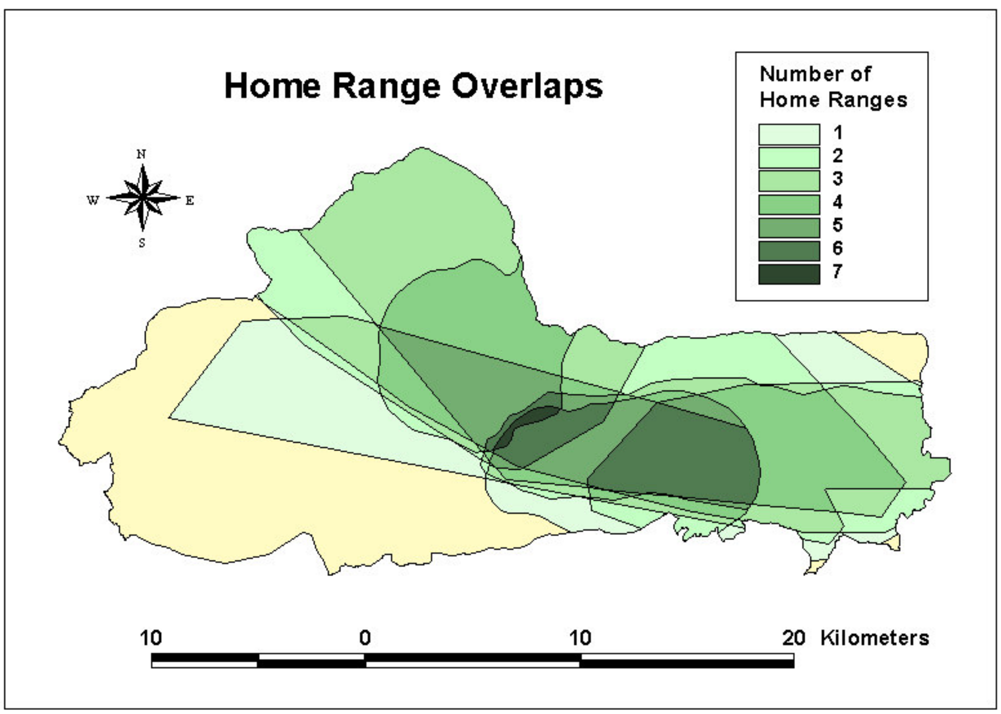

Figure 3.2. Number of elephants present, from the known eight individuals in the study area

Various thematic layer combinations were tried for the study area. Comparison between Liss III satellite bands were made as well as comparison between outputs with different environmental variables and between the raw satellite image and the classified coverage were conducted. Output and between the raw satellite image and the classified coverage were conducted. Output were also obtained using the area with seven home ranges, areas with five and more home ranges and areas represented by the random points as a observations dataset. Table 3.3 and 3.4 shows a list of the different outputs obtained and the data that was used.

Table 3.3. Main outputs obtained from the study area.

Outputs	*OD	Satellite	Land cover	Environmental Variables (EV)
1	7	X	5 classes	all
2	7	X	5 classes	slope
3	5+	X	8 classes	all (slope, rainfall, dist. to rivers, -forest & - urban areas)
4	5+	X	8 classes	slope
5	5+	X	8 classes	slope, rainfall, dist. to rivers
6	5+	X	8 classes	slope, dist. to forest, dist. to urban areas
7	5+	X	8 classes	slope, rainfall, dist. to rivers, dist. to forest
8	7	Sat 2000	X	slope
9	5+	Sat 2000	X	slope
10	** RP	Sat 2000	X	slope
11	7	G Band	X	slope
12	7	R Band	X	slope
13	7	NIR Band	X	slope
14	7	SWIR Band	X	slope

*OD = Obervations Dataset
**RP = Random Points

Table 3.4. Main outputs obtained from the applied area.

Outputs	OD	Satellite Year	Bands	EV
15	7	2000	All (G,R,NIR,SWIR)	Slope
16	5+	2000	All (G,R,NIR,SWIR)	Slope
17	Random Points	2000	All (G,R,NIR,SWIR)	Slope
18	Random Points	1993	All (B,G,R,NIR)	Slope
19	Random Points	2000	G, R, NIR	Slope
20	Random Points	1993	G, R, NIR	Slope
21	Random Points	2000	R, NIR (NDVI)	Slope
22	Random Points	2000, 1993	G, R, NIR (Change Detection)	Slope

B = Blue, G = Green, R = Red, NIR = Near Infrared, SWIR = Short Wave Infrared
EV= Environmental Variables
OD = Obervations Dataset

3.3.1. Result Comparison

In this section the outputs derived are compared and described. When referred to as ‘better’, this implies closer representing the real world scenario as it was assessed during fieldwork. In the areas outside of the study area it should be noted that the model only identifies potential habitat, but does not imply that the species is actually present at a given location. Stochastic processes, such as disturbance, weather fluctuations or population dynamic, can prevent otherwise suitable habitat from being occupied (Stoms *et al.* 1992).

Comparison between observations datasets: Various observations datasets were used for modeling. The area containing seven home ranges (Observations dataset 7) was chosen first as it was assumed that this is the most preferred region for elephants in the study area. Due to its very small size of 199 ha it was fairly homogenous not allowing for much environmental variation. Results obtained with this observations dataset (output 1, 2, 8) did not represent the real world scenario as only this area was classified as suitable, even when applying this model on the larger area of 13547 km^2 (output 15) no other suitable areas could be found. Results obtained using an observation dataset representing the areas containing six and more home ranges gave similar results, were as areas containing five and more home ranges (Observations dataset 5+) included more environmental variety and showed closer results to the real world scenario (output 9, 16). A further observations dataset (Observations dataset RP) was prepared later for the applied area. This observations dataset consisted of random points generated within each home range (points were also in those regions outside of the study area). When comparing the results (output 10, 17) to elephant occurrences (information established during field work) close resemblance could be found.

Small homogenous areas should not be chosen, they should only be considered when dealing with animal with highly specified environmental needs, and not when dealing with generalists such as the elephant, which inhabits a wide range of habitats.

