Effect of change in land use and land cover on elephant habitat and corridor in Lower Shivaliks area of Uttarakhand

APOORVA MARIA
March, 2014

ITC SUPERVISOR
Dr. Ir.T.Groen

IIRS SUPERVISORS
Dr .A.Roy
Dr.Stutee Gupta

Effect of change in land use and land cover on elephant habitat and corridor in Lower Shivaliks area of Uttarakhand

APOORVA MARIA
Enschede, The Netherlands [March, 2014]

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geoinformatics

THESIS ASSESSMENT BOARD:

Chairperson	: Prof. Dr. Ir. V.Jetten
External Examiner	: Dr. M.C Porwall
ITC Supervisor	: Dr. Ir. Thomas Groen
IIRS Supervisor	: Dr. Arijit Roy
IIRS Supervisor	: Dr. Stutee Gupta
ITC Observer	: Dr. N.A. Hamn
IIRS Observer	: Dr. P.K Champati

Indian Institute of Remote Sensing
Indian Space Research Organisation
Department of Space, Government of India,
ISO 9001-2008 Certified

FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION,
UNIVERSITY OF TWENTE,
ENSCHEDE, THE NETHERLANDS

ABSTRACT

Asian elephant has been a species of high mythological and ecological importance to the Asian subcontinent but due to perpetual interference by humans the habitat of this pachyderm has shrunk down and the population has taken a toll. Shiwalik elephant reserve covering parts of Uttarakhand and Uttar Pradesh state of north western India in particular has faced gradual increase in man elephant conflicts and therefore was chosen as the area of study. The main forest types in the study area are Himalayan moist temperate, Himalayan sub tropical pine, Moist sal, Northern dry Mixed deciduous and Sub tropical broadleaved hill. The use of potential vegetation scenario is novel in context to large mammals and forms the basis of this study. Using spatial data on LULC, climatic and topographic regimes, along with GPS locations of elephant movement and conflicts, the potential regions of the human elephant conflicts have been modelled.

The approach used was to model the potential vegetation map of the region (a hypothetical scenario without human interference and land use) with help of climatic and topographic information and comparing the modelled potential corridors for the two scenarios. Maximum entropy based species distribution model (MaxEnt) was used to predict elephant distribution in the area followed by Least Cost Path analysis to find out the least resistant path used by elephants.

The highlights of study were 1)MaxEnt gave a high probability distribution of elephants in Rajaji national park and Lansdowne forest division 2) A significant shift in the potential corridor was observed from potential to present vegetation as a result of various land use practises. 5) Regions in Dehradun and Haridwar district were observed to be liable to high degrees of Human Elephant Conflict (HEC)

ACKNOWLEDGEMENTS

I would start by thanking God for granting me with perseverance and my parents for being immensely supportive and cooperative throughout the research.

I thank IIRS the institution, Director IIRS Dr.Y.V.N Krishna Murthy, course –coordinator of NHDRM Dr.P.K Champati Ray ,Head Forest and ecology department(FED) Dr.S.P.S Kushwaha.

I am highly thankful to my IIRS supervisor Dr.Arijit Roy who has shown faith in me and my work and has been a mentor for this research. I would also like to thank my co-guide at IIRS Dr. Stutee Gupta who has been very motivating. I express my gratification towards Dr.T.Groen, my ITC supervisor for being patient and cooperating at every front.

My sincere thanks to the Department of Forestry and Ecology for providing me with all the support for carrying out the study. I am also thankful to the Forest departments of Uttarakhand and Uttar Pradesh with utmost regards to director Rajaji National Park Mr. S.P Subudhi (I.F.S). I also appreciate the support of Wildlife Institute of India (WII) for providing me with literature.

I acknowledge the help and support of my colleagues and friends Ranjeev, synergy of Soumya Rajan and Kimeera Tumala, Joyson Ah. , Akhil Kallepali, Yeshu Sharma and Dhruwal for being supportive at various fronts.

I would take the opportunity to appreciate myself for not giving up, when I could have and believing in my capabilities. Last but not the least I would also extend my hand for thanking Juno, my dog who although can't read this, but has been instrumental in my zest.

Date **Apoorva**

`

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Background:

The Indian elephant (*Elephas maximas indicus*) is native to Asia and is one of the subspecies of the Asian elephant. India is a home to around 25,000 wild elephants accounting it to be 50% of the total species population. Till recent past, elephants used to cover a huge range in the country but now the area has shrunk to about 110,000 sq.km[1]. The elephant range which once covered the entire stretch from Iraq to China is now restricted to only parts of Nepal, India and Sri Lanka. The mega-herbivore had started getting affected since the first human civilization, but marked decline was in 1800s[2]. According to Fernando, in the past two centuries, there has been a significant increase in agriculture practices by local population, accompanied by increased demand of cash crops like tea and coffee[2]. With the advent of time, population increased and demand for fuel and timber also increased, leading to increase in logging and conversion operations. In the beginning of 20th century, per year increase in deforestation rate in Asia was recorded to be 1.4 [3]. Hence, the main driver leading to fragmentation of elephant habitat is population expansion and increase in demand of forest products[2]. As a result, International union for conservation of nature (IUCN) categorizes Asian elephant as endangered[4].

Elephants feed on several kilograms of plants everyday which accounts to be mere 8-10 % of their body weight. They can eat anything from roots to stem, to flower, to bark of a plant. They feed on a variety of plants including bamboo, sugarcane, bananas and twigs and branches of tree species[5]. 200 litres of water is the daily requirement an elephant[6]. Due to their acute need for water, elephants prefer to be near water(drinking, bathing) sources[7] .

Elephants play a vital role in forest ecology by causing seed dispersal and thereby increasing genetic diversity[8]. Asian elephants are mostly found in grasslands, moist deciduous, dry deciduous, tropical evergreen, semi evergreen and dry thorn forests. Elephants need a large habitat for survival, hence their conservation will also lead to protection of other species in the same area and hence they are often known as "umbrella species."Owing to their role in increasing genetic diversity of the forest ecosystem, they are also regarded as keystone species [4].

Elephants move around in search of food, water and possible mates from one forest patch to the other. To do so, they generally follow a predefined path and this occurs as a result of hereditary behaviour. They tend to follow a path which provides least resistance while travelling from one forest patch to the other and is governed by preferences and impedances in the path. Rivers, water holes, favourable vegetation type which offer forage, etc. act in favour of elephant movement while roads, settlements, steep slope, etc. offer a resistance to their free movement. Any such area, which acts as a connecting link between large habitats (with elephant population) is known as an elephant corridor. Corridors are of vital importance to the wild population from the point of view of free movement between the two habitats. A corridor acts as means of gene sharing, interbreeding and connection of fragmented habitats of the same species[9]. A biological corridor can be defined as "A geographically defined area which provides connectivity between landscapes, ecosystems and habitats, natural or modified, and ensures the maintenance of biodiversity and ecological and evolutionary processes[10]."

Increased human interference in corridors has resulted in Human elephant conflict (HEC) and isolation of elephant populations in fragmented areas. Habitat loss and fragmentation due to human interference has become a huge threat to their survival. Across the range of Asian elephants, the main cause of habitat loss is conversion of natural elephant habitats to commercial agriculture sites. In most cases the natural habitat is found to be productive for some particular crop and hence is subject to agricultural practices. The local population, being unaware of elephant behaviour, expects that elephants will perhaps progress to a different area, which is often not the case. The result is crop raiding, population fragmentation and elephant and human fatalities due to high incidents of HEC[11].

The Government of India has been very active in the past in order to conserve, maintain and rebuild the wildlife habitat and corridors for elephants. Project elephant launched in the year 1991 has been very helpful in mitigating the number of elephant deaths and elevating the elephant status in South East Asia. Techniques like electronic fencing and digging of trenches at boundaries of forest land and agriculture have been tried by state forest departments but haven't met with significant success due to poor maintenance and high rainfall, respectively [5]. In 2001, Wildlife Trust of India (WTI) identified 88 corridors in India with the help of different State forest departments of India. These corridors were granted considerable protection by the State government under various wildlife protection laws. The survey conducted by International fund for animal welfare (IFAW), (USFWS), Elephant Family, World Land Trust and IUCN-Netherlands affirmed that out of the total corridors in India only 22.8% were free from human settlements[1].

The elephant corridor of Shiwaliks in the North West part of India has noteable human elephant conflict, due to various land use changes. The corridor facilitates elephant migration across the Terrai region of Nepal[12] right up to eastern border of India. Increase in vehicular traffic, train traffic and road construction in the last few decades, has led to a decrease in the migration rate of elephants from one forest patch to the other. The corridor which once formed a contiguous stretch under the foothills of Himalayas, is now subject to fragmentation, resulting in smaller corridors[13]. This region includes, Shivaliks of Uttarakhand and Uttar Pradesh having Rajaji National Park and Parts of Dehradun and Lansdowne forest division.

One of the main causes of the HEC is the forest dwellings of various nomadic tribes of the region. A fraction of Rajaji national park is inhabited by the Gujjar tribe [12]. Although process of their dislocation exists, with 1222 tribal being dislocated hitherto, a part of the tribe still resides inside the forest. Under the Scheduled Tribe's Bill of 2005, this population occupies a part of the prime forests which are in the elephant migration path. They are generally nomadic by behaviour but lately have become less migratory perhaps due to shrinking habitats. They practice subsistence agriculture in the forest and have also been found to encourage monoculturing of tree species like eucalyptus. The community which once had a kinship with these forests and were considered guardians of forests, have recently started unsustainable exploitation of the forest for fuel and fodder[14]. Due to Gujjar settlements in this area , the elephants have been reported to destroy crops by raiding agricultural fields of the farmers [12]. Between the years 2007-2011, 32 male elephants died an unnatural (accidents due to traffic or shooting incidents) death in the Rajaji-Corbett corridor which can be attributed to various anthropogenic disturbances. During the same time period 50 human deaths were reported in the same zone as a result of HEC (Human Elephant Conflict)[15]. From the year 2000-2008 128 elephant deaths have been reported only in Haridwar forest division[16].

The Shiwaliks in Uttarakhand harbour an elephant population of around 1350 as per the wildlife census of 2008[17] and constitutes one of the major elephant corridors[18]. Today the elephant reserve of Uttarakhand, under which the study area falls, has a railway track as well as some major roads over a significant stretch of area. This stretch is a hindrance to the free movement of elephants across the corridor and has been a major reason for their deaths. The corridor has also been subject to agricultural expansion and other related activities by local farmers fragmenting it further[13].

The main motivation of the study was to trace the changes in elephant movement by creating the landscape without any land use and modelling the potential corridor. The variation of the elephant distribution and their potential migratory routes of the two scenarios i.e. without land use and with land use, will help us get a clearer picture of as to what are the main factors behind the decline of elephant population. Hence, reconstructing the vegetation of past will play a vital role in the research.

1.2. Problem Statement

The research aims at estimating potential elephant corridor and analysis of the habitats used by elephants for temporary shelter foraging etc. The study will also model elephant distribution with the help of species distribution modelling techniques. The research includes a comparison of the potential elephant corridor, probable elephant distribution and vegetation map of present day with those of the past, when the area was free from any kind of anthropogenic interference.

The research includes usage of climatic and topographic inputs to construct a potential vegetation map for comparing it with present day vegetation map, so as to identify the changes over years. The next part of the research will include habitat modelling to predict elephant distribution extent in the study area, followed by least cost path analysis (LCP), thereby suggesting the potential elephant corridor. The result will be analysis of change in elephant distribution over years.

1.3. Research Identification

1.3.1. Main Objective

The main objective of the research is to identify potential elephant corridor between forest patches and to identify the disruptions in the corridor.

1.3.2. Sub Objectives

1. To construct a potential vegetation map for past when the study area is assumed to be free from any kind of human interference.
2. To model potential elephant habitats in lower shiwalik range for present and past.
3. To estimate the path followed by elephants in the corridor area between two forest patches.
4. To identify the land use areas that can be reclaimed in order to rebuild the corridor thereby lessening the instanced of HEC.

1.4. Research Questions

1. What would have been the potential vegetation of the study area based on climatic and topographic factors prior to introduction of land use practices?
2. What is the potential path followed by elephants with and without land use practices?
3. How do the corridors prior to LU practices differ from ones in the present scenario?
4. Which areas have the highest possibility of HEC?

1.5. Innovation

Till date no scientific study has been carried out to model the spatial distribution of the elephants in the elephant reserve of Uttarakhand. Habitat suitability analysis in Lower Shivalik area is also novel for assessing influence of land use on elephant habitat and their fragmentation. The approach of using reconstructed vegetation type map prior to land use changes will enable us to innovatively identify the regions where the natural migratory routes of the elephants have been modified or encroached by the various land use practices.

2. LITERATURE REVIEW

2.1. Elephant Habitat and Ecology:

India has around 60% of wild population of Asian elephants. After independence of India in the year 1947, the primary goal of the government was economical development. To do so agriculture expansion was considered as an option and implemented, at the wake of which forest were degraded to a large extent. Around 5% of the present forest cover was lost during 1951-1976. As a result elephants and other fauna faced habitat fragmentation and isolation. By the mid of 19th century elephant habitat in the state of Uttar Pradesh/Uttarakhand was shrunk to 1000 sq.km. Due to perpetual human intrusion in various parts of forest human elephant conflict started gaining pace. The elephants which once moved from Western India through Nepal to Myanmar changed their path and started moving from Dudhwa national park (U.P). Recent elephant census shows elephants being segregated into six sub populations in the Shiwaliks with their total number being 1000-1600 [19] .

The main reasons for fragmentation of Asian elephants in elephant reserve of North West India can be attributed to vehicular traffic on roads and extensive human interference around the remnant forest patches and also inside the forest area. A study by Joshi et al in 2010, marks out how different highways in the study area are being used by elephants for movement, especially during dry season. Haridwar-Binjour Highway that links Khara and Anjani forest of Rajaji national park is the one being used for elephant movement throughout the year. Other highways are used seasonally by elephants[13]. Ranging pattern of elephants in natural vegetation and plantations in the Anamalai hills of southern India depicts the effect of change in landscape over elephant population. The five main vegetation types used as the basis of research were namely tea, coffee, *eucalyptus*, natural vegetation and other. In a study of three years, 33% of elephant locations were found to fall under natural vegetation, followed by tea (32%). A significant difference was found in the elephant usage of vegetation types during day and night.51 % of the observations of daytime were attributed to natural vegetation while majority (68%) of the observations in night were that of tea plantations. Choice of landscape preferred by elephants changed with seasonality (Dry/wet).With the changing season the most significant vegetation types to elephant movement were still natural vegetation and tea[20] .

