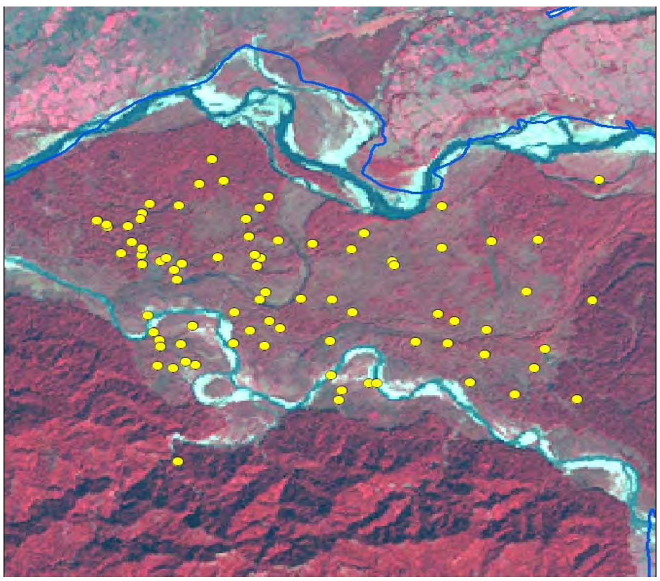
Habitat Evaluation and Suitability Modeling of *Rhinoceros unicornis* in Chitwan National Park, Nepal: A Geospatial Approach

Project Report



Submitted by:
Hemanta Kafley
Department of National Parks & Wildlife Conservation
Nepal

Supervisor
Dr. Eric Dinerstein
Chief Scientist and Vice President
Conservation Science Program
World Wildlife Fund US

INSTITUTE OF INTERNATIONAL EDUCATION
ALCOA FOUNDATION
ITTO
WWF

Conservation and Sustainability Fellowship Program
2008

Habitat Evaluation and Suitability Modeling of *Rhinoceros unicornis* in Chitwan National Park, Nepal: A Geospatial Approach

By Hemanta Kafley
(hemuosho@yahoo.com)
December 2008

Project Report Submitted to
Alcoa Foundation, Conservation and Sustainability Fellowship Program
Institute of International Education
World Wildlife Fund
ITTO

DISCLAIMER
This document describes work undertaken as part of Alcoa Foundation's Conservation and Sustainability Fellowship Programme. All views and opinions expressed herein remains the sole responsibility of the author, and do not necessarily represent those of the Institutes.

- Hemanta Kafley

Conservation and Sustainability Fellowship Program
2008

Dedicated to
Distinguished conservationist ***Late. Narayan Prasad Poudyal***
The then Director General of Dept. of National Parks & Wildlife Conservation
Government of Nepal

Acknowledgements

This work is a combination of the efforts of many people in my life who have helped me to place myself in this position that I could successfully complete the research fellowship activities including this project report. It is certainly very rewarding part of the report that allows me to realize and document their supports hereby.

Firstly, I would like to extend my sincere thanks to **Department of National Parks and Wildlife Conservation** of the Government of Nepal that supported me to undertake this fellowship. I am thankful to **Alcoa Foundation**, Conservation sustainability Fellowship Program and **Institute of International Education** for my selection to the fellowship program and providing me an opportunity to be a part of prestigious community of Alcoa Fellows. **Chitwan National Park** authority made my work possible by providing permission to conduct field work. Therefore, I am obliged to the authority and all the staffs who hosted me and created comfortable ambience for completing field work. My field work in Chitwan would not have been possible without the help of my trusted research colleagues **Rupak Maharjan** and **Madhav Khadka** who were always together with me in the field and provided all possible support, whenever required. Their tremendous effort in arranging logistics and providing intellectual insights for conducting field survey were of immense importance for undertaking field work. I thank them a lot.

My sincere thanks go to my supervisor **Dr. Eric Dinerstein**, who helped me conceptualizing my work from the very beginning. His constant support and technical insights from project development phase to final report preparation was crucial for accomplishing this work. I am indebted to **Jessica Forrest** who helped me during entire office work of the project for data analysis and GIS modeling. Her analytical ideas and tremendous experiences in wildlife habitat modeling guided me to complete the work efficiently. Thanks to Jessica for spending lot of time helping me in data preparation, data analysis and model generation. I had great time working with her. I cannot overlook help extended, whenever required, by fellow interns and other staffs at CSP. I am thankful to all of them.