Comparison between environmental variables: Outputs 3 to 7 are the results obtained by using different variables. In all outputs the land cover image and Observations dataset 5+ was used. All models included the environmental factor 'slope' as it can be assumed to be a limiting factor (e.g. elephants can not climb extreme slopes). Comparing output 3, 5 and 6 it can be seen that distance to urban created bias results. A small village was contained in the area of five home range overlaps and therefore forest areas that were not within close proximity of urban areas were classified less suitable (northern parts of output 3 and 5). From observing elephant occurrences in the study area one can derive that urban areas do not have an effect on elephants, they do not depend on villages nor do they get disturbed by villages. As most home range included urban areas the environmental variable 'distance to forest' was incorporated in some models. When comparing output 6 and 7 it can be clearly seen that the presents or absence of this variable gives nearly the same results. It therefore did not affect the model in any significant way. Including distance to river and rainfall in the model only had an effect on a small area on the north east side of the study area (comparison between output 4, 5, and 6). The largest effect here is obtained through rainfall as precipitation increased in this area. Rainfall and distance to rivers should only be incorporated in a model if the area suffers from severe draughts and water sources are scarce. This is not the case in the study area therefore their incorporation into the model will lead to bias results. The model does not deferential between more or less rainfall it only calculates the distance from the optimal. It would be more correct if only areas of less rainfall would be regarded as less suitable and areas of more rainfall should be set even with the optimum. The result that was deviating most from the real world scenario was that which included all environmental variables (output 3 whereas the most accurate results were obtained from the model were only slope was taken into account.

It can be assumed that using less environmental variable will give more accurate results as less bias and uncertainty is then incorporated in the model.

Comparison between classified image and satellite image: While using a classified image in this modeling approach each class is assumed to be a separate entity without any relationship. In this case for example urban areas would be classified as suitable as they fall within the observations dataset but Shola forest will not. It can be believed that any kind of forest would be more suitable for elephants than a built up area such as a large city. The model would not reflect that. If the environmental factor 'distance to forest' would be incorporated in this model the output would show higher suitability for the surrounding areas of the Shola forest but would show not suitable for the actual forest, which again is incorrect. If using a satellite image instead of a classified image the output would be very different. All forest will show similar spectral values, therefore areas that are not found within the observations dataset can still be accounted for and will not be classified as not suitable. Using satellite images also eliminate the creation of errors that occurs during classification. According to Stoms *et al.* (1992) even a 5 percent change in classification accuracy of a land-cover map can make a significant difference in levels of habitat suitability index.

Comparison between different satellite Bands including NDVI: The four bands of the Liss III sensor are illustrated in output 11 to 14. In these results the raw satellite image was used without calculating the mean of the focal window. It can be seen that the near infrared band gives best results as it incorporated the scrub forest in the south eastern parts of the study area in its suitable areas and it excludes more of the urban area at the south-western region of the study area. Best results were achieved using the green, red and infrared band in both the Liss I (output 20) and the Liss III (output 19) image, although little difference was seen when comparing it with the images that include the short-wave infrared band of Liss III (output17) and the Blue band of Liss I (output 18). Using NDVI for deriving a habitat suitability index is not advised as all agricultural areas and plantations or included in the most suitable areas (output 21).

Comparison between two time periods: Using the green, red and infrared bands of a Liss I and of a Liss III image from February 1993 and December 2000 respectively suitability changes could be observed (output 22). Both increase and decrease can be observed. When visually comparing output 19 (2000) and output 20 (1993) it appears that suitability has increased slightly since 1993. This could be due to the fact that the 1993 satellite image was taken at the end of the dry season wherefore the 2000 satellite image was taken after the rainy season.

Third order selection areas (preferred areas within a home range) should be chosen in a more accurate way by for examples analysing raw tracking data and identifying areas that are transverse more often by more elephants for longer periods of time. Simply overlaying home ranges and using overlapping areas is an approach that integrates a higher amount of uncertainty and biasness. In the two studies conducted from which the home ranges were derived it was not stated how the elephants were chosen. In the radio tracking study therefore it might have been that elephants were chosen randomly from one area, accounting for there home range overlays and that if elephants were chosen from an entirely different area the presumed preferred area would have been entirely different. In the first study when sightings were used to determine home ranges the estimated home ranges may tell more about the preferences of the observers than of the wildlife. As all three home ranges were found in easily accessible areas with more human presents.

For first order selection areas (range of species) the above approach is more suitable, this approach is also easier to validate as only the presence or absence of the species has to be recorded.

3.3.2. Model Accuracy

Habitat evaluation has been criticised because of its assumed poor accuracy (de Leeuw & Albricht 1996). The relatively low accuracy reflects the complexity of topography and vegetation in an area and the difficulty in capturing that complexity at a relatively small map scale (Storms e*t al.* 1992). The model outcomes have rarely been validated, although it has clearly been advised in the habitat evaluation procedures. The overall reliability depends on how well the output corresponds to reality. This overall reliability is determined by two sources of error. These could be errors contained in the spatial database, which may be subdivided into geometric and thematic, or errors generated by the habitat suitability model. The reliability of such a model depends on the selection of the relevant variables, and an unbiased estimation of the model parameters (de Leeuw & Albricht 1996). There will be uncertainty in the GIS output product due to error and uncertainties in data inputs. Tracking the propagation of errors as several map layers are combined into a habitat suitability map is often beyond our capabilities (Storms e*t al.* 1992).

Chapter 4

CONCLUSION

4.1. Main Research Findings

In which areas do elephants occur?
It was found that elephants occurred throughout the study area. All villages visited observed elephants in the vicinity. According to the Tamil Nadu Forest Department elephant concentrations were the highest in the protected areas. In the fringe areas between natural vegetation and human populated areas elephants were very commonly seen while passing through and destroying crops and sometimes killing people. Elephant were also sighted in areas more than 3 km away from natural forests. Elephant concentrations were the lowest in the developed areas in the south/southwest region of the study area.

Which environmental variables show the highest correlation with elephant distributions?
Elephant distributions were best modelled using only a DEM and a Satellite image. Using classified images in the model created errors and it is advised to work directly with satellite images. This will not only save time but it will also give more accurate results. In short land cover (optioned by a satellite) and slope were the variables that best represented elephant distributions in the north-western part of the Nilgiri Biosphere Reserve.