Elephants are said to have a huge appetite as they eat several hundred kilograms of plants materials a day but it only accounts to be 8-10 % of their body weight. Elephants feed on shrubs, bamboos, trees, saplings and grasses. They eat everything from a flower to the bark of a tree. Due to human encroachments of the forests due to agriculture, elephants are also found to be feeding on crops like sugarcane and rice, resulting in extensive damage [5]. Crop raiding is generally an act of an adult male elephant. The range of elephants is decided upon by availability of source of nutrition. They may wander up to several kilometres in search of food or remain confined to a smaller area if sufficient food is available. Elephant is a highly social animal and prefers to be in large herds of 7-35 (ref). Generally the females form a clan with the young ones and males wander alone [5].

Despite of being one of the largest living mammals, elephants are quite efficient at climbing hills. They are sure footed and walk with strides. According to J.C Daniel, in some cases elephant presence was observed also on hill tops[21].But mostly they avoid slope more than 30 %[22].

Foraging by elephants varies according to locality and food availability. They are exclusively vegetarians, with their preferences being soft plant twigs of species like sal (*Shorea robusta*), bamboo, herbs and other grasses .The grasses commonly eaten by elephants are *Saccharam spontaneum, Panicum sp., Themeda and Sorghum*.Elephants are also fond of eating sappy bark of plants like Kydia *calycina, Grewia tiliaefolia* and teak. They strip the bark with their trunk upto a width of 6".Amongst shrubs they generally feed on *Acacia sp., Hibiscus sp., Zizyphus sp*. Certain forest fruits like *Aegle marmelos , Pandanus sp., Emblica sp*. And figs also form a part of their daily diet [21] . The elephant diet consisted of more browse species relative to grass. Major part of feeding was in dry deciduous forest[23].

Elephants are social in nature and form clans. The bull (male) elephant is a loner and joins with other elephants depending upon environmental conditions or during mating season. Cows (female) however live with the young ones until they grow and can be on their own. Relationship between a bull and cow is mainly sexual with no responsibilities on the bull. Several clans may join during feeding and drinking water. Elephants are found to react to human presence. Charging, and trampling of plants are the most common reactions. The reaction is mainly to protect the young ones in case of a cow[24] .

A study was carried out in Nilgiri biosphere reserve of southern India by radio collaring some of the elephants and on foot observations as well as observing from trees. The study established that foraging was more in wet season as compared to the dry season. The group also established that 60% of daylight was spent in foraging, 20% for rest and rest for moving and other activities. It was also observed that increased with increase in temperature resulted in elephants allocating more time for rest. [23] .

2.2. Species Distribution Modeling (SDM)

Maximum entropy modeling (MaxEnt) is a machine learning technique and has a lot of potential in wildlife research. It can work with only presence location inputs unlike other SDM softwares, which require both presence and absence data. Hence MaxEnt has a very basic advantage over other methods of requiring only presence data as input, along with environmental layers[25]. The software has the capability of showing results with mere five locations, however more the location data, more is the expected accuracy. The output is a probability map depicting probability of occurrence of a particular species ranging from 0-1. Interpretations can be made by jacknife estimate of test and training gain, Area under curve (AUC), response curves and standard deviation outputs. Baldwin in his paper of 2009 discussing about advantages, shortcomings, working and result interpretations of the MaxEnt

,highlights the importance of needed advancement in MaxEnt in order to define thresholds in a better manner [26] .

Species geographic distribution has been tried by modelling tools like Genetic algorithm for rule set prediction (GARP). Philips *et al*. (2004) suggest use of MaxEnt in comparison to GARP in the study conducted on North American bird species with available location data including use of four feature types namely, raw environmental variables (linear), square of environmental variables (quadratic), product of pair of variables (product), thresholding of environmental variables (threshold).The results were interpreted by analyzing AUC and receiver operating characteristics (ROC) outputs of GARP and MaxEnt. MaxEnt seemed to give a better prediction probabilistic distributional pattern. Hence MaxEnt proves to give more interpretable and efficient results[25] .In his another paper in 2006 on a study of a sloth and rodent species in order to predict their geographic distribution.,the results of maxent and GARP were compared so as to conclude which of the two depicts a better output. The AUC of ROC in case of maxent was found to be better than GARP. It was also found to give further advantages over GARP like less time required for process completion and less output size[27] .

MaxEnt was use to model the probable distribution of six small carnivore species (*Felis chaus ,Viverricula indica, Paradoxurus hermaphrodites, Herpestes vitticollis, H.smithii, H.edwardsii)* in Madumalai tiger reserve. Using presence only locations of the animal species, bioclimatic variables, forest and land cover type, topography, vegetation index and anthropogenic variables, AUC for ROC for training dataset was found to be 0.81-0.93 and that for testing data set was found to be 0.72-0.87 .Distance from the village and precipitation of warmest quarter turned out to be the most significant variables for all the six species in general [28] .

2.3. Corridor Modeling

Corridors act as a medium of connectivity for isolated populations in fragmented forest patches. A.Roy *et al*. suggest a method to connect 14 protected areas in Orissa by introducing a potential corridor model. The input is a vegetation map along with an impedance and preference layers. Impedance in the study was considered to be due to anthropogenic disturbances and change in vegetation from uniform to agriculture or other management practices being followed in the study area. All variables were assigned weights according to their significance. Impedance was then converted into cost thereby contemplating that any animal species is likely to follow the path offering least resistance. Cumulative cost distance was found after computing vegetation and disturbance cost distance. With the available point locations, source and sink were decided upon and least cost path was calculated with the help of Arc GIS software [22] . Using similar approach, Rameshan modelled the potential elephant corridor between Anamalai and Periyar tiger reserve[29].

Tarangire national park of Tanzania is a home to African elephant population. A study was conducted to identify five transit corridors in the area. The study was conducted for both wet and dry seasons. Permanent waters, protected areas, settlements and vegetation were found to be significant in predicting elephant population in both seasons. Whereas, altitude and monthly average NDVI and distance from temporary water were found to have an indirect effect on elephant presence in dry and wet season respectively. Elephant locations were converted into presence and absence with logistic regression. Distribution map was a result of Kernel probability and logistic regression. Path analysis with AMOS 5.0.1 was employed in order to conclude the extent of environmental and anthropogenic variables contributing in prediction of elephant distribution. Distance form protected areas, settlements and roads were studied for negative effects if any on elephant population due to their nearness to water sources and preferable vegetation type. Four corridors were found to be matching with archive data thereby justifying the use of the corridors for movement by elephants [30] .

A study was conducted to identify and link two elephant habitats by a corridor in Zimbabwe. Different vegetation types were weighted according to their contribution in facilitating elephant movement. Areas were identified and digitized for forest patches and settlements by aerial photographs. Nearness to water/river was considers decisive in elephant presence and presence of forest. A 250 m buffer was created around riverine vegetation and sacred grooves. Likewise a buffer of 500 m and 250 m was also created for settlements and roads. All these layers were dealt with in Arc view and a least resistance path was predicted, thereby ascertaining elephant movement in the area [31] .

Geospatial modelling techniques were used to identify the potential elephant corridor in the state of Chhattisgarh of India. The area is actively visited by elephant population of neighbouring states of Orissa and Jharkhand. Proximity to water, proximity to settlements and vegetation cover were taken as input variable to create a habitat suitability map. All the variables were assigned weights with the help of Analytical hierarchical process (AHP).All the input layers were multiplied to these weights and along with the vegetation map were subject to weighted sum approach in Arc GIS to give a habitat suitability map. A least cost path was predicted by analyzing the suitability map [32] .

3. STUDY AREA AND DATA SET:

3.1. Study Area:

The study area (280 43'N to 310 27'N – 770 34'E to 810 02'E) is guarded by the mighty Himalayas and Shiwaliks in the north and Terai lands to the south in the state of Uttarakhand. From west to east the area is bounded by river Yamuna and Ganga respectively. Elevation varies from 800 mts. to 4500 mts. Majority of soil parent material are either conglomerate or alluvial. The area experiences wide ranges of precipitation with some areas receiving ample amount of rainfall while other remaining relatively dry. The annual precipitation ranges from 1000-2500 mm. The area doesn't experience very cold weather but summers are significantly warm. The minimum temperature remains above freezing whereas maximum temperature goes up to 40^0 C.

The study area is a part of Shiwalik elephant reserve comprising Siwalik forest circle, Dehradun Forest Division, Ramgarh, Kansrao, Motichur, Chilawalli, Dhaulkhand and Ramgarh , Gohri and Chilla ranges of Rajaji National Park (RNP), Lansdowne Forest Division (LDFD) and Haridwar Forest division(HFD). Elephant population in this area has been fragmented and hence segregated to six sub populations due to various form of human interventions.

The area encompasses fertile gangetic plains with the forest cover formed mainly by mixed deciduous, sal moist bearing, sal dry bearing, chir pine and Himalayan moist temperate forest. The area which once had a big continuous stretch of elephant corridor has now been fragmented into five main smaller corridors, namely Chilla-Motichur corridor (3.5*1.0 m), Khara-Anjani corridor (8.0*3.0 m), Motichur-Kansro-Badkot corridor (2.5*2.0 m), Motichur-Gohri (4.0*1.0m), Rawsan-Sonandini corridor (10.0*5.0 m) .The area is also subject to fringes of agriculture plantations by local tribal population. The plantation mainly includes rice (*Oryza sativa*), sugarcane (*Sacchaurum officinarum*) and wheat (*Triticum aestivum*). The tribes (Gujjar) also pose pressure on the habitat by fuel wood collection and illegal collection of Bhabhar grass. Another reason for the fall in habitat quality is conversion of forest to monoculture plantations of exotic species like teak (*Tectona grandis*), gum(*Eucalyptus sp.*) and poplar(*Populus deltoides*) in the terai region. Lopping of non timber forest products like bamboo and canes and grazing by livestock of local villagers have contributed furthermore to degradation of elephant habitat.

Apart from agriculture acting as a source of disturbance, there are some major roads and rail tracks passing through the area. There are mainly five National highways which pass through the area and have witnessed instances of HEC. These are Haridwar-Binjor NH of 17 km, Haridwar-Dehradun NH of 3 and 9 km, Haridwar-Rishikesh NH of 3,1 and 2.5 km ,Dehradun-Delhi NH of 14km, Rishikesh-Dehradun NH of 6kms.Haridwar-Dehradun and Haridwar-Rishikesh rail tracks passing through the study area are another hindrance to free elephant movement.

Figure 3-1: Study area

3.2. Data Used:

3.2.1. SRTM DEM

Shuttle Radar Topography Mission (SRTM) provides near global scale data for digital elevation model (DEM) from 56° S to 60° N. The dataset is downloaded at 5 deg × 5 deg tiles. Each tile has 3,601 rows.

3.2.2. Vegetation type map

A national level vegetation type and land use map at 1:50,000 generated as part of Biodiversity Characterization at Landscape Level (BCLL)[33] was used as the base for further land use and land cover mapping. Linear imaging self scanning sensor (LISSS III) imagery and Advanced Wide Field Sensor (AWiFS) II satellite data was used along with intensive field survey to modify the above mentioned map.. Biogeography and elevation zones were also handy in delineating the classes along with climatic and topographic regimes. The map was initially classified into 151 vegetation /land use classes for entire India. The map was provided with 5000 sample plots by stratified random sampling technique[34].

3.2.3. LISS III

(LISS III) is a multi- spectral sensor having four spectral bands. Three bands are in visible and NIR and one band is in SWIR range. The data was used in making and updating the LULC map. The products from the sensor are radio metrically corrected.

3.2.4. Bio Climatic Layers

Bioclim layers were generated from monthly temperature and rainfall data (averaged over past thirty years) in order to make more biologically meaningful variables [35]. These variables are indicative of trends, seasonality and extremes of temperature and precipitation. The data is often used for niche modelling techniques like MaxEnt and GARP.

Table 3-1: Bioclimatic layers

BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

4. SOFTWARES AND METHODOLOGY:

For the execution of species distribution modelling (SDM) techniques and geospatial modelling of elephant corridor and habitat softwares mentioned in were used.

Table 4-1: Softwares used in the study.

Sr.No.	Software	Purpose
1	Arc GIS 93	Data pre-processing, Least cost path(LCP) analysis
2	ERDAS Imagine 10	Data pre-processing, Accuracy assessment
3	MAXENT (Maximum entropy)	SDM
3	Quantum GIS	Data pre-processing
4	DIVA GIS	Data pre-processing(Generation of Bioclim layers)
5	MATLAB	Multicolinearity testing

4.1. Field Visit

Field visit was conducted mainly to procure elephant location data. It mainly focused in the areas of Rajaji national park, Timli forest range and Saharanpur district of Uttar Pradesh. Hand held GPS was used to gather geographical coordinates for elephant presence. The readings were recorded for elephant dung (fresh/old), foot marks (fresh/old) Indications of foraging on plants, twigs, bamboos, signs of bark ripping by their tusks or rubbing, trampled vegetation and destroyed building structures. The study area was covered from range to range with the help of the forest departments of Uttarakhand and Uttar Pradesh.

Field visit also included ground truth data collection, adding to the accuracy assessment of LULC map for the present scenario. GPS locations were taken for conspicuous river channels, forest types, land use types, manmade structures and forest brakes. Interactions with local population in the areas of Rajaji national park was also encouraged (Appendix-3) in order to get a better know how of change in vegetation patterns over time. Problems faced by the villagers as a result of man-elephant conflict were also discussed. Water holes data was also recorded during field survey and added to the available water holes data.