I am grateful to **Dr. Eric Dinerstein**, **Donna Kutchma**, **Jon Miceler and Shubash Lohani** for supporting me to undertake an internship at CSP, World Wildlife Fund. This enabled me to interact with the experts and use necessary software for completing the project. I am also indebted to **Dr. Mahendra Kumar Shrestha,** Director, Save the Tiger Fund, who provided me images of the study area and technical insights while preparing the project report. I am thankful to **International Tropical Timber Organization (ITTO)** that provided me with the fellowship to undertake an internship at WWF, Washington DC to complete the project.

My friends **Dr. Michael Spinelli** and **Cindi Spinelli** encouraged and supported me at every step of my conservation endeavor, be it academic or professional. **Dr. Felix Spinneli and Margaret Spinelli** hosted me for the entire internship period. Their parental love and encouragement is the main source of inspiration that enabled me to accomplish this work more efficiently. My loving sister **Ruthie** and brother **Louis** were always ready for any support I wanted. It is extremely hard for me to express my sincerest heartfelt thanks through mere words to the **Spinelli family**. It is lot more than any word can imply.

My parents, who brought up me to this position inspiring and supporting my pursuits, are always my guide to step ahead. My wife **Mandira Sharma** and daughter **Abhiru Kirti** who accepted my stay away from them for about a year during field work in chitwan and internship in USA, are always memorable and source of my inspiration. Without this support from my family members this project would not have been possible. I thank all of them a lot.

-Hemanta Kafley

Abstract

Effective Management and conservation of wildlife populations and their habitats largely depend on our ability to understand and predict species-habitat interactions. Intensive ground surveys cannot keep pace with the rate of land-use change and consequently habitat composition over large areas. We explored how effectively do Remote sensing satellite imagery and GIS modeling technique could be used for assessing habitat suitability of *Rhinoceros unicornis* and what are the habitat factors influencing rhinoceros distribution in lowland floodplain of Nepal.

The Landsat ETM+ satellite imagery (Path-142&Row-041) of the study area was used for classifying land use/land cover. Image processing and feature extraction was done in Erdas Imagine 8.7. We used supervised classification technique and maximum likelihood decision rule. GIS layers of habitat parameters- continuous distances from grasslands, water body, sand bank / barren land, guard posts, Agriculture/ settlement and categorical land use/land cover map were used as predictor variables. The animal presence-only locations were used as dependent variable and Maximum entropy (MAXENT) modeling was run for predicting species potential geographic distribution.

The most significant result of the image classification was that the proportion of pure grassland patches in the chitwan National Park is only 7 percent of the total area. Riparian forest, developed as a result of grassland succession, accounts for 8 percent of the park area which otherwise, as a grassland, served as a food source for *R. unicornis*. The Maxent model based on remotely sensed factors, habitat factors and rhino presence locations resulted in much larger area (443sq.km) classified as suitable for Rhinos. The contribution of the variable *distance to water* (62.9 percent) was highest to impact the model. The model performance was assessed using receiver operating Characteristics (ROC) plots and Jackknife tests.

The area under the training data ROC cuve (AUC) was 0.952 and that of test data ROC curve was 0.931 highly acceptable than the Random model AUC of 0.5. Therefore we concluded that Maxent modeling approach can be used to model the species geographic location for

assessing habitat suitability of the target wildlife with the help of presence-only datasets. The suitability map resulted from the modeling was useful to delineate the sites that required specific planning and management interventions. This result can be effectively used for enhancing suitability of different habitat types in favor of Rhinoceros and the ecosystem services the area provides for overall socio-economic and ecological sustainability that the conservation sector aims to provide.