Is it possible to make a model for suitable habitat with limited data available?
It is possible to create a model with limited data. It was found that less environmental variables give better results as less biasness and correlation between environmental variables is introduced. Data should however be very precise as the accuracy of the model depends on the accuracy of its input.

What are the limitations and possibilities of using this model? - How can one improve this model?
Preferred areas (third order selection) could not be determined by using overlapping home range areas. More precise information is needed to acquire preferred areas of elephants in the field. This could be done by analysing tracking data of elephants found in places with environmental variation. The model however is suitable for determining elephant ranges (first order selection).

Variables with a continues nature created biasness in the model as their suitability decreases when deviating from the optimum, as it was defined. In a few cases this would be true but in many incidences deviating only from one margin (either more or less) would give accurate results. Eg., if the optimum area for the elephant was located 200 meters from a river, 50 meters should not have been classified as less suitable but 250 m should have. Such variable should not be incorporated into this model, instead they could have been added to the output later by excluding areas that surpassed the optimum threshold.

Is there a change in environmental suitability for elephants in Southern India?
The world is a dynamic place were change is a continues process. Minor changes in suitability have been observed. In some areas suitability have increased whereas in other areas it has decreased. It can be assumed that the changes are due to seasonal factors and that the suitability for elephants in this region of the Nilgiri Biosphere Reserve has not been altered in any significant way since 1993.

4.2. Improvements and Further Research Suggestions

The robustness of the model could have been tested by applying sensitivity analysis. Here many outputs with different random points could have been generated to observe if the models results were robust. Other methods such as calculating the variance instead of the mean during focal functions could also have given additional information by showing heterogeneous and homogenous regions. It can be assumed that forest would be classified as more homogenous than urban areas.

There will always be uncertainty in GIS output products due to errors and uncertainties in data input. Sources of uncertainty could be loss of detail from spatial generalisation, similar loss of detail due to the level of precision of the classification system, errors in class label or boundary location and choosing a study area that is unrepresentative of the entire range (Stoms *et al.* 1992). These aspects could have been given more attention so that to reduce the error expected in this habitat modeling. Researching these aspects could have given partial insight on how much error was introduced and could have assisted it validating the results.

Further research should be conducted on how to standardise model outputs for a more accurate comparison. Environmental Suitability is continuous in nature. Any place on earth could be given a suitability index value although small for elephants, investigating the actual threshold of a species environmental requirement or tolerance, and therefore their optimal or intolerable suitability index, would be a huge step in environmental suitability analysis.

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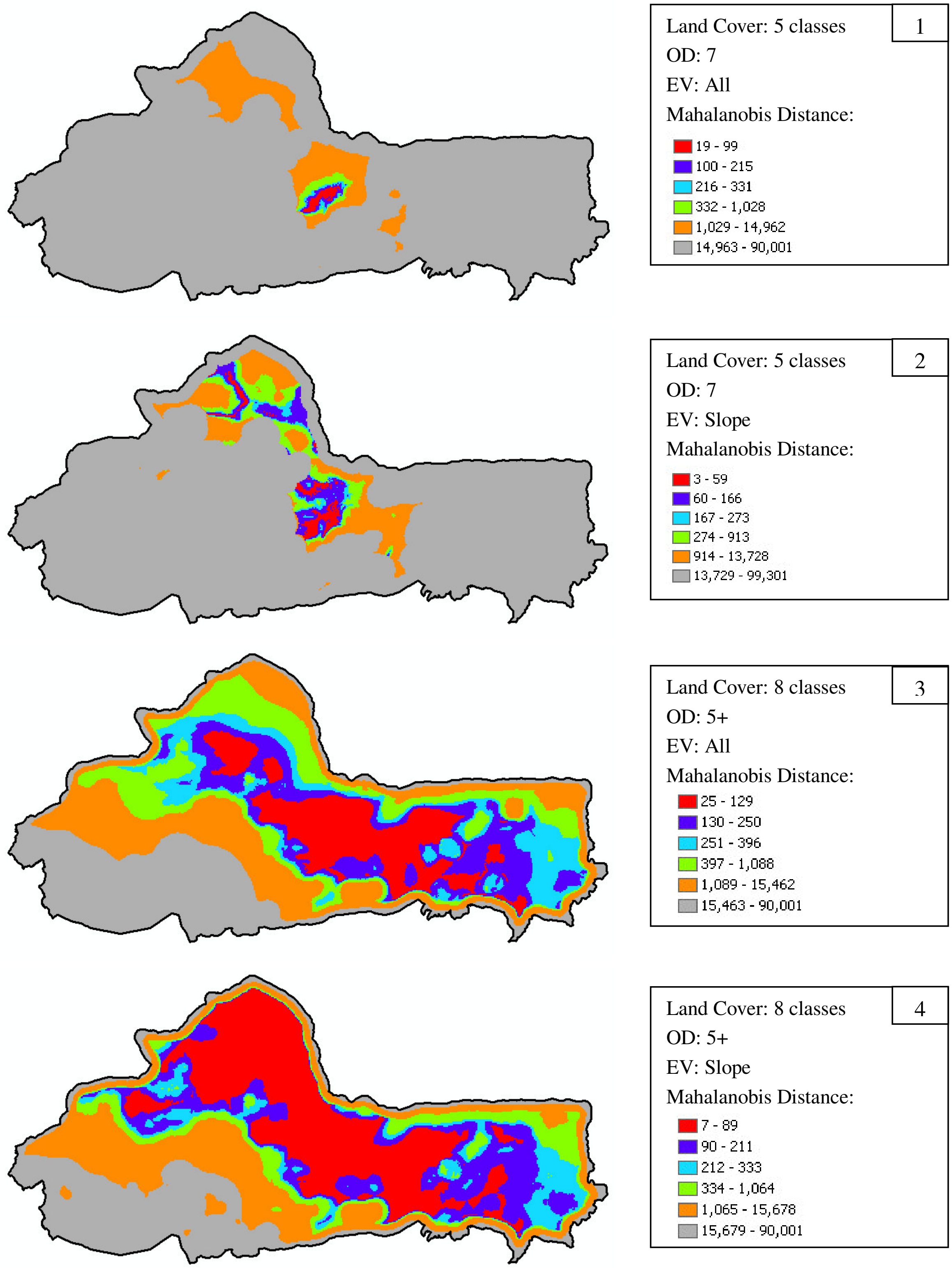
DEM Source for the Applied Area: ftp://edcftp.cr.usgs.gov/pub/data/srtm