4.2. Methodology

4.2.1. Data Processing:

Climatic and topographic data: WorldClim data for precipitation, maximum monthly temperature and minimum monthly temperature averaged over past thirty years was one of the primary data used. The data set had a resolution of 861.5*861.5 m and the coordinate system was WGS-84. All the 36 WorldClim layers were masked according to the area of study. The cell size was resampled to 90*90 m with reference to SRTM DEM, and reprojected to Lambert conformal conic (LCC). DIVA GIS software was used to make 19 Bioclim layers from the WorldClim data which were thereafter resampled and reprojected as required (Coordinate system-LCC, cell size-90*90 m). Data pre-processing was done to make data compatible to MaxEnt software as all the data input layers i.e. environmental layers and other pertinent variable layers, should all be in same projection system, have same cell size, same row and column count and same spatial extent.

The selected Bioclim layers were further subjected to pre-processing for modelling the potential vegetation map. BIO 5(Maximum temperature of warmest month), BIO6 (Minimum temperature of coldest month) and BIO12 (Annual precipitation) and elevation (DEM) were multiplied by different factor of ten in to enable merging of all the datasets for further classification into the potential vegetation.. The purpose of multiplying the layers to a factor of ten was giving them a hierarchical importance in order to decide upon the vegetation type of potential map. For Ex. Elevation plays a very important role in deciding upon the presence or absence of a species hence it was placed highest in the hierarchy Elevation layer was multiplied by 10^7, BIO12 by 10^5, BIO5 by 10^3 and finally BIO6 by 10.These layers were finally added and made into one layer which was thereafter classified in potential vegetation types.

The study included generating a LULC map for the present scenario. For the same, BCLL vegetation type and land use map was updated for the year 2013 with help of field survey, visual image interpretation using AWiFS, LISS-III and TM.

Potential vegetation map and present day LULC map were compared in order to mark out the changes in forest cover. The change was useful in depicting which land cover type was affected most over the years. The comparison was also pertinent in deciding which land use types replaced the forest vegetation types and hence led to degradation of forest which indirectly led to fragmentation of elephant population. The flow of methodology is as shown in the Fig. 4-1.

Roads and Rail, and Inland water data was downloaded from DIVA GIS open source for serving as an input to impedance and preference layers respectively which was later on used in calculating least resistant path of travel by elephants. The downloaded layers were updated with the help of digital analysis in QGIS with OSM (Open Street Map) road and railway data. Water holes were identified with the help of both, Google satellite image and field survey. Water hole data also added as an input to preference layers in LCP.

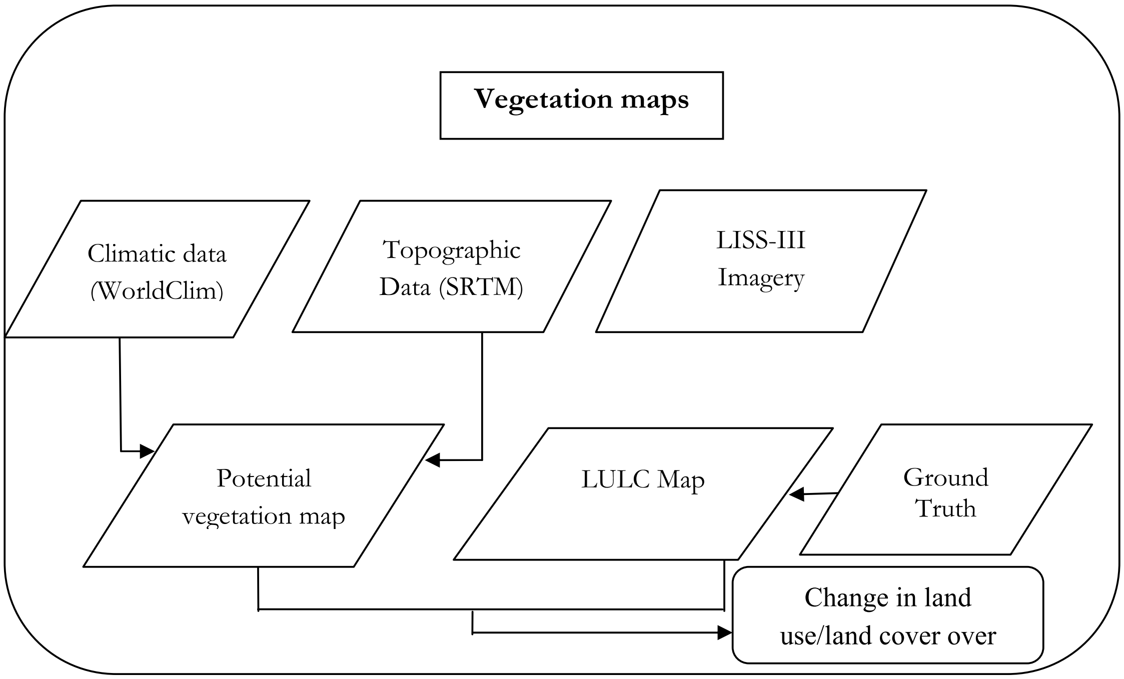

Figure 4-1: Flow chart depicting the comparison of potential vegetation map and LULC map (Present day)

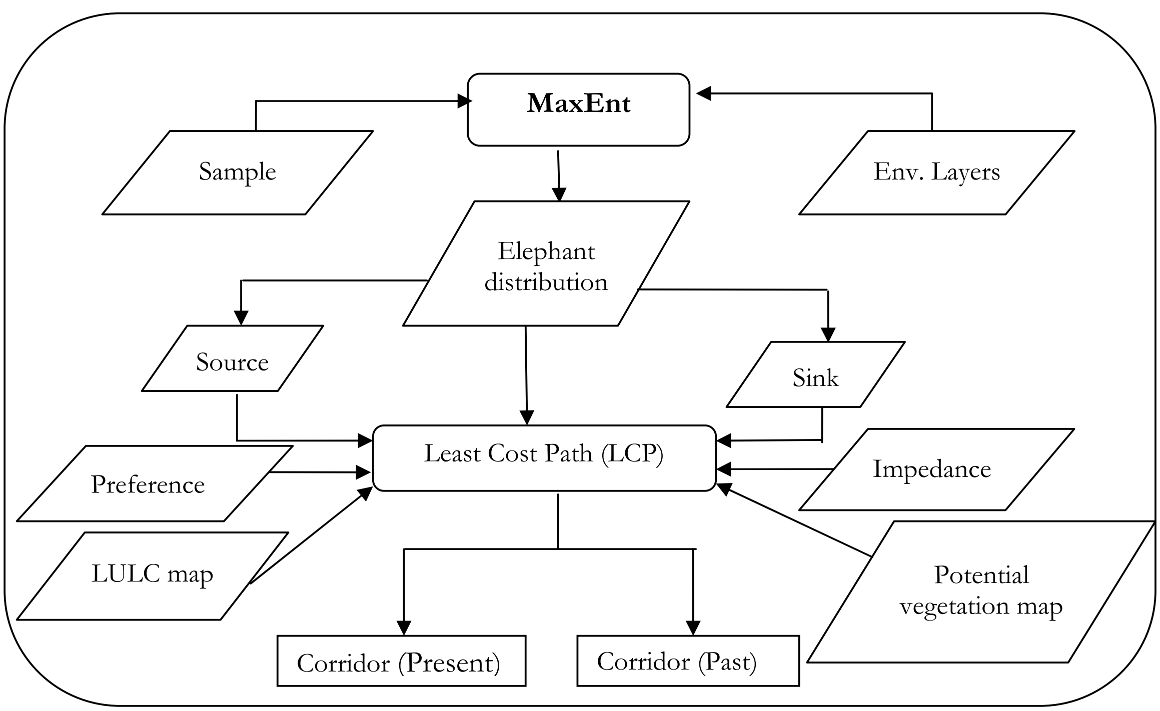

Figure 4-2: Flow chart showing SDM and LCP

Comparison of maps was followed by MaxEnt species distribution modelling technique. MaxEnt takes locations as inputs of a species (*Elephas maximus* in this case) along with environmental layers. The output which is a probability map helps in deciding upon the source and sink of elephant movement which finally gives a least resistant movement path and hence the elephant corridor as shown in Fig. 4-2.

4.2.1. Potential Vegetation Map

Presence of vegetation is influenced by environmental, atmospheric and geographic variables. Potential vegetation is a summed up algorithm of environmental, atmospheric and geographic factors that are decisive in existence of a particular plant species. These different precipitation, temperature, elevation and soil patterns interact with the plant and amongst themselves influencing presence/absence of a particular species. The main difference between potential and actual vegetation is that potential vegetation is an ideal disturbance free environment while the actual vegetation is realistic and with existing human induced disruptions.[36]

Table 4-2: Classification of forest types based on climatic and topographic regimes.

FOREST TYPE	Temperature(^{0}C) Max	Min	Total annual rain (mm)	Elevation (m)	*Reference*
Moist sal bearing forest	19.00 - 35.60	5.00-23.40	1900-2500	300-683	*Champion and Seth and S.S Negi*
Himalayan sub tropical pine forest	19.70 - 25.40	11.10 - 14.54	1000-1200	800-1859	*Champion and Seth*
Northern dry mixed deciduous forest	30.10 - 40.30	16.80 - 20.80	1000-1500	274-650	*Champion and Seth and S.S Negi*
Himalayan moist temperate	16.74 - 23.30	0.50-9.40	1300-1500	1500-3300	*Champion and Seth*
Subtropical Broadleaf Hill forest (Northern)	20.00 - 24.26	12.27 - 16.42	2100-2400	500-1000	*Champion and Seth*

The above table (table 4-2) has been made on the basis of the most widely used forest type classification of Indian forest, Champion and Seth's classification system. They divide Indian forests into 16 type groups on the basis of temperature and moisture regimes. These type groups have been further classified into 200 forest types, based on the local conditions.

Potential vegetation map in this study depicts what would have been the vegetation, had there been no human intervention (roads, rail, settlements, agriculture practices) in the study area. It is a hypothetical scenario of around 200 years ago. The map shows the area being categorized into five main forest types, free from any kind of disturbance. These forest types are considered to be a result of active precipitation, temperature and elevation regimes.

The inputs to potential vegetation map were annual precipitation(BIO 12), maximum temperature of warmest month(BIO5), minimum temperature of coldest month(BIO6) and Elevation (SRTM DEM).All these layers were added(in order of their relevance) in Arc GIS. The output layer was edited for attribute information of precipitation, temperature and elevation ranges and each pixel was categorized into a forest type according to table no.
The map was not subject to a validation procedure as such but field visits and interaction with local population was an affirmation towards change in land use and land cover classes over years,

4.2.2. Land Use and Land Cover Map (Current scenario):

FAO defines land cover as "the observed (bio) physical cover on the earth's surface."Land cover is distinctly visible on satellite imagery and is mainly formed by vegetation or features existing on earth surface. Whereas Land use is humans use of land in order to derive benefits.FAO defines land use as "the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it"[37].

Available BCLL map for land use and land cover (LULC)[33] made from LISS-III imagery was updated according to existing conditions in the study area using AWiFS (2013) and LISS III data of 2012-13). The map was there after recoded into 19 main LULC classes, depicting the change in vegetation patterns over years. The map was made in wake of making a comparison between present and past scenarios. It represents the following classes:

Table 4-3: LULC classes

CLASS NO.	LULC TYPE
1	Himalayan moist temperate
2	Sub tropical pine
3	Moist sal
4	N.dry mixed deciduous
5	Plantation
6	Non forest vegetation
7	Degraded/scrub
8	Agriculture

9	Barren/River bed
10	Water body/river
11	settlements

4.3. Species Distribution Modelling

4.3.1. Multi Collinearity – Variance Inflation Factor:

Multi colinearity is a state when the independent variables are correlated or indicate duplication of data .It is indicative to linear relationship between one more variables. Independent variables help in describing as to what extent a dependent variable can be predicted in case of regression [38] .

Multi co linearity can be detected in various ways, one of which is Variance inflation factor (VIF).VIF shows how much is variance inflated as compared to when the variables are non linear in relation. In case of the explanatory variables being correlated to each other, R2 will be closer to1, thereby increasing the VIF. Higher the R2 higher is the VIF and it tends to be lower in case the variables are not correlated to each other [39] .

VIF of the k^{th} predictor is:

$$VIF_k = 1\frac{1}{1-R^2\,k}$$

R^2k being variance of k^{th} variable[39]. VIF was calculated with Bioclim layers, slope and DEM in MATLAB. The results were analyzed and the layers with higher VIF were opted out of species distribution modelling.VIF higher than 100 was kept as a threshold, above which the values were regarded as having high collinearity.

4.3.2. Maximum Entropy Modelling (MaxEnt):

Geographic distribution of a species is dependent on participation of environmental factors of an area. Predictive modelling is a technique which determines distribution of a particular species in an area with the help of environmental variables and available occurrence data. With available absence and presence data, a basic statistical model can be used in order to predict species distribution. However, in most cases only presence data is available hence, techniques demanding presence only data are pertinent.[27].

MaxEnt takes presence data as input which should in the form of x, y coordinate and same as the coordinate system of the environmental layers. The result of MaxEnt is a probability distribution map showing values between 0-1.The pixels with species distribution are presence while the ones without it are considered background (not absence).

In this particular study 308 elephant locations were given as sample input out of which 45 were taken on field and rest were provided by the forest department. The coordinate system of the GPS readings was made similar to that of the environmental layers i.e. Lambert conformal conic (LCC). MaxEnt takes csv as sample input which should have x,y coordinates in the same coordinate system of that of the environmental layers(LCC in this case). After being filtered for multi collinearity (layers with high VIF were removed), the layers taken as input environmental layers were slope, DEM, BIO1, BIO2, BIO3, BIO4, BIO6, BIO7, BIO9, BIO11, BIO14, BIO15, BIO16, BIO18 and BIO 19.All the input environmental layers were beforehand converted ASCII format and it was made sure that they have similar properties in terms of number of rows, columns, cell size, projected coordinate system and datum.