Contents

ACKNOWLEDGEMENTS .... **IV**

ABSTRACT .... **VI**

CONTENTS .... **VIII**

LIST OF FIGURES .... **IX**

LIST OF TABLES .... **IX**

CHAPTER 1 INTRODUCTION **1**

1.1 Wildlife Habitat Evaluation 3
1.2 Remote Sensing 8
1.3 Geographic Information System (GIS) 9
1.4 Rhinoceros unicornis in Chitwan National Park 10
1.5 Remote Sensing and GIS in Habitat Suitability Analysis 13
1.6 Rationale 16

CHAPTER 2 CHITWAN NATIONAL PARK **18**

CHAPTER 3 OBJECTIVES **21**

CHAPTER 4 DATA, SOFTWARE AND EQUIPMENT **22**

4.1 Satellite Data 22
4.2 Software 24
4.3 Equipment 25

CHAPTER 5 METHODOLOGY **26**

5.1 Data collection 26
5.1.1 Pre-field activity *26*
5.1.2 Field Work *26*
5.1.3 Post-field work *28*
5.2 Database creation 28

CHAPTER 6 RESULTS AND DISCUSSION **31**

6.1 Land use / Land cover classification 31
6.2 Maxent Modeling 33
6.1 Rhino Habitat suitability 38

CHAPTER 7 CONCLUSIONS & RECOMMENDATIONS **43**

7.1 Conclusions 44
7.2 Recommendations 45

REFERENCES **47**

REFERENCES **47**

List of Figures

Figure. 1 Greater one-horned rhino: Historic and present distribution 12
Figure. 2 Location of Chitwan National Park 20
Figure. 3 Landsat FCC of study area (P 142, R 41) 24
Figure 4. Map showing Rhinos presence locations 29
Figure. 5 Area under land use/land cover categories 31
Figure 6. Land use / Cover map of Chitwan National Park and periphery 32
Figure 7. Response Curve of Variables affecting Maxent Prediction 34
Figure 8. Jackknife of AUC for *Rhinoceros unicornis* 35
Figure 9 Jackknife of regularized training gain for *Rhinoceros unicornis* 35
Figure 10. Omission rate and predicted (All variables) 36
Figure 11. Jackknife of regularized training gain for R. unicornis 37
Figure 12. Response curve of variable 'Distance from water source' 37
Figure 13. Omission rate and predicted area (Uncorrelated variables) 37
Figure 14. Comparison of ROC Curves of the two models 38
Figure 15. Maxent habitat suitability map 39
Figure 16. Three categories of habitat suitability 39
Figure 17. Suitable/Unsuitable habitats for rhinos in Chitwan National Park 40
Figure 18. Area under suitability category 41

List of Tables

Table 1. Features of landsat ETM+ sensor 22
Table 2. Relative contribution of the independent variables to the Maxent 33

Chapter 1 Introduction

Historically greater one-horned rhinoceros were limited to the floodplains and forest tracts in the Brahmaputra, Ganges, and Indus River valleys. These Rhinos maintained their extensive distribution until relatively recently. However, at present, no more than 2000 individuals remain in the wild, with only two populations containing more than 100 individuals: Kaziranga National Park in Assam, India and Chitwan National Park in Nepal (Dinerstein, 2003). In Chitwan this fabulous species faced tremendous pressures from hunters, poachers and concentration of human settlements during 1950s. Poaching and habitat destruction resulted extinction of swamp deer and buffalo, and Spillet and Tamang (1967) guessed that there were only 100 rhinos in 1966 (Laurie, 1978). Concerned at the rapid decline of the forest areas and rhinos from Chitwan, His Majesty's Government of Nepal laid out series of conservation interventions viz. establishment of Mahendra Deer Park, proposed for establishment of a wildlife sanctuary, declaration of wildlife sanctuary etc during 1950s and 60s.

Chitwan has seen dramatic decrease and increase in rhino population as shown by the census carried out in different times. Wildlife habitat management is becoming increasingly important around the globe and especially in the developing countries where indiscriminate deforestation continues. As human populations increase in size and demand more resources, their expansion, typically happens at the expense of wildlife habitat (Mwalyosi, 1991). The demand by an ever-growing population in such countries results in rapid depletion of natural resources thereby posing threat to wildlife.