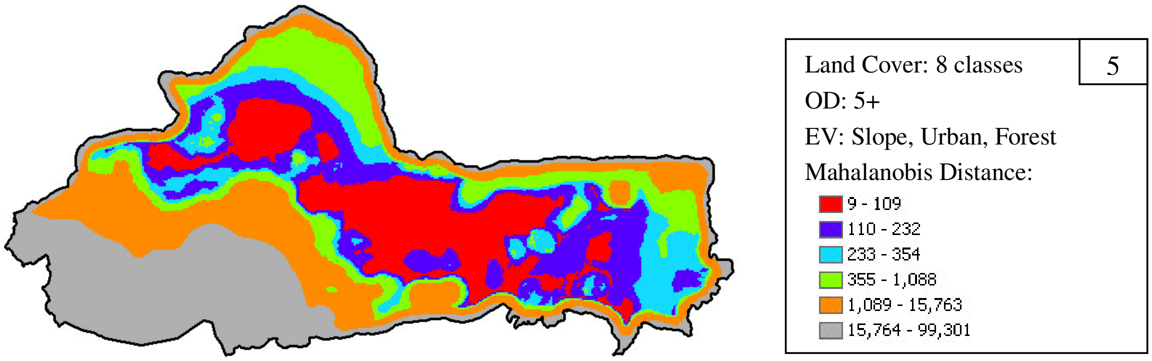
APPENDIX

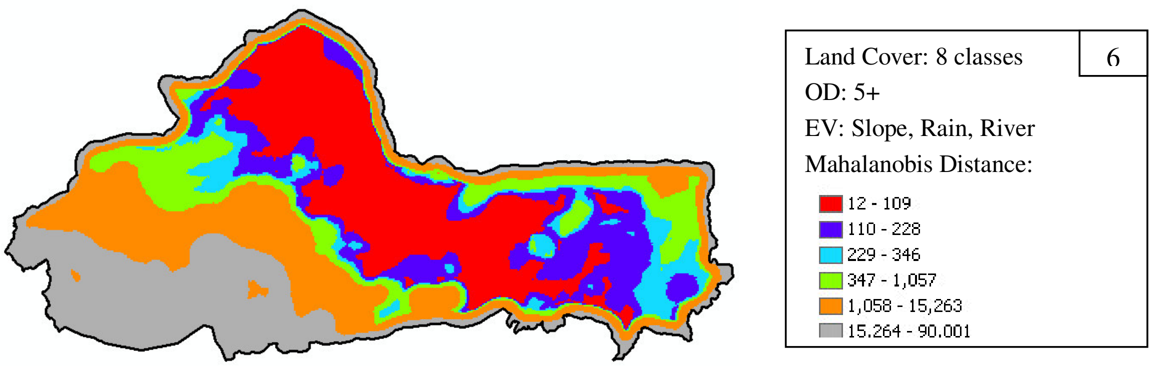
- MOST SUITABLE
- SUITABLE
- LESS SUITABLE
- LESSER SUITABLE
- LEAST SUITABLE
- NOT SUITABLE

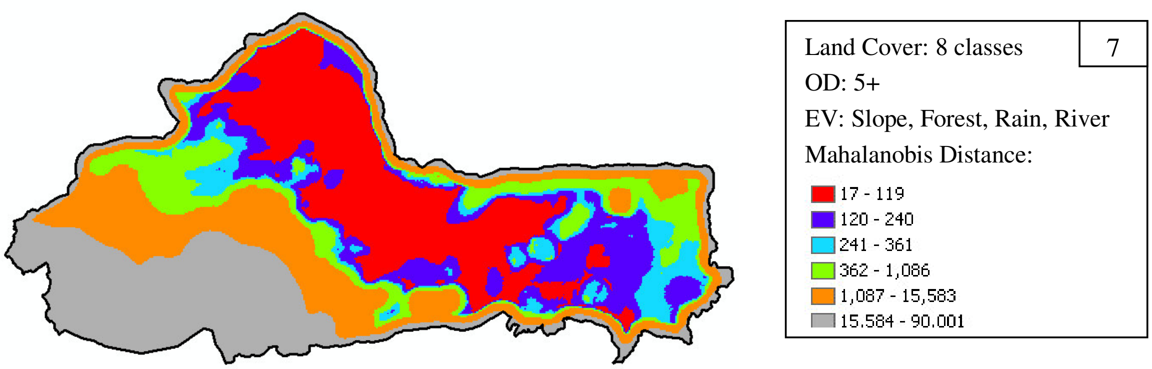
1 **Output number**

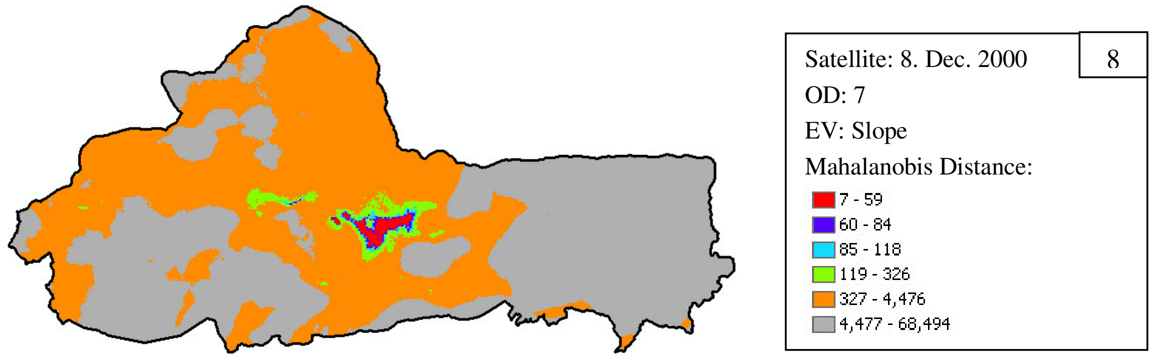
OD = Observations dataset
EV = Environmental Variable
Land cover classes refer to number of classes taken into account
(Only classes that were present within the mask could be taken into account)