MaxEnt allows the ability to run a model multiple times and then advantageously averaging the results from all models created. For this particular study MaxEnt was run 15 times. MaxEnt gives a gain as a result of contribution of each variable towards best fit of model..It's basically a function that needs to be maximized in order to get best fit. A certain amount of data was withheld for testing model performance.25 % of the data was kept for testing and the rest was kept as training data. Not specifying any random test percentage makes the software use the exact sample data and hence show bias results. So specifying a test file or random test percent is an important step.

Number of iterations was made 5000 as with the increase in the iterations the output becomes more certain. Regularization was left to default value 1. Regularization function keeps a check on the gain function so that it doesn't fit the presence records too tightly. It is a useful parameter in preventing model over fitting.

4.3.3. Preference and Impedance Rasters:

Presence and absence of elephants or rather any species for that matter is dependent upon the local factors in the area. Factors like favourable vegetation, water, forage grounds are likely to invite elephant population, whereas nearness to settlements road and rail cause a hindrance to free elephant movement. Therefore preference and impedance layers concept was included in the study owing to their importance in deciding elephant movement.

Preference and impedance layers were chosen acknowledging presence of favourable and unfavourable resources in the area. Preference layers are generally natural resources that already exist, whereas impedance is more often than not a function of anthropogenic interference. The layers selected for acting as preference were forest vegetation, water holes, water areas (big rivers, lakes) and water lines. Roads, rails settlements and slope were however used as impedance inputs. Euclidean distance was calculated for all these layers except forest area.

Table 4-4:Weights assigned according to Analytical hierarchy process(AHP)

Vegetation type	Weight(LULC)	Weight(Potential vegetation)
Himalayan moist temperate forest	0.52	0.71
Himalayan sub tropical pine forest	0.79	0.46
Northern dry mixed deciduous forest	1	1
Moist sal bearing forest	0.94	0.95
Sub tropical broadleaved hill forest	-	0.88

Euclidian distance computation was followed by Analytical hierarchy process (AHP). AHP is a method to assign weights to particular inputs in order to decide upon their prioritization. The weights are in the form of numerical values with 1being the highest. The output shows a ranking with all the variables having a particular weight which refers to their relative importance in a study. In this the study AHP was applied with the help of definite software. Pair wise comparison for each alternative variable was used to distribute weights and hence rank the variables. The method was applied to vegetation type (preference) at first, for both potential vegetation map and of that of LULC map of present scenario. Forest types were hence ranked as shown in table 4-4.

Further AHP was applied to all impedance and preference layers and they were ranked in the order as mentioned in the table 4-5 and 4-6.

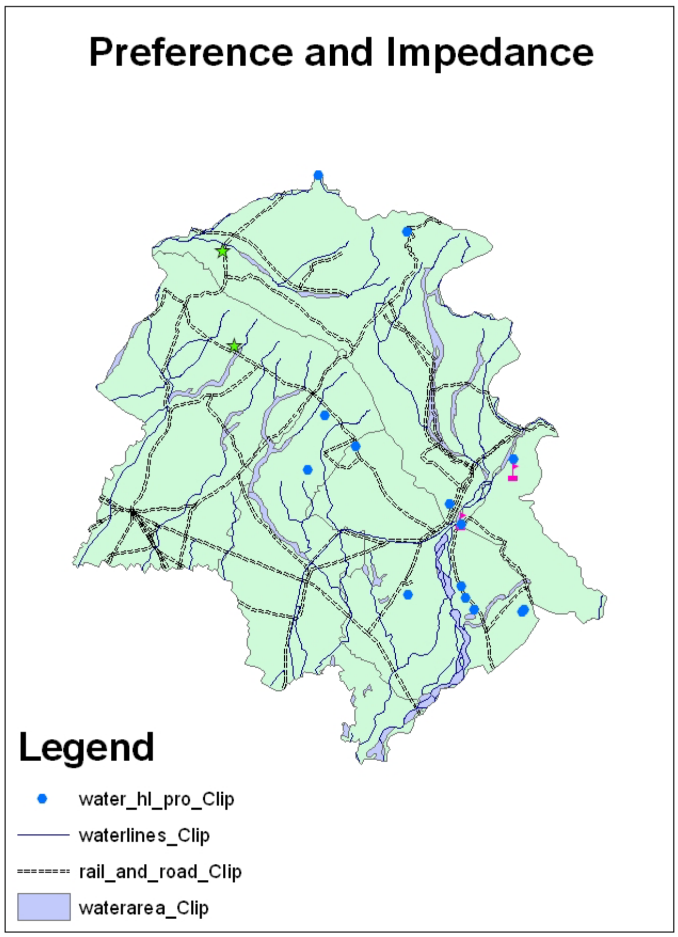

Table 4-5: Weights assigned to preference layers.

Preference layer	LULC	Potential vegetation
Water holes	0.87	-
Water line	0.83	0.61
Water area	0.99	0.98
Forest vegetation	0.57	0.91

Table 4-6: Weights assigned to impedance layers.

Impedance layer	LULC	Potential vegetation
Slope	0.61	1
Settlement	0.93	-
Road and rail	0.96	-

All the layers were normalized between 0 -100 before multiplying by their respective weights. Preference and layers were separately computed by weighted sum operation with ArcGIS.

4.3.4. Least Cost Path Analysis:

Least cost path analysis gives a least resistance path between two points of probable elephant distribution. Execution of the process requires a source and sink which were selected on the basis of MaxEnt's average probability distribution map output (Fig. 4-2). The areas having concentrated high probability values were identified and hence were selected for acting as source and sink. Two sources and two sinks were identified from the probability and hence were subject to LCP.

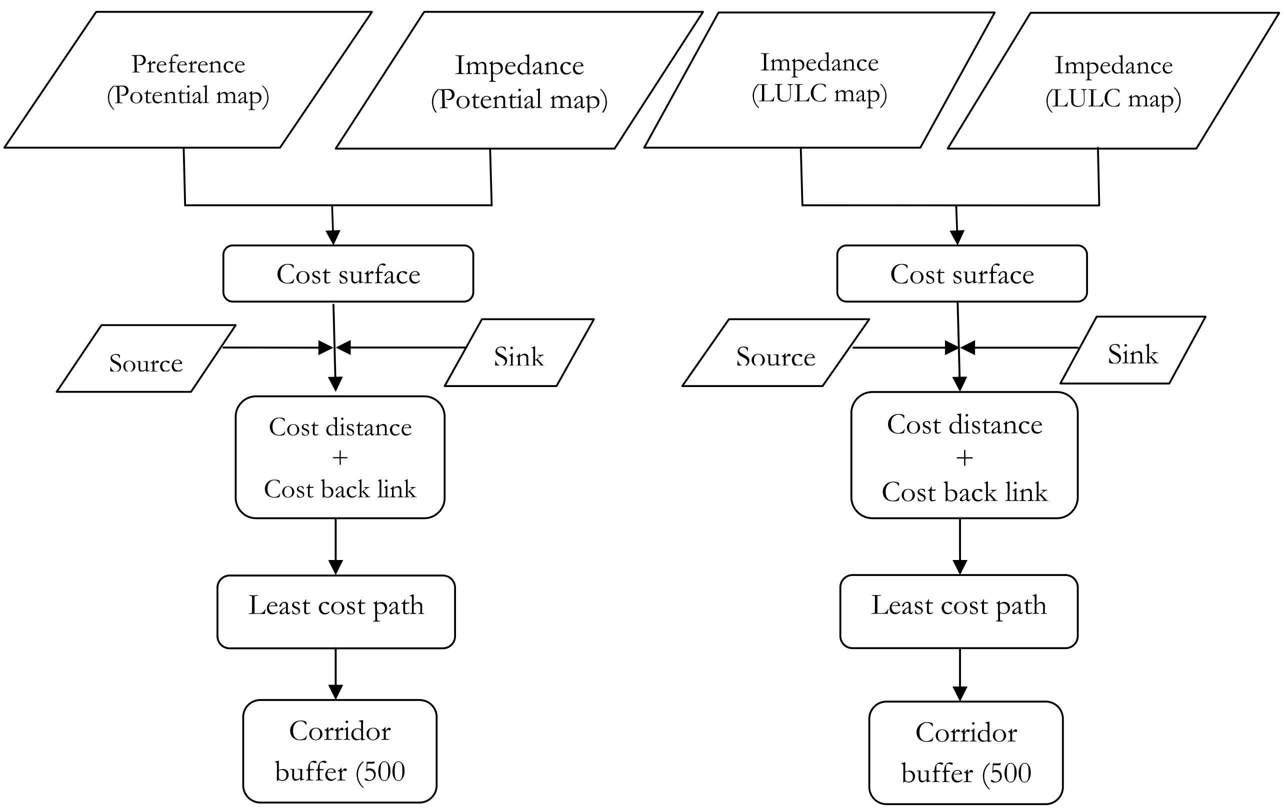

Figure 4-3: LCP Analysis

`

Table 4-7: Source and sink points

Source	Sink
3783420.907 N 4699708.686 E	3837489.016 N 4658492.391 E
3785521.508 N 4681905.585 E	3827762.219 N 4649440.969 E

Preference and impedance layers for potential and present day map were added to give two cost rasters respectively. After defining the source (identified from probability map), cost distance and cost back link were calculated in Arc GIS. Cost Distance tool was run using the cost dataset (preference impedance) which is used to identify the cost of travelling through each cell. The outputs from this tool were a distance dataset in which each cell contains a value representing the accumulated least cost of travelling from that cell to the source and a back link dataset that gives the direction of the least costly path from each cell back to the source. Least cost path was thereby calculated (see Fig.4-3) by defining distance raster, back link raster and sink (destination) input.

5. RESULTS AND DISCUSSIONS:

By using the framework designed for the study, the results mentioned ahead were obtained.

5.1. Potential Vegetation Map:

Potential vegetation map representing hypothetical vegetation of around 200-300 years ago (when there was no anthropogenic interference) is a result of Bioclimatic layers (as discussed in the methodology). Larger portion of the map was perhaps covered by northern mixed deciduous forest as shown in Fig 5-1 and table 5-1, which is believable as it is the most common forest type in the study area. The vegetation type is also fairly suited for elephant preference. Other forest types like moist sal cover as significant portion of Rajaji National Park which is indicated in the map. Rest of the forest types cover relatively less area. The map, has no impedance except slope as it is believed to have no anthropogenic interference. Therefore it is more favourable to elephant occurrence. Rivers, serving as preference to elephant presence and movement were super imposed on the map, with an assumption that the river course hasn't changed considerably over years.

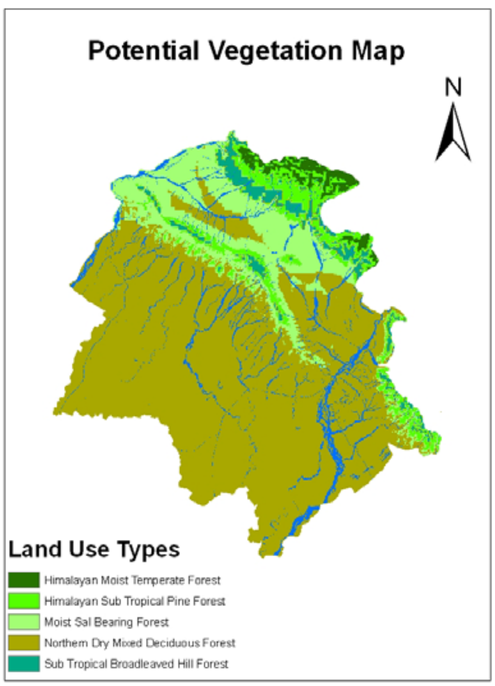

Figure 5-1:Potential vegetation map

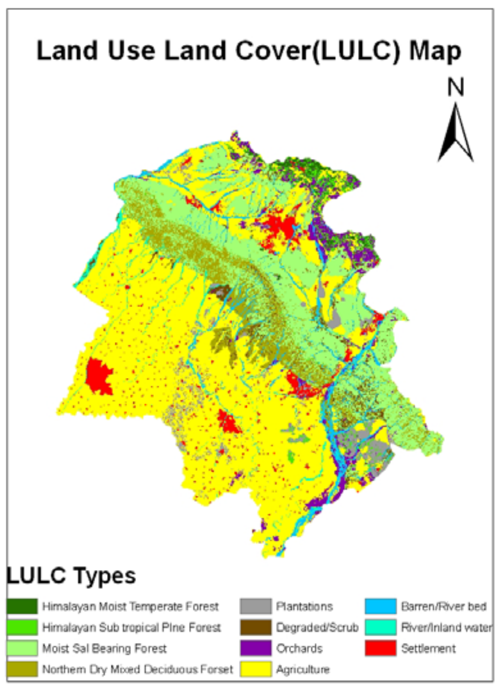

Figure 5-2: LULC Map (Present scenario)

The map is a hypothetical insight into the past and was not subject to any validation process but was validated by field surveys and interactions with the local population (Appendix-3).

Table 5-1: Areas covered by different LULC classes in the vegetation maps.

Sr.No.	LULC Classes	LULC Map (Present day)(Ha.)	Potential map (Ha.)
1.	Himalayan moist temperate	5307.93	11919.2
2.	Sub tropical pine	11468	41532.8
3.	Moist sal	121876	95349.2
4.	N.dry mixed deciduous	49266.6	434650
5.	Plantation	21471.5	21593.8
6.	Non forest vegetation/Orchards	13291.3	-
7.	Degraded/scrub	21091.6	-
8.	Agriculture	301288	-
9.	Barren/River bed	24744.7	-
10.	Water body/river	11105.9	-
11.	settlements	24129.9	-

Introduction of land use practises in the region has accounted for a loss of significant vegetation in the area. Northern dry mixed deciduous forest has faced maximum degradation of 385383.4 Ha. , Followed by Himalayan moist temperate forest with a loss of 6611.27 Ha and 30064.8 Ha. of subtropical pine and complete extinction of subtropical broadleaved hill forest.

5.2. LULC Map (Present Scenario)

Available DOS (Department of space) DBT(Department of biotechnology) map at a scale of 1:50,000 of 2010 were updated with frequent field visits. The map was divided into 11 land use and land cover classes. It depicts a large area being subject to agriculture plantation. Settlements are also observed dispersed over the area. The most important forest type playing a major role in elephant presence, northern dry mixed deciduous forest has been drastically reduced and is now confined mainly to Rajaji NP and the adjoining districts. Moist Sal bearing forest type also covers a smaller area relative to that in the potential map. Himalayan moist temperate forest is more or less the same as the potential vegetation. Subtropical broad leaved hill forest has completely vanished which covered a decent portion of area in the potential vegetation map.