Wildlife management and conservation initiatives are only possible with the appropriate information on wildlife and its habitat. Wildlife habitat basically comprises of food, cover and water. Each species require a particular habitat or the space, food, shelter and other needs of survival so much so that species are said to be the product of their habitat (Smith, 1974). Wildlife and its habitat management essentially require information on food, water, shelter and site conditions suited to a particular animal species much accurately and frequently. The quantity and quality of habitat is generally reflected in the status of life requisite factors, its seasonal variation and the spatial extent. Moreover, the site characteristics like edges between vegetation covers have to do much with animal categories, species diversity and abundance (Westman, 1985).

The spatial relationship between cover types, their respective areas, nearness to water, suitable corridors for daily movement and seasonal migration have to do with abundance and steady progress of wildlife (Kamat, 1986). Wildlife conservation and management effort at different levels has been handicapped due to non-availability of good quality data on species, habitat and suitability of the habitats for different species. The problem is more acute in the developing countries, where wildlife and biodiversity conservation is often less prioritized due to more pressing demands of food security and poverty alleviation (Kushwaha *et al.*, 2004).Consequently, human encroachments on natural habitats, impacts of various developmental projects as rail, roads, polluting industries etc are the critical issues facing wildlife conservation today.

The greater one horned rhinos (*Rhinoceros unicornis*), once ranged throughout terai plains, is a globally endangered species survived as fragmented population in some protected areas of India and Nepal (Fig. 1). The declaration of Chitwan National Park in 1973, including floodplains of Reu, Rapti and Narayani, was instrumental to help survive rhinos in their natural habitat. This reduced poaching and illegal activities significantly. As a result, the population increased to nearly 600 individuals (Dinerstein and Price, 1991) marking this as one of the most successful conservation stories in the world.

This study attempted to use remote sensing data and GIS technology aided with field study for analysis of habitat condition to predict suitable habitat for rhinoceros in the Chitwan National Park. Habitat suitability modeling predicts the suitability of habitat for a species based on an assessment of habitat attributes such as habitat structures, habitat type and spatial arrangements between habitat features. Habitat models have become well-accepted tools to understand the habitat characters of different organisms evaluating habitat qualities and developing wildlife management strategies (Verner *et al*., 1986)

1.1 Wildlife Habitat Evaluation

Conservation biologists and managers need a range of both classical analyses and specific modern tools to face the increasing threats to biodiversity (Caughley and Gunn, 1996; Austin, 2002). Among these tools, habitat-suitability modeling has recently emerged as a relevant technique to assess global impacts (for example, those due to climate change, Berry *et al*., 2002; Thuiller, 2003), to define wide conservation priorities (Margules and Austin, 1994). Wildlife management is a multi-disciplinary field based applied science, essentially aimed at understanding of the relationships between the wild animals and their habitats, as influenced by human interference. The habitat themselves are complex ecosystems deriving their supportive attributes from a host of biotic and abiotic components. Habitat is a place occupied by a specific population within a community population (Smith, 1974). Habitat selection is important part of organism's life history patterns. Roy et al., 1986 states that preservation of wildlife requires a complete knowledge of their spatial requirements commonly referred to as ‘habitat’.

Wildlife habitat includes a variety of factors viz., soil, topography, geology, geomorphology, temperature, rainfall, water availability and persistence, vegetation composition and cover characteristics including human influence on all of these factors. Hence it has also been defined to incorporate several interrelated concepts dealing with space, time and function (Columbe, 1977). Not to be confused with mere vegetation associations for a site, Hall et al., 1997 consider habitat as “Resources and conditions present in an area that produce occupancy (including survival and reproduction) by an organism and it is always organism specific”. It is considered to be the key to organizing knowledge about wildlife. In conclusion, maintenance of the appropriate habitat is the core function to all management (Foose and Strien, 1997).