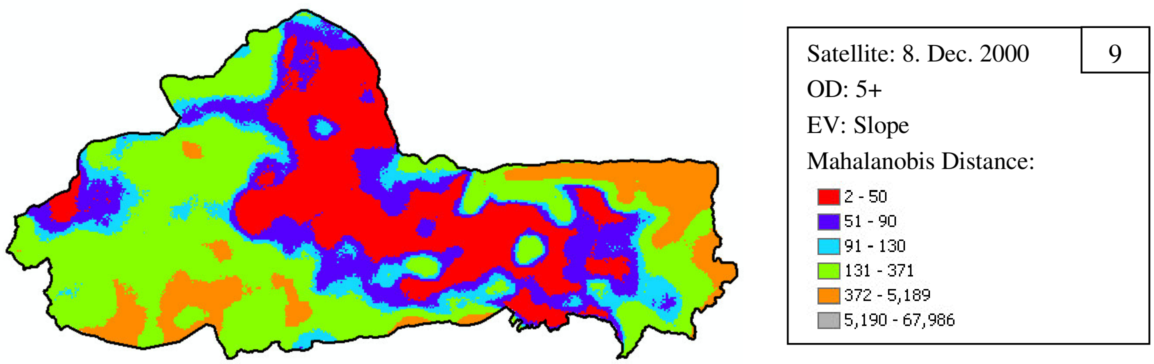

Land Cover: 5 classes
1
OD: 7
EV: All
Mahalanobis Distance:
19 - 99
100 - 215
216 - 331
332 - 1,028
1,029 - 14,962
14,963 - 90,001
Land Cover: 5 classes
2
OD: 7
EV: Slope
Mahalanobis Distance:
3 - 59
60 - 166
167 - 273
274 - 913
914 - 13,728
13,729 - 99,301
Land Cover: 8 classes
3
OD: 5+
EV: All
Mahalanobis Distance:
25 - 129
130 - 250
251 - 396
397 - 1,088
1,089 - 15,462
15,463 - 90,001
Land Cover: 8 classes
4
OD: 5+
EV: Slope
Mahalanobis Distance:
7 - 89
90 - 211
212 - 333
334 - 1,064
1,065 - 15,678
15,679 - 90,001

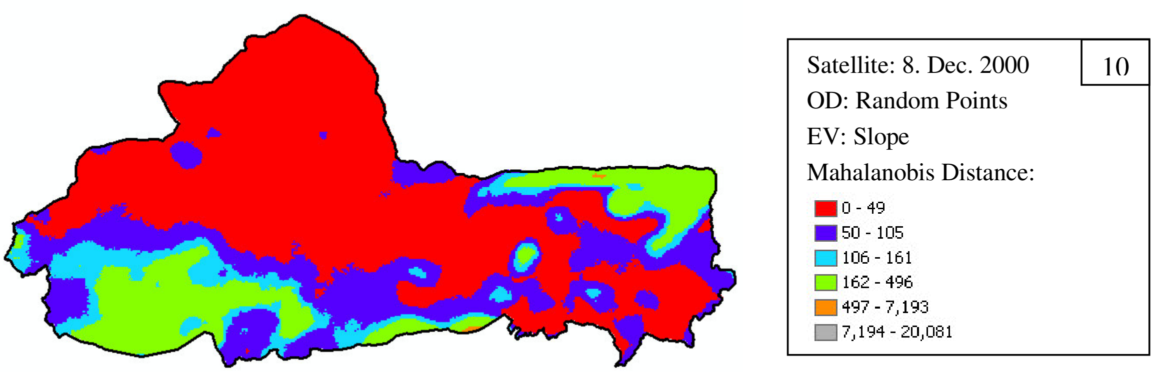

5
Land Cover: 8 classes
OD: 5+
EV: Slope, Urban, Forest
Mahalanobis Distance:
9 - 109
110 - 232
233 - 354
355 - 1,088
1,089 - 15,763
15,764 - 99,301

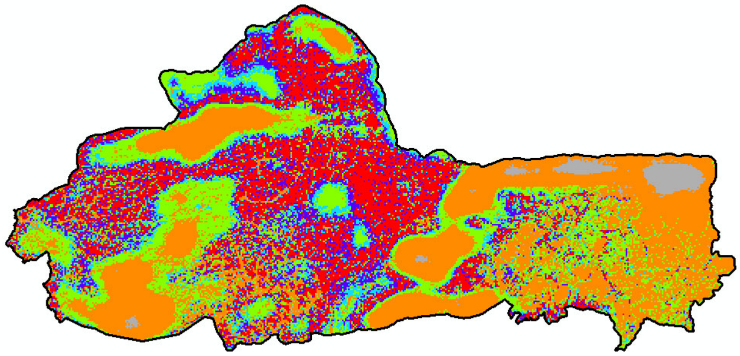

6
Land Cover: 8 classes
OD: 5+
EV: Slope, Rain, River
Mahalanobis Distance:
12 - 109
110 - 228
229 - 346
347 - 1,057
1,058 - 15,263
15.264 - 90.001


7
Land Cover: 8 classes
OD: 5+
EV: Slope, Forest, Rain, River
Mahalanobis Distance:
17 - 119
120 - 240
241 - 361
362 - 1,086
1,087 - 15,583
15.584 - 90.001


Satellite: 8. Dec. 2000
8
OD: 7
EV: Slope
Mahalanobis Distance:
7 - 59
60 - 84
85 - 118
119 - 326
327 - 4,476
4,477 - 68,494


Satellite: 8. Dec. 2000
9
OD: 5+
EV: Slope
Mahalanobis Distance:
2 - 50
51 - 90
91 - 130
131 - 371
372 - 5,189
5,190 - 67,986