Himalayan sub tropical pine forest which perhaps used to cover parts of areas near Rajaji NP is now confined only to the extreme north part of the study area as the region has been subject to plantation of mixed deciduous species (generally undergrowth) like *Mallotus phillipinensis, Bauhinia varigeta, Aegl marmalos* etc. in order to overcome forest degradation. Chir pine being the major species of subtropical pine forest has been lopped for fuel and fire wood[40] and hence can be believed to be degraded.

5.2.1. Accuracy Assessment:

Validation was done in ERDAS imagine 2013 with the help of GPS locations collected on field(42) and a few points(20) referred to Google satellite image were added as the field points were not sufficient .

Table 5-2: LULC Map accuracy assessment report

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
----------	----------	----------	-------	---------	-----
Class 0	1	1	1	---	---
Himalayan moist temperate	2	2	2	100.00%	100.00%
Sub tropical pine	1	1	1	100.00%	100.00%
Moist sal	7	6	5	71.43%	83.33%
N.dry mixed deciduous	30	28	25	83.33%	89.29%
Plantation	3	2	2	66.67%	100.00%
Non forest vegetation/Orchards	1	1	1	100.00%	100.00%
Degraded/scrub	4	6	4	100.00%	66.67%
Agriculture	10	12	10	100.00%	83.33%
Barren/River bed	5	6	4	80.00%	66.67%
Water body/river	2	3	2	100.00%	66.67%
settlements	5	3	3	60.00%	100.00%
Totals	71	71	60		

Overall Classification Accuracy = 84.51%

Overall Kappa Statistics = 0.8023

Moist sal has been classified into northern dry mixed deciduous forest as it is adjacent to dry deciduous forest in the study area which has lead to mixing of spectral signature of these two classes., thereby affecting Producers' and user's accuracy of this class.(Table 5-2). For the same reason northern dry mixed deciduous forest also shows less accuracy. Plantations have also been found to be mixing with northern dry mixed deciduous forests as plantations constitute of deciduous tree species. Therefore producer's accuracy of plantations has taken a toll. Barren land/river bed has been mistakenly classified into moist sal or deciduous forest type perhaps due to gaps in these forests or nearness to rivers. Settlements have been spectrally mixed with barren land and hence have low producers accuracy.

5.3. Multi Collinearity Testing:

Multi co linearity testing is an indicator of correlation amongst the explanatory variables. It was accomplished with the help of MATLAB. Variables having high coo linearity (>100) were opted out (indicating high coo linearity). However VIF close to values of 100 was included. In general VIF values higher than 10 are said to show high correlation among variables, but due to their importance in elephant distribution most of the variables were included. Another possible reason for VIF being high amongst the layers could be the fact that most of the layers are either factors of each other or are similar owing to the fact that they are derived from three main variables namely, maximum temperature, minimum temperature and precipitation. The results can be seen in table 5-3 and the layers in italics were left out of SDM.

Table 5-3: VIF results in MATLAB

Layers	Slope	DEM	BIO1	BIO2	BIO3	BIO4	*BIO5*	BIO6	BIO7	*BIO8*	BIO9
VIF	32.9	2.8	131.2	34.4	11.3	111.2	*240.0*	35.2	104.9	*165.7*	10.7
Layers	*BIO 10*	BIO 11	*BIO 12*	*BIO 13*	BIO 14	BIO 15	BIO 16	*BIO 17*	BIO 18	BIO 19	
VIF	*193.2*	86.0	*763.1*	*152.2*	16.5	80.7	30.2	*960.5*	53.9	27.4	

5.4. Species Distribution Modeling with MAXENT:

In total, 16 environmental layers mentioned in Jacknife analysis of fig 5-3 were used as input to MaxEnt and the following results were obtained:

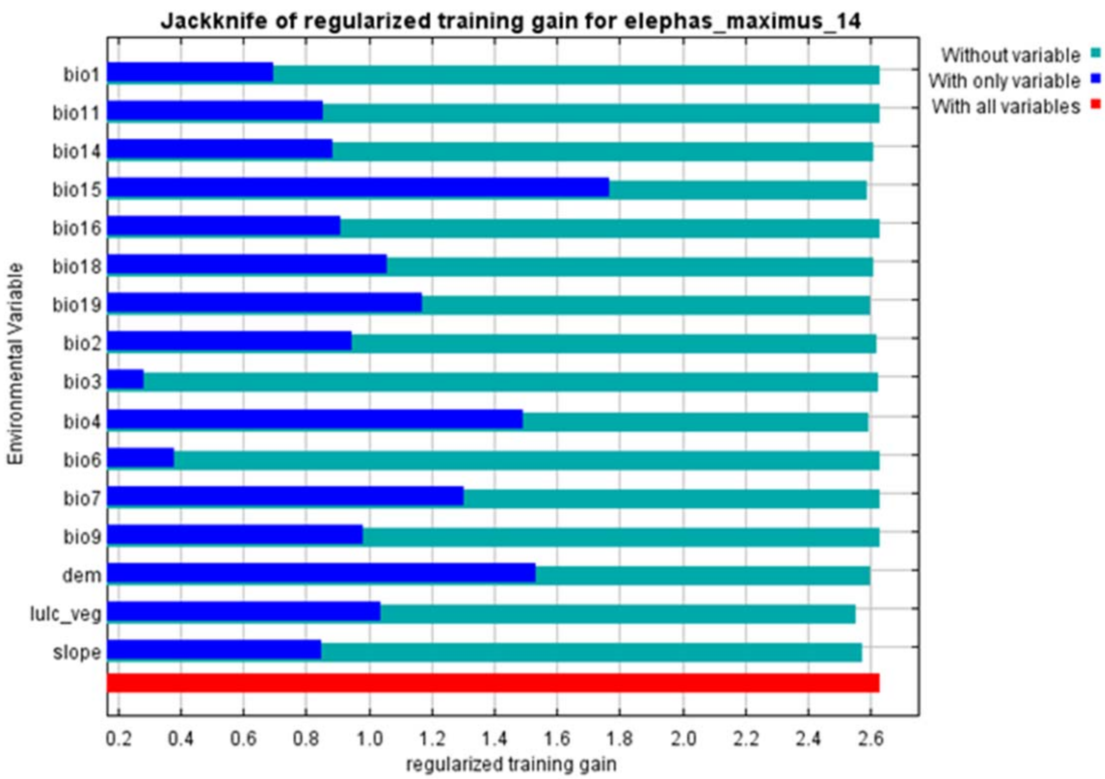

Figure 5-3:Jacknife of training gain

The Jacknife graphs shows the training gain of each variable if the model was run in isolation, and compares it to the training gain with all the other variables.

As shown in Fig.5-3 Bio 15(Precipitation of seasonality) has the maximum individual contribution in predicting elephant distribution with Bio3 (Isothermality) contributing least for Regularized training gain (the same for test gain) .This means that BIO 15 alone has a considerable contribution in increasing the gain for both testing and training samples.

BIO 15(Precipitation seasonality) has been found to affecting range patterns of elephants in Zimbabwe where the range was found to increase in wet season as compared to late dry or early dry seasons[41]. The fact can be related to distribution patterns of Asian elephants as well.

`

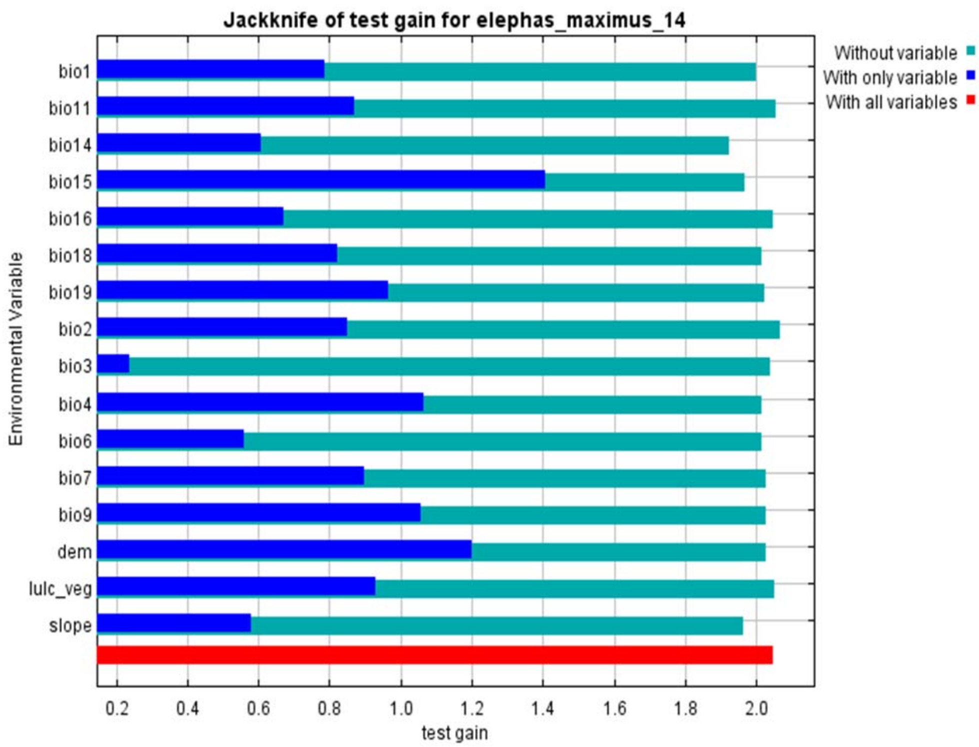

Figure 5-4: Jacknife of test gain

Fig. 5-5 shows the AUC to be 0.968 indicating the model to be a good fit as compared to random. The closer the value is to 1, the better the model has performed, where 0.5 indicates model no better than random. This indicates that the model has predicted the elephant habitat with more than 96% spatial accuracy.

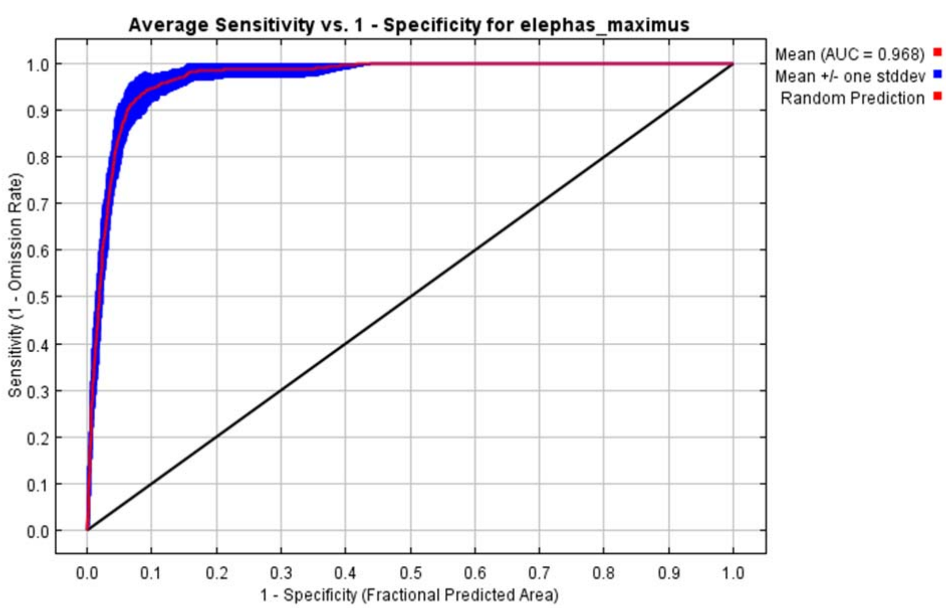

Figure 5-5:Avg. sensitivity versus specificity graph

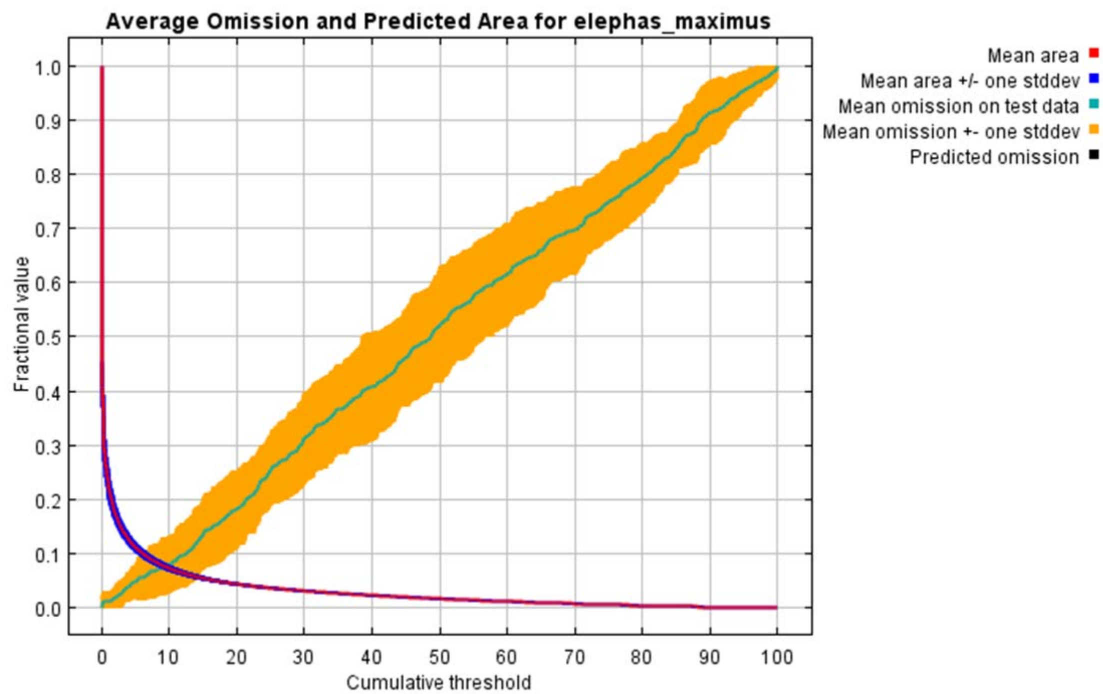

Figure 5-6:Avg. Omission and predicted area

Fig.5-6 displays the omission rate and area predicted for elephant suitability at different thresholds. The orange and blue shading surrounding the lines on the graph represent variability.

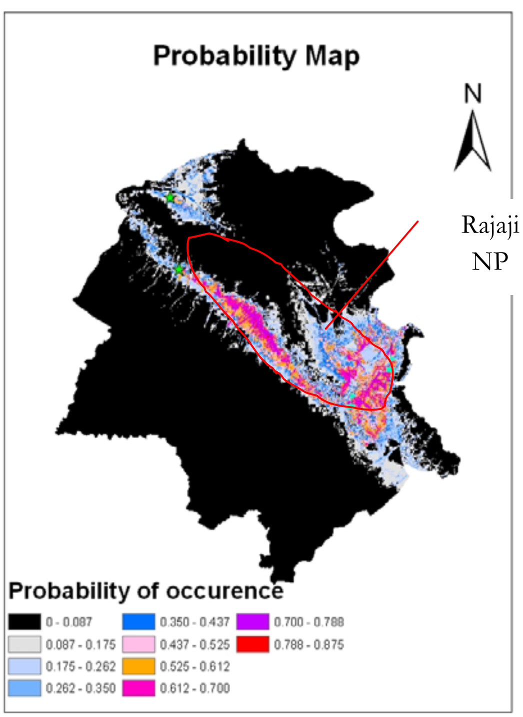

Figure 5-7: Probability map

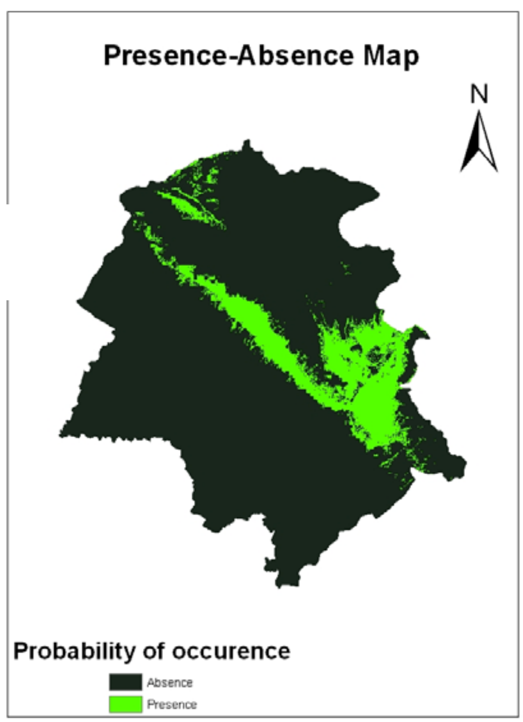

Figure 5-8: Presence-absence map

The high probability of occurrence are the areas chosen as source and sink for LCP because high probability of target species denotes high concentration per unit area and the migration from the area for food and shelter[42]. Sources (denoted by stars) and sinks (Denoted by flags) can be identified in Fig 5-10. The areas having the highest probability values from 0.612-0.875 are the areas of Rajaji NP and the surrounding areas.

Fig. 5-8 represents the probability map being converted into only two values of absence and presence at a threshold of equal training sensitivity and specificity of 0.223.Equal training sensitivity and specificity threshold was used as it is known to be giving good results in geographic distribution of animal species in general[43].

Table 5-4: Percent contribution of variables

Variable	Percent contribution
BIO 15	50.8
LULC_veg	13.7
BIO 16	10.4
BIO 19	7.4
BIO 18	5.8
DEM	4.3
BIO 4	3.5
Slope	2.4
BIO 7	0.5
BIO 1	0.3
BIO 14	0.3
BIO 11	0.3
BIO 2	0.2
BIO 9	0.1
BIO 6	0.1
BIO 3	0

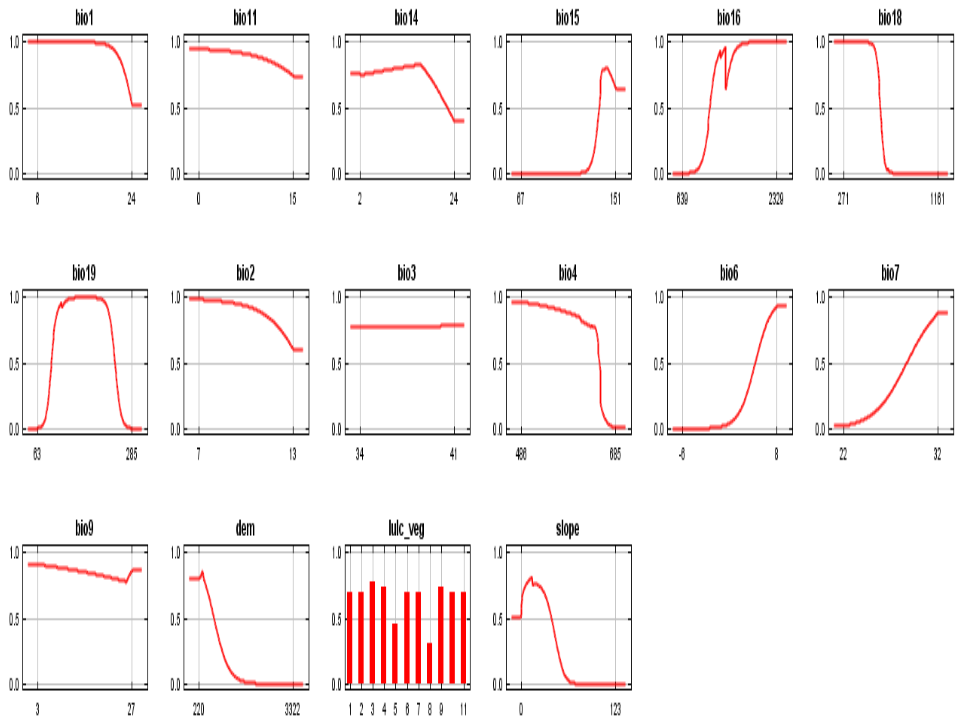

Figure 5-9: Response curves

As evident from the table 5.4, the percent contributions of the different bio-climatic variables vary. But bio15 which denotes precipitation seasonality accounts for more than 50% of the factor responsible for elephant distribution. Apart from seasonality, the land use and land cover of the region also plays a significant role in the distribution of the elephants. It is interesting to note that isothermality (BIO3) has negligible role in the elephant distribution implying that the annual temperature variations have a lesser role to play in the migration of elephants in the region.

The response curves in Fig. 5-9 shows how logistic prediction value changes by change in the environmental variables.BIO 15, which has the highest contribution to the gain as observed in jackniff and percent contribution table shows higher predicted suitability values between 100-151 and lesser towards 60.Bio 16 has higher values of predicted suitability at around 2000-2329 increasing its contribution in however BIO 18 has higher values from 270-800 an lower towards 1000. Observing DEM and slope we find that logistic prediction is more when the values are less and is liable to decrease with increase in values.

5.5. Least Cost Path (LCP) Analysis:

Cost path which were afterwards buffered to give potential corridors were calculated for two sources and two sinks respectively. The result was four paths as shown in Fig.5-10, 5-11, 5-12 and 5-13.Figure 5-10 and 5-11 represent cost paths of the potential map. These two maps show the probable path when the area was free from anthropogenic intrusions.

The paths/corridors can be seen to pass through most preferred elephant vegetations viz. northern dry mixed deciduous and moist sal [44].Other forest types which are low in elephant preference do not depict LCP crossing through(Fig. 5-10).

However in Fig. 5-11 the path/corridors can be seen crossing even subtropical broadleaved hill forest which is relatively low in preference but still preferable.

The forested area at higher elevation covered by mainly Himalayan moist temperate forest do not show elephant movement as generally elephants are not found to be reaching higher elevation areas[22].

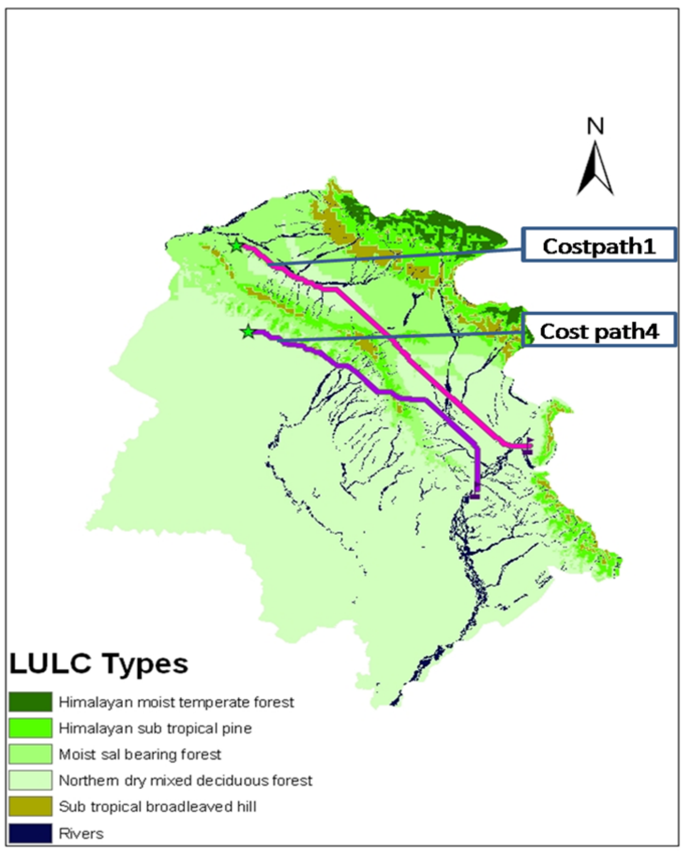

Figure 5-10: LCP (Potential map)

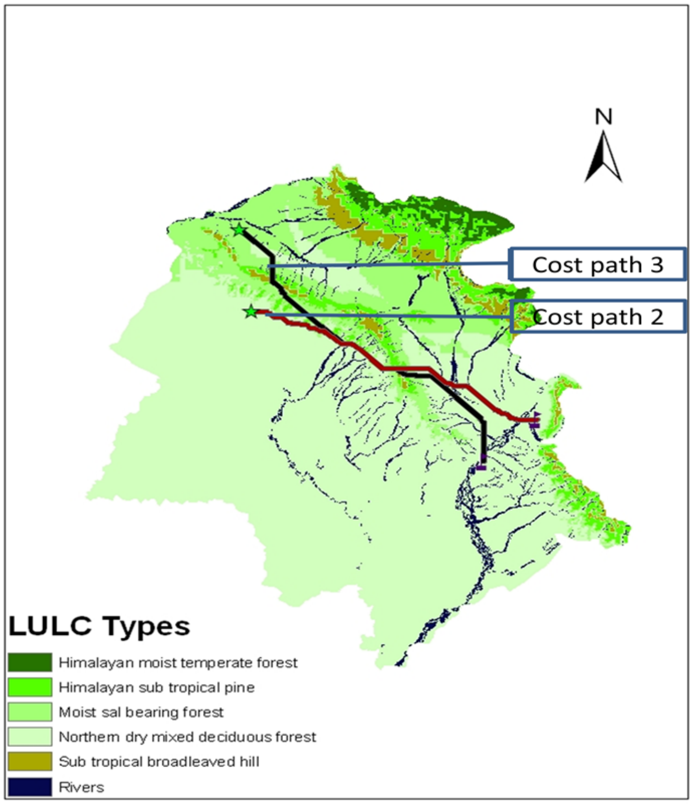

Figure 5-11: LCP (Potential map)

The LULC maps in Fig.5-10 and 5-11 show the four corridors as a result of LCP analysis on the maps. The corridors have been generated as a line. A buffer of 500 m has been taken as this is the area used by the elephants during their movement. and hence have a width of 1 km. The path is a result of preference and impedance that the elephant is likely to face while moving from source to destination. The species is liable to face least resistance while choosing these paths.

On observing these paths we realise that they cover the favourable elephant vegetation viz. moist sal and northern dry deciduous forests and avoid the settlements and road and rail tracks.

It is also interesting to note that the path crosses over rivers and streams and hence it can be safely said that that elephants are going to cross the rivers while moving from one forest path to the other which is also a known fact [45].The species also avoids higher elevation[22] hence no corridor is seen crossing forest temperate forest land (which are found in higher elevations).

The migration paths/corridors have changed over years as we can observe in the Fig.5-12 and 5-13.Cost path 1shows the maximum shift in the LULC map relative to the potential map perhaps due to introduction of land use practises like settlements and road and rail.

`

All the other paths except cost path 1 haven't shown any significant changes so Cost path 1 can be said to have the most significance and the land use areas falling under this path can said to be most effective in changing the elephant movement as compared to what it used to be before introduction of any land use practises.

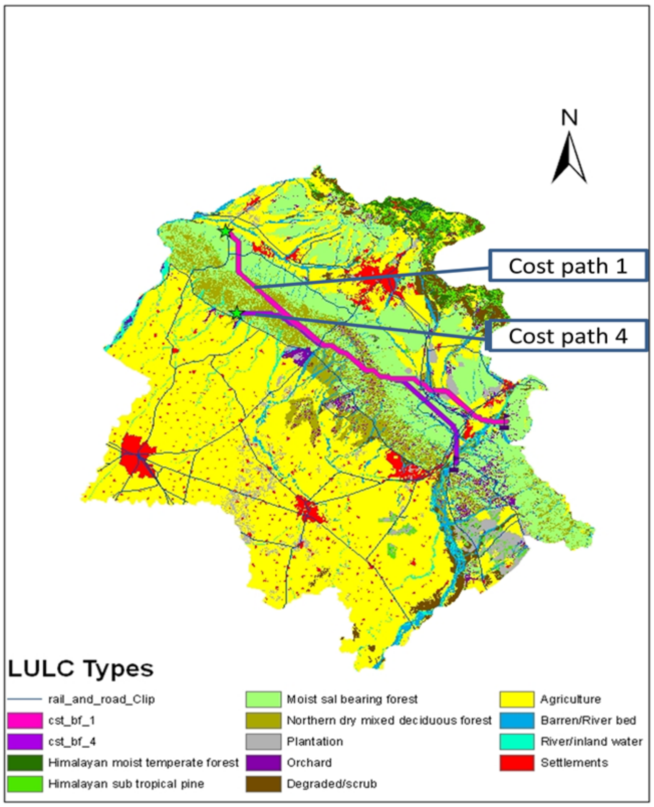

Figure 5-12: LCP (LULC Map)

The table 5-5 shows length and area of different corridor paths in both the vegetation maps.