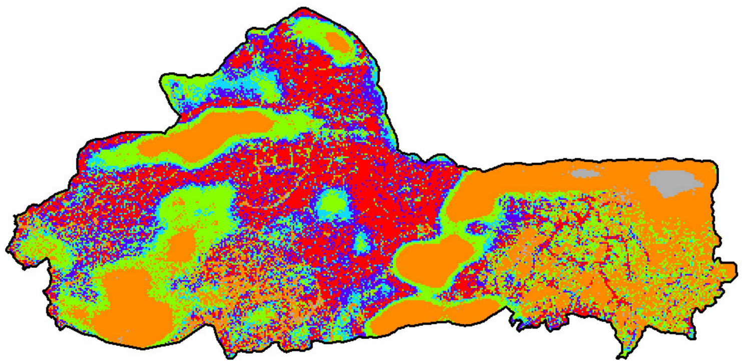

Satellite: 8. Dec. 2000
10
OD: Random Points
EV: Slope
Mahalanobis Distance:
0 - 49
50 - 105
106 - 161
162 - 496
497 - 7,193
7,194 - 20,081



11

Satellite: 8. Dec. 2000
Band: 1 (G)
OD: 7 , EV: Slope
Mahalanobis Distance:

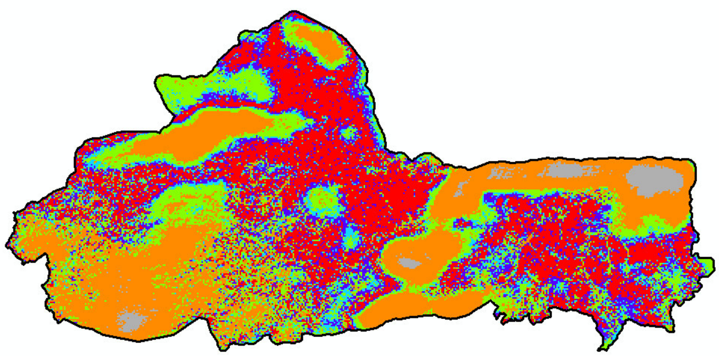
- 0 - 20
- 21 - 38
- 39 - 56
- 57 - 167
- 168 - 2,372
- 2,373 - 13,558



12

Satellite: 8. Dec. 2000
Band: 2 (R)
OD : 7 , EV: Slope
Mahalanobis Distance:

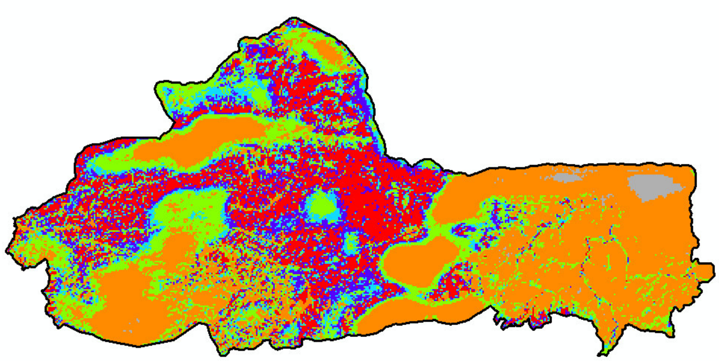
- 0 - 19
- 20 - 42
- 43 - 65
- 66 - 203
- 204 - 2,958
- 2,959 - 16,425



13

Satellite: 8. Dec. 2000
Band: 3 (NIR)
OD: 7 , EV: Slope
Mahalanobis Distance:

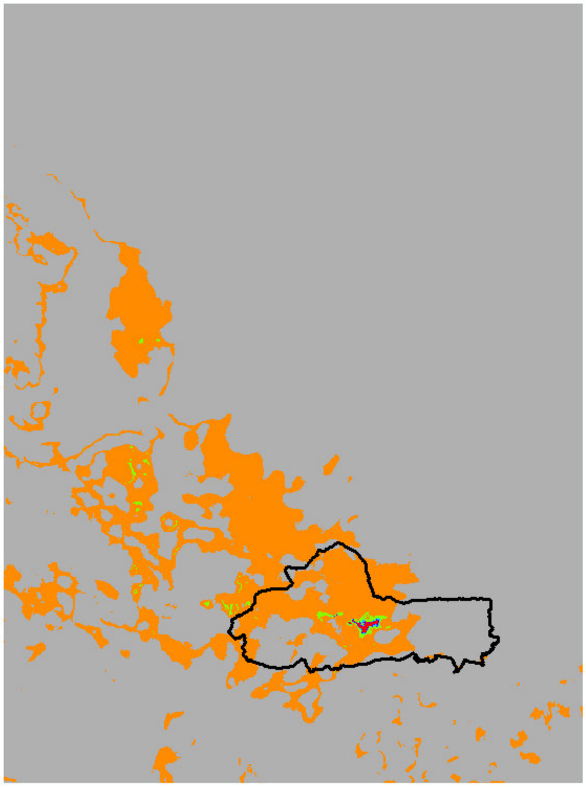
- 0 - 20
- 21 - 42
- 43 - 65
- 66 - 199
- 200 - 2,889
- 2,890 - 7,252



14

Satellite: 8. Dec. 2000
Band: 4 (SWIR)
OD: 7 , EV: Slope
Mahalanobis Distance:

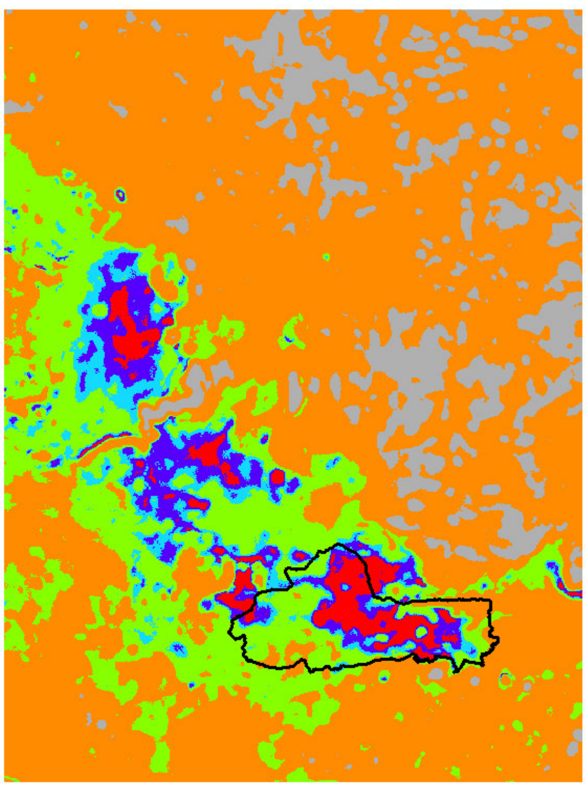
- 0 - 20
- 21 - 42
- 43 - 65
- 66 - 202
- 203 - 2,944
- 2,945 - 5,731