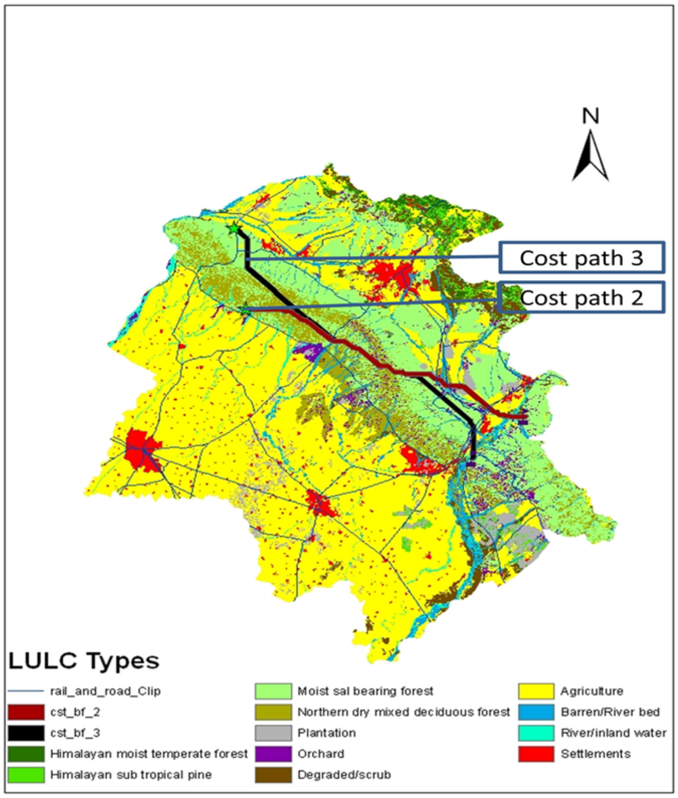

Figure 5-13: LCP (LULC Map)

Table 5-5: Area of cost paths

	Cost path 1	Cost path 2	Cost path 3	Cost path 4
Area-**LULC Map(Present)(Sq.Km.)**	76.07	62.70	74.67	61.27
Length-**LULC Map(Present)(Km.)**	74.65	61.30	73.21	59.84
Area-**Potential vegetation Map(Sq.Km.)**	72.60	63.00	75.30	61.95
Length-**Potential vegetation Map(Km.)**	71.14	61.16	73.82	60.53

Fig shows that cost path 1 has undergone most change perhaps due to intervention by settlements and road and rail. As clear from the picture Cost path 1 has been changed as a result of settlements being introduced in the area which was once free from them in the potential vegetation map. Other cost paths show a minor shift and are more or less the same as in the potential vegetation map.(Fig5-10).

The most favourable forest type being northern dry mixed deciduous and moist sal shows the corridor area passing through a significant stretch in the potential vegetation map .(cost path 1 of 5-12)

5.6. Human elephant conflict(HEC)

The area has been facing human elephant conflicts due to change in elephant movement over years[12] as observed in the LCP maps(Fig 5-11, 5-12 ,5-13 and 5-14).Elephant movement has been changed as a result of introduction of manmade practises like built up area, roads and rail .The development and settlements inside forests by tribal population has lead to instances of causalities for both man and elephants in the areas in around Rajaji NP and other districts of Uttarakhand falling under Shiwalik elephant reserve[12].

The map of fig. 5-14 shows the areas liable to be affected by human elephant conflict. It is a result of change in corridor paths from that of potential vegetation map and LULC map of present day. The highlighted yellow area is basically the land use areas from present day that fall under potential corridor paths derived from the potential vegetation map. The map explains that the highlighted area should have been the elephant movement path in present scenario too but due to anthropogenic disturbances, the species has been forced to change their path and hence has resulted in conflict instances between man and elephant.

As observed in Fig 5-14 areas of District Dehradun and Haridwar show a very high chance of facing HEC. These areas have previously also been found exposed to conflict instances. However parts of district Saharnpur are not seen very susceptible to HEC with just a few highlighted areas. HEC in the highlighted areas can be attributed to rail and road construction and settlements in forest by tribal people.

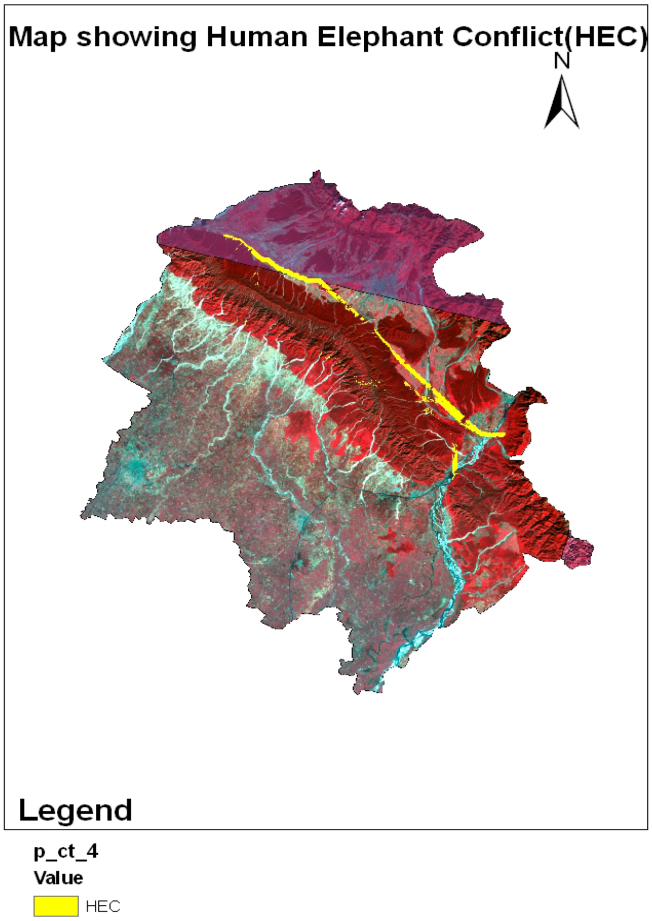

Figure 5-14: HEC

5.7. Land use and land cover areas(from LULC map) falling under corridors of potential vegetation and that of present day vegetation:

Table 5-6 and 5-7 depicts the land use areas falling under corridor paths of potential vegetation map and LULC of present day respectively. It is interesting to note that cost path 1 which has faced the most change if taken up by the elephants today is probable to find under a significantly big area of land use practises like settlements and agriculture which justifies the HEC map and confirms the change in elephant movement as a result of anthropogenic interference.

`

Table 5-6:: Cost path covering land use and land cover types of Potential Vegetation Map

Sr.No.	**LULC TYPE**	**Area (Cost path 1) (Ha.)**	**Area (Cost path 2) (Ha.)**	**Area (Cost path3) (Ha.)**	**Area (Cost path4) (Ha.)**
1	Himalayan moist temperate	19.44	-	-	-
2	Sub tropical pine	34.02	4.86	17.01	6.48
3	Moist Sal	1408.59	2194.24	4559.49	3243.24
4	N.dry mixed deciduous	188.73	1900.26	1799.82	1902.69
5	Plantation	250.29	313.47	34.02	34.02
6	Non forest vegetation	56.7	196.02	224.37	219.51
7	Degraded /scrub	251.1	187.11	20.25	20.25
8	Agricultur e	3244.86	844.02	218.7	188.73
9	Barren/Ri ver bed	962.28	270.54	235.71	199.26
10	Water body/rive r	57.51	142.56	76.95	105.30
11	settlement s	506.25	-	62.37	62.37

Table 5-7: Cost path covering land use and land cover types of LULC Map (Present scenario)

Sr.No.	LULC TYPE	Area (Cost path 1) (Ha.)	Area (Cost path 2) (Ha.)	Area (Cost path3) (Ha.)	Area (Cost path4) (Ha.)
1	Himalayan moist temperate	-	-	-	-
2	Sub tropical pine	29.00	10.53	21.00	09.72
3	Moist sal	4165	2191.86	4429.08	3215.70
4	N.dry mixed deciduous	2475	1995.84	1981.26	1935.90
5	Plantation	363	294.03	34.02	34.02
6	Orchards	277	221.13	187.11	183.87
7	Degraded/ scrub	186	150.66	20.25	20.25
8	Agriculture	1149	862.65	251.91	183.37
9	Barren/River bed	351	276.21	199.26	191.16
10	Water body/river	113	119.88	76.14	104.49
11	settlements	-	-	61.56	61.56

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Observations from the potential vegetation shows that the region was totally covered by the five forest types namely Himalayan moist temperate, moist sal bearing, Himalayan sub tropical pine, northern dry mixed deciduous and sub tropical broadleaved hill forest. The loss of forest cover as a result of various land use practises was 65.39 % with complete extinction of subtropical broadleaved hill forest type from the area. Hence the study helped us in interpreting what was probable vegetation of the area which has now been put to several land use practises. Potential vegetation map generated is a fairly accurate prediction of the past as validated by literature and discussion with local. The course of river being considered same as that of present day can be biased to an extent and could have been overcome with a more extensive knowledge of the geology of the area.

Maximum entropy (MaxEnt) based species distribution model (SDM) was used for mapping elephant distribution, which gave very good results and hence can be considered for mapping other mammal species in the area. MaxEnt results show that the probability of finding elephants is higher mainly in areas of Rajaji NP, Timli range and Lansdwone division. The SDM technique proved that precipitation seasonality and LULC map play a major role in deciding upon elephant preference and hence made the highest contribution in their distribution Another interesting conclusion of the study was the shift in potential corridor (mainly Corridor 1) with the change in vegetation resulting into change in elephant movement. The reasons for which were found out to be mainly human settlements in and around forest area and developmental activities. Running an LCP in the area has also led us to infer the areas liable to being affected by man and elephant conflict. The areas mainly affected by HEC according to this study are parts of District Dehradun and Haridwar[12].

6.2. Recommendations

Potential vegetation map can be used as a base map to assess the forest types that are favourable to elephants and can be taken up as a challenge by the policy makers to reclaim these vegetation types. Study of change in elephant preference with seasonality can also be included for a more explicit elephant preference and impedance pattern. Sub types of the main forest types can be included in more extensive studies as it is likely to lead to more accurate predictions. LULC map has been validated with decent accuracy but can be improved by taking more field points and use of higher resolution dataset. Classes showing mixing of pixels (Sal and deciduous forest) can be merged for higher accuracy or more field points of these land cover types can be included.

Including more number of land use classes can lead to a get a better picture of true preference and impedance layers. Agriculture however not a hindrance as such for elephant movement can be included as an impedance layer (which is otherwise in the study) and LCP can be run in order to see what changes does it lead to in the migration path.

Collinearity amongst variables is high and can be worked out for. Each variable can be separately checked for VIF and the once having less importance can be ruled out. Dataset used can be experimented with by using different set of environmental layers and more climatic and topographic variables can be included to get a more precise distribution of elephant presence. Other SDM approaches like GARP, boosted regression can be tried for obtaining better results.

More number of source and sink points can be included in the study with an approach of obtaining more number of cost paths thereby making the results more accurate and reliable. Including more variables as impedance and preference by extensive study of elephant behaviour with literature and filed surveys can come in handy.

The change in corridor paths shows the land use areas playing a major role in the shift. Reclamation of these areas with preferred vegetation cover can be dealt with and structuring of ecological flyovers or artificial corridors concept can be incorporated by the policy makers.

HEC results show the areas of District Dehradun and Haridwar to have higher exposure to conflicts hence these areas can be put to HEC zonation with least and highest probability is further studies. The results can also be helpful to policy makers in order to deal with the present HEC problem in the area.

`

REFERENCES

[1] "WTI." [Online]. Available: http://www.wti.org.in/oldsite/project-in-focus/nov2008-national-elephant-corridor-project.html. [Accessed: 25-May-2013].

[2] P. Fernando and P. Leimgruber, "Asian Elephants and Seasonally Dry Forests."

[3] N. S. Sodhi, L. P. Koh, B. W. Brook, and P. K. L. Ng, "Southeast Asian biodiversity: an impending disaster," *Trends Ecol. Evol.*, vol. 19, no. 12, pp. 654–660, Dec. 2004.

[4] "Elephas maximus (Asian Elephant, Indian Elephant)," *The IUCN red list of threatened species*. [Online]. Available: http://www.iucnredlist.org/details/7140/0. [Accessed: 24-May-2013].

[5] R. Sukumar, "Ecology and conservation of Asia's elephants," in *The story of Asia's elephants*, Marg foundation, 2011, pp. 282–305.

[6] "About the Asian elephant | Elephant Family." [Online]. Available: http://www.elephantfamily.org/what-we-do/about-the-asian-elephant/. [Accessed: 13-Nov-2013].

[7] "Asian Elephant | Species | WWF." [Online]. Available: http://worldwildlife.org/species/asian-elephant. [Accessed: 13-Nov-2013].

[8] "EDGE of Existence," *EDGE of Existence*. [Online]. Available: http://www.edgeofexistence.org/mammals/species_info.php?id=12. [Accessed: 30-Oct-2013].

[9] Prepared by the National Wildlife Corridors Plan Advisory Group, "Draft National Wildlife Corridors Plan March 2012," Prepared by the National Wildlife Corridors Plan Advisory Group.

[10] "Biological Corridors." [Online]. Available: http://www.biodiversidad.gob.mx/v_ingles/corridor/biologicalCorridors1.html. [Accessed: 19-Dec-2013].