15

Satellite: 8. Dec. 2000
Bands: All
OD: 7
Mahalanobis Distance:

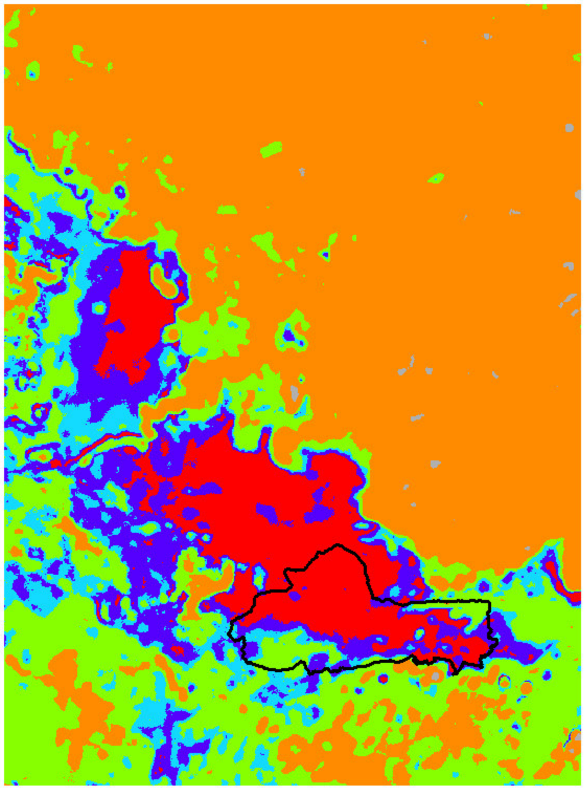
- 7 - 59
- 60 - 84
- 85 - 118
- 119 - 326
- 327 - 4,476
- 4,477 - 68,494



16

Satellite: 8. Dec. 2000
Bands: All
OD: 5+
Mahalanobis Distance:

- 0 - 50
- 51 - 90
- 91 - 130
- 131 - 371
- 372 - 5,189
- 5,190 - 67,986



Satellite: 8. Dec. 2000

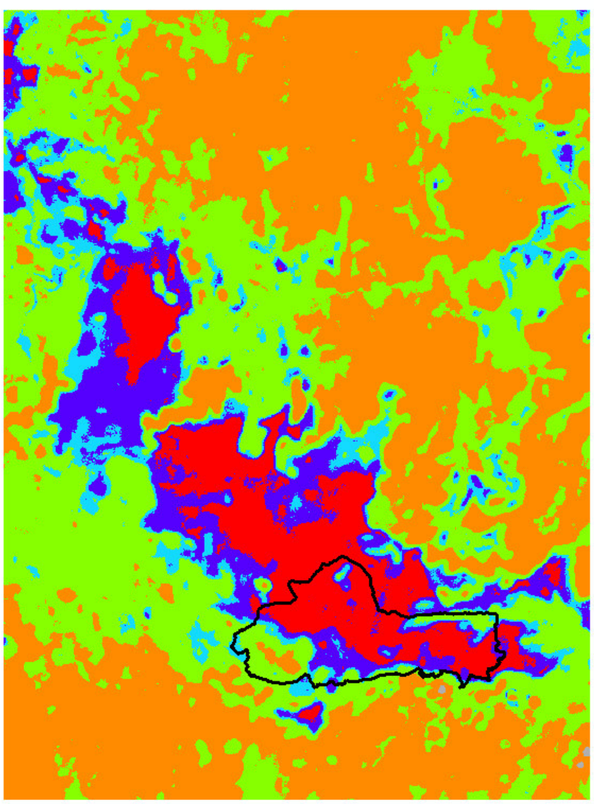
17

Bands: All

OD: Random Points

Mahalanobis Distance:

- 0 - 49
- 50 - 105
- 106 - 161
- 162 - 496
- 497 - 7,193
- 7,194 - 20,081



Satellite: 19. Feb. 1993

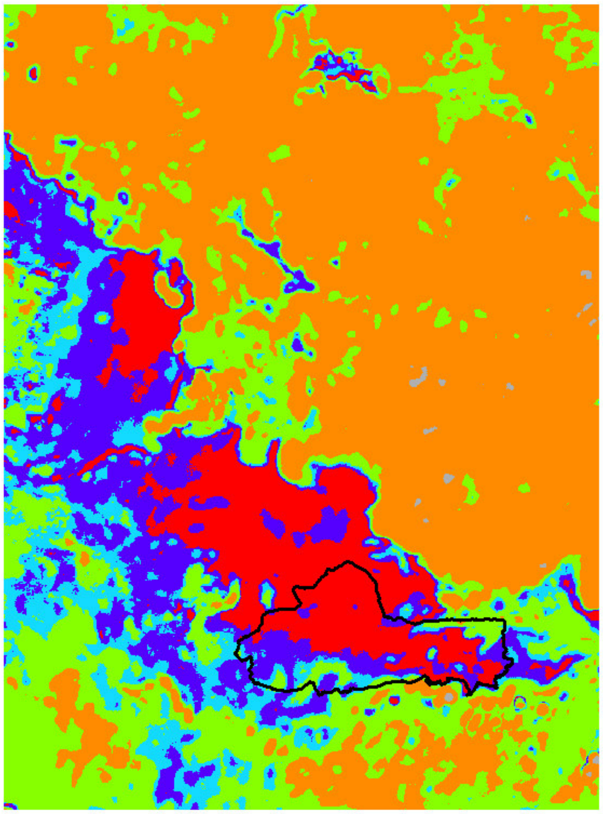
18

Bands: All

OD: Random Points

Mahalanobis Distance:

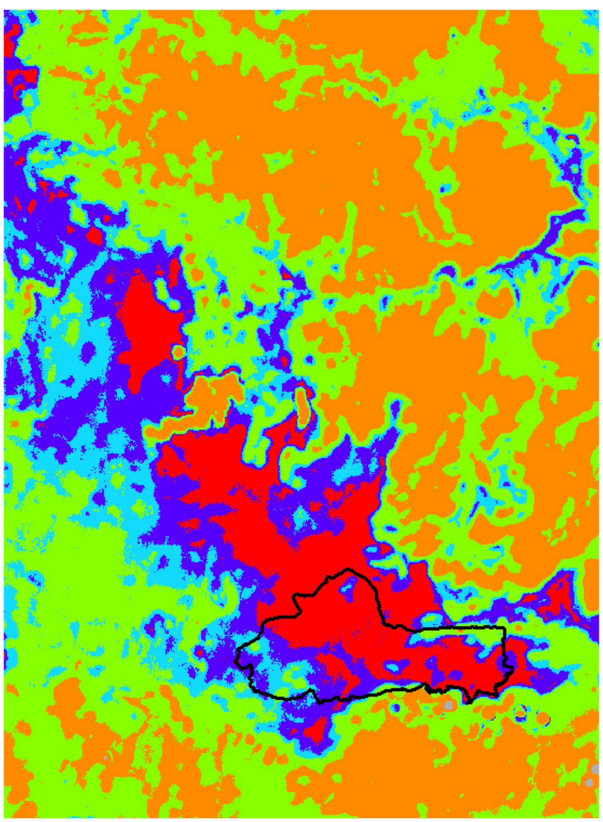
- 0 - 49
- 50 - 116
- 117 - 184
- 185 - 586
- 587 - 8,629
- 8,630 - 25,871



19

Satellite: 8. Dec. 2000
Bands: 1, 2, 3
OD: Random Points
Mahalanobis Distance:

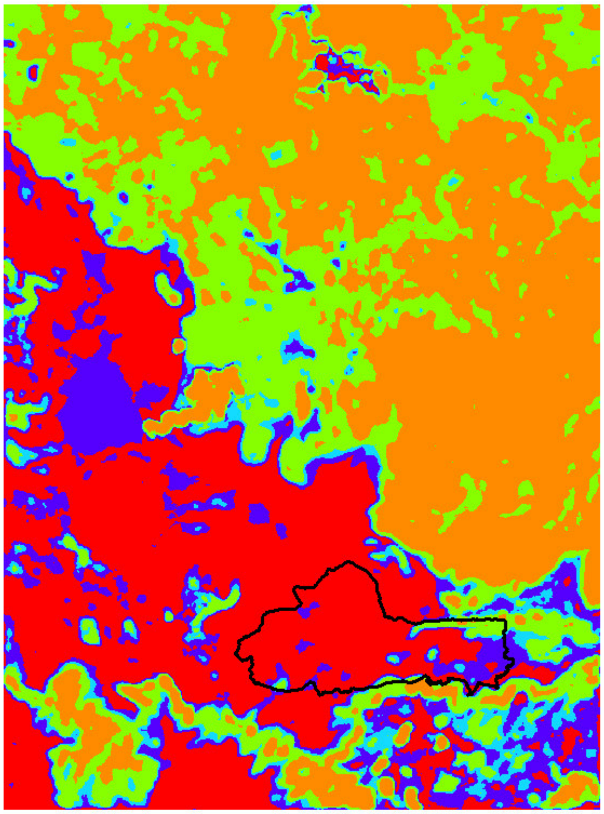
- 0 - 39
- 40 - 86
- 87 - 133
- 134 - 412
- 413 - 6,004
- 6,005 - 17,527



20

Satellite: 19. Feb. 1993
Bands: 2, 3, 4
OD: Random Points
Mahalanobis Distance:

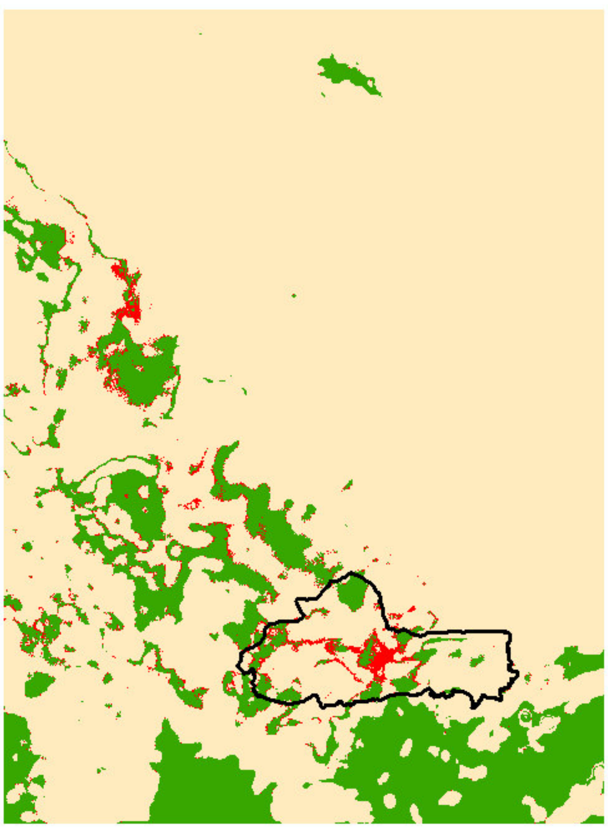
- 0 - 40
- 41 - 94
- 95 - 149
- 150 - 476
- 477 - 7,021
- 7,022 - 25,432



21

Satellite: 8. Dec. 2000
Bands: NDVI
OD: Random Points
Mahalanobis Distance:

- 0 - 20
- 21 - 53
- 54 - 86
- 87 - 284
- 285 - 3,023
- 3,024 - 4,247



Change detection of Environmental Suitability for elephants between Februrary 1993 and December 2000:

- Decrease
- No Change
- Increase

22