[11] P. Fernando and J. Pastorini, "Range wide status of asian elephants," Centre for Conservation and Research, Rajagiriya, Sri Lanka , Anthropologisches Institut, Universität Zürich, Zürich, Switzerland.

[12] "Human-Elephant Coflict (HEC) Issues in Uttarakhand, India." [Online]. Available: http://www.conservationhimalayas.com/index.php?option=com_content&view=article&id=122:protect-the-elephants&catid=42:wildlife-news. [Accessed: 25-May-2013].

[13] R. Joshi, R. Singh, A. Dixit, R. Agarwal, M. S. Negi, N. Pandey, R. Pushola, and S. Rawat, "Is Isolation of Protected Habitats the Prime Conservation Concern for Endangered Asian Elephants in Shivalik Landscape?," *Glob. J. Environ. Res.*, vol. 4, no. 2, pp. 113–126, 2010.

[14] "The Hindu : Opinion / Leader Page Articles : Tribal people and preserving prime forests." [Online]. Available: http://www.hindu.com/2005/11/29/stories/2005112900931400.htm. [Accessed: 20-Dec-2013].

[15] R. JOSHI and R. SINGH, "Unusual Behavioural Responses of Elephants: A Challenge For Mitigating Man-elephant conflict in'Shivalik Elaphant Reserve', Northwest India," *Interanational J. Conserv. Sci.*, Sep. 2011.

[16] S. . Sahoo, "Elephant News Sri Lanka: Update of the Uttarakhand Elephant Project from Dr Santosh Kumar Sahoo." [Online]. Available: http://elephantssrilanka.blogspot.nl/2008/09/update-of-uttarakhand-elephant-project.html. [Accessed: 19-Aug-2013].

[17] "WILDLIFE CENSUS : Uttarakhand Forest, Government Of Uttarakhand, India." [Online]. Available: http://forest.uk.gov.in/pages/display/81-wildlife-census-. [Accessed: 20-Dec-2013].

[18] R. . Semwal, "The terrai arc landscape in India," Forests & Biodiversity Conservation Programme W orld Wide Fund for Nature- India.

[19] R. Sukumar, "The elephant in independent Asia," in *The story of Asia's elephants*, Marg foundation, 2011, pp. 242–282.

[20] M. A. Kumar, D. Mudappa, and T. S. Raman, "Asian elephant Elephas maximus habitat use and ranging in fragmented rainforest and plantations in the Anamalai Hills, India," *Trop. Conserv. Sci.*, vol. 3, pp. 143–158, 2010.

[21] J. . Daniel, "Habitat," in *The asian elephant, a natural history*, Rajaji national park,25th anniversary edition., Natraj publishers.17 Rajpur road,Dehradun, 2009, pp. 62–83.

[22] A. Roy, B. S. S. Devi, B. Debnath, and M. S. R. Murthy, "Geospatial modelling for identification of potential ecological corridors in Orissa," *J. Indian Soc. Remote Sens.*, vol. 38, no. 3, pp. 387–399, 2010.

[23] N. Baskaran, M. Balasubramanian, S. Swaminathan, and A. A. Desai, "FEEDING ECOLOGY OF THE ASIAN ELEPHANT ELEPHAS MAXIMUS LINNAEUS IN THE NILGIRI BIOSPHERE RESERVE, SOUTHERN INDIA," *J. Bombay Nat. Hist. Soc.*, vol. 107, no. 1, p. 3, 2010.
[24] J. . Daniel, "Behaviour," in *The asian elephant, a natural history*, Rajaji national park,25th anniversary edition., Natraj publishers.17 Rajpur road,Dehradun, 2009, pp. 84–115.
[25] S. J. Phillips, M. Dudík, and R. E. Schapire, "A maximum entropy approach to species distribution modeling," in *Proceedings, Twenty-First International Conference on Machine Learning, ICML 2004*, 2004, pp. 655–662.
[26] R. A. Baldwin, "Use of Maximum Entropy Modeling in Wildlife Research," *Entropy*, vol. 11, no. 4, pp. 854–866, Nov. 2009.
[27] S. J. Phillips, R. P. Anderson, and R. E. Schapire, "Maximum entropy modeling of species geographic distributions," *Ecol. Model.*, vol. 190, no. 3–4, pp. 231–259, Jan. 2006.
[28] R. Kalle, T. Ramesh, Q. Qureshi, and K. Sankar, "Predicting the Distribution Pattern of Small Carnivores in Response to Environmental Factors in the Western Ghats," *PLoS ONE*, vol. 8, no. 11, p. e79295, Nov. 2013.
[29] E. Rameshan, "A study of human elephant interaction in an environmental perspective.," Mahatma Gandhi University, Kottayam, Kerala, India, 2014.
[30] A. J. Dickman, "Key determinants of conflict between people and wildlife, particularly large carnivores, around Ruaha National Park, Tanzania," University College London (University of London), 2009.
[31] E. . Osborn and G. . Parker, "Linking two elephant refuges with a corridor in the communal lands of Zimbabwe," *Afr. J. Ecol.*, vol. 41, pp. 68–74, 2003.
[32] G. Arrendran, K. Raj, and M. Munsi, "Geospatial modeling to assess elephant habitat suitability and corridors in northern Chhattisgarh, India," *Int. Soc. Trop. Ecol.*, 2011.
[33] P. S. Roy, S. P. S. Kushwaha, A. Roy, and S. Saran, "Biodiversity Characterization at Landscape level using Geospatial Model," *An. XVI Simpósio Bras. Sensoriamento Remoto-SBSR Foz Iguaçu PR Bras.*, pp. 3321–3328, 2013.
[34] "Welcome To ISRO :: Remote Sensing Applications :: NRC." [Online]. Available: http://www.isro.org/scripts/rsa_bc.aspx. [Accessed: 05-Mar-2014].
[35] R. J. Hijmans, S. E. Cameron, J. L. Parra, P. G. Jones, and A. Jarvis, "Very high resolution interpolated climate surfaces for global land areas," *Int. J. Climatol.*, vol. 25, no. 15, pp. 1965–1978, Dec. 2005.
[36] D. C. Powell, C. G. Johnson, E. A. Crowe, A. Wells, and D. K. Swanson, *Potential vegetation hierarchy for the Blue Mountains section of northeastern Oregon, southeastern Washington, and west-central Idaho*. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, 2007.
[37] "LAND COVER CLASSIFICATION SYSTEM." [Online]. Available: http://www.fao.org/docrep/003/x0596e/x0596e01e.htm. [Accessed: 07-Feb-2014].
[38] R. K. Paul, "Multicollinearity: Causes, Effects and Remedies," 2006.
[39] "Detecting multicollinearity using variance inflation factors | STAT 501 - Regression Methods." [Online]. Available: https://onlinecourses.science.psu.edu/stat501/node/83. [Accessed: 16-Feb-2014].
[40] S. S. Negi, *Uttarakhand: Land and People*. M.D. Publications Pvt. Ltd., 1995.
[41] M. Chase and C. Griffin, "Seasonal Abundance and Distribution of Elephants in Sioma Ngwezi National Park, southwest Zambia," *Pachyderm*, vol. 0, no. 45, pp. 88–97, Jul. 2009.
[42] A. . Singh and R. Chalisgaonkar, "Restoration of Corridors to Facilitate the Movement of Wild Asian Elephants in Rajaji-Corbett Elephant Range, INDIA," Uttarakhand State Irrigation Department, May 2006.
[43] R. A. Bartel and J. O. Sexton, "Monitoring habitat dynamics for rare and endangered species using satellite images and niche-based models," *Ecography*, vol. 32, no. 5, pp. 888–896, Oct. 2009.
[44] J. Borah and K. Deka, "Nutritional Evaluation of Forage Preferred by Wild Elephants in the Rani Range Forest, Assam, India," *GAJAH*, p. 41, 2002.
[45] E. A. van der Grift and R. Pouwels, "Restoring habitat connectivity across transport corridors: identifying high-priority locations for de-fragmentation with the use of an expert-based model," in *The Ecology of Transportation: Managing Mobility for the Environment*, P. J. Davenport and J. L. Davenport, Eds. Springer Netherlands, 2006, pp. 205–231.

APPENDICES

APPENDIX 1:

LISSS-III

Temporal Coverage	2003-12-31 to current day
Spatial Coverage	90 N
90 S	180 W
180 E	
Data Type	Optical/Multi Spectral Radiometry High Resolution
Spatial Resolution	23.5 meters
Original data format:	BSQ+TIFF

APPENDIX 2:

MATLAB code for multicollinearity

```
x = dlmread('database.txt', '\t', 1, 3);
info = colldiag(x);
disp(info.str);
colldiag_tableplot(info);
```

Result:

```
"NEW_MASK_D".

>> x = dlmread('database.txt', '\t', 1, 3);
>> info = colldiag(x);
>> disp(info.str);

    Variance decomposition proportions
         X1    X2    X3    X4    X5    X6    X7    X8    X9    X10   X11   X12   X13   X14   X15   X16   X17   X18   X19   X20   X21
CondInd
1        ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
4        ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
11       ----- 0.649 ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
13       ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
26       ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
33       ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
57       ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
70       ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
83       ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
130      ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
134      ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
167      ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
228      ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
261      ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
296      ----- ----- 0.715 ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
333      ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
382      ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
415      ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
482      ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
560      ----- ----- ----- ----- ----- ----- 0.524 ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
847      ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- 0.846 ----- ----- ----- 0.899 ----- ----- -----

  VIF:  32.9   2.8 131.2  34.4  11.3 111.2 240.0  35.2 104.9 165.7  10.7 193.2  86.0 763.1 152.2  16.5  80.7  30.2 960.5  53.9  27.4

>> colldiag_tableplot(info);
```

`

APPENDIX 3:

Field interactions

QUES: What used to be the most prevalent forest type around 50-60 years ago?
Ans: Sal forest and mixed forest constituting *Bombax ceiba, Bauhinia varigeta, Greiwa optive, Toon ciliate, Mallotus phillipinensis* etc..
QUES: How have the elephants interfered in your life?
Ans: Elephants are responsible for picking of cattle, raiding of agriculture crops and trampling of people at certain encounter instances.
QUES: What is your livelihood practice?
Ans: Agriculture and cattle rearing.

Figure 6-1:Rajaji National Park

APPENDIX 4: ELEPHANT LOCATIONS

The map was drawn at scale of 1:75,000 .

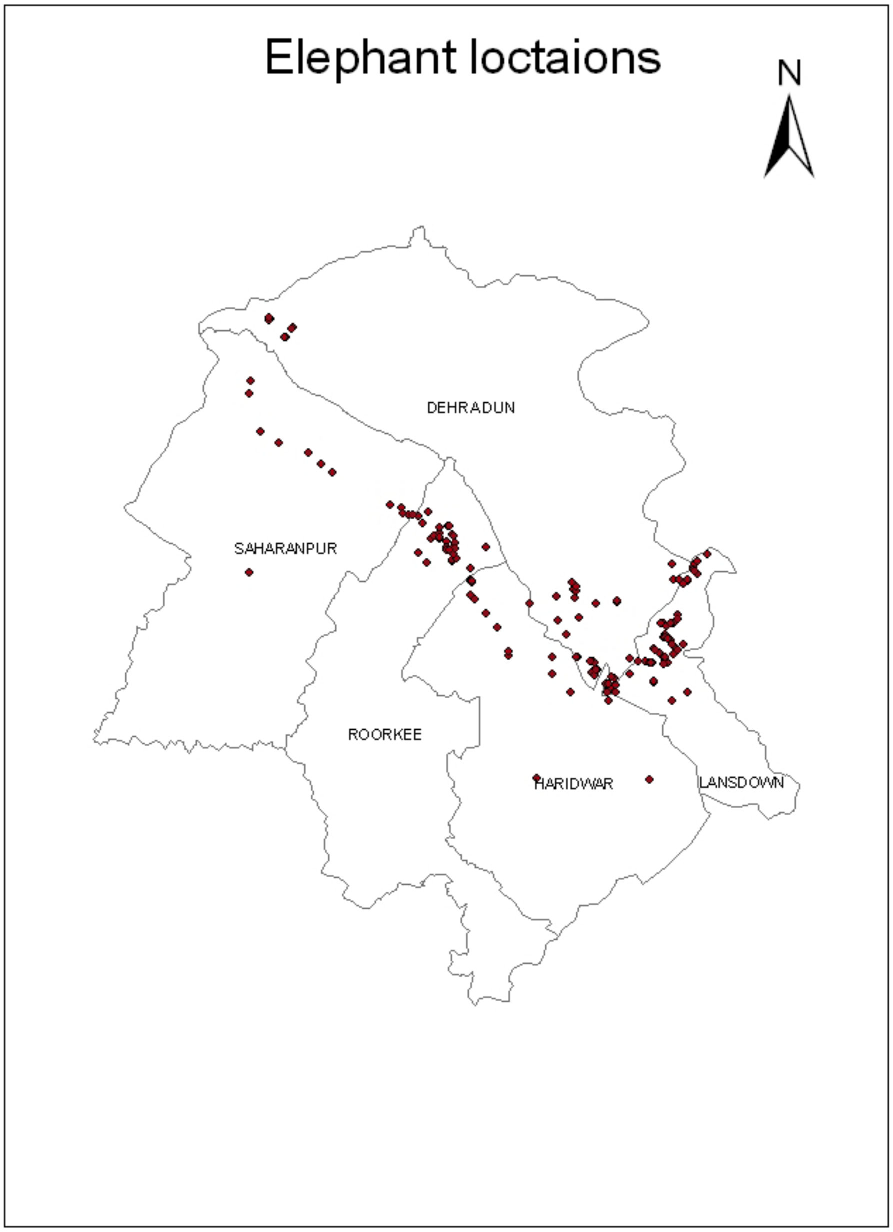

Figure 6-2:Elephant locations

`

APPENDIX 5: Field photographs


Figure 6-3: Eucalyptus plantation


Figure 6-4: Sal forest


Figure 6-5: Elephant droppings


Figure 6-6: Waterhole


Figure 6-7: Hill covered by deciduous forest


Figure 6-8: Bamboo clump trampled by elephant