Habitat evaluation comprises of assessing the quality and quantity of available habitat for selected wildlife species for appropriate management and maintenance objectives. Systematic habitat evaluation was first developed in the 1970s by the

U.S. Fish and Wildlife Service. Habitat evaluation is the assessment 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 (DeLeeuw and Albricht, 1996). It is based on ecological science, well researched in USA in connection with environmental impact assessments, where aim has been to ensure that appropriate consideration is given to wildlife in the decision making process. Simultaneously, it has been made obligatory to use standardized procedures in Habitat Evaluation Procedure (HEP) developed by U.S. Fish and Wildlife Service (USFWS) for habitat evaluation, both for cost reasons and for ease of communication of data both between and within organizations and professionals. The aim of any HEP is to evaluate an area on the basis of the sustainability of key habitat factors for target species. That is with detailed ecological information about the species; the characteristics of the habitat can be evaluated (using numerical rating schemes) on the basis of key habitat factors.

Large spatial extensions and dynamic temporal dimensions along with its indefinite components have made nature extremely vast and complex. This complexity of natural phenomena demands highly efficient instruments and technology to amplify our understanding power. Whilst measuring instruments and experiments are extensions to our senses, mathematics, statistics and numerical algorithms are extensions to our brain. Statistics allow exploring, extracting and summarizing useful information hidden in an overwhelming quantity of data, and analytical and numerical models try to reproduce natural processes and test their sensitivity to parameter changes (Hirzel, 2001). Hence, as the real world is unreachable to experimentation, mentors try to duplicate it in computer or on blackboard where it may be easily manipulated: this operation is called “modeling”.The whole art then consists in selecting the few factors that will be included in order to reproduce adequately the phenomena of interest. The model mimics the real world by keeping only those elements that are relevant to achieve a particular purpose (Hirzel, 2001).

Interactions between organisms and their biotic and abiotic environmental characteristics strongly influence habitat use, the spatial occupancy of species, and the proportion of each species within the community, and thus, the community composition and structure. The study of the relationships between species and their environment has traditionally been a central issue in ecology and nowadays of prime importance in conservation and planning. Modeling and simulation are useful tools to roughly mimic the ecosystem structure and their functioning but their ability to model individual distribution, populations and ecosystems depends on the available modeling techniques and computing power (Brosse *et al*., 1999). However, dynamic properties of animal distribution can seldom be reflected accurately in a static map though we have a perfect knowledge of the biology of a species. Moreover, human and logistic limitations make it impractical to survey large areas and, inevitably, our knowledge of the spatial distribution of most species will have many gaps. A common solution to this problem is to resort to predictive habitat modeling and regard the results as potential habitat, able to be reached and colonized by a species (Seone *et al*., 2004).

Habitat models relate the occurrence pattern of a species (either as presence/absence or abundance) with some predictors selected from a set of ecologically plausible candidate variables. A large number of potential predictors can be obtained due to the increasing development of (GIS) techniques and digital cartography (thematic maps and satellite imagery). Thus, potential predictors, such as topographic and climatic data, on the one hand and vegetation or land-use/land-cover digital maps on the other are widely available potential sources of information for modeling (Seoane *et al*., 2004). Many statistical tools are available to reproduce the structure and functioning of ecosystems, according to environmental features (Reyjol *et al*., 2001). Therefore a wide variety of statistical and machine-learning methods have been introduced for habitat 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. Inductive or empirical approaches are based on the analysis of field collected data. Thus predictions are induced from empirical observations (Vogiatzakis, 2003). Therefore when the species-environment relationships are not known, the inductive approach is used to derive the ecological requirements of the species from locations in which the species occurs (Corsi *et al*., 2000 and Omullo 1996). Guisan and Zimmerman (2000) grouped statistical approaches into seven groups viz. Generalized regressions, classification techniques, environmental envelopes, ordination techniques, artificial neural networks and other simple models that can be generated directly from GIS, using overlay of environmental variables, measures of variation, measures of similarity and final rules for combining single probabilities.

This study uses the Maximum entropy modeling of species geographical distributions, popularly known as MaxEnt modeling technique to model the habitat suitability in the study area. The study focuses on applicability of remote sensing and GIS techniques for rhinoceros habitat suitability modeling. The focus of this study is to explore as much habitat information as possible from the Landsat ETM+ satellite remote sensing data of 30m resolution and use the satellite data and GIS techniques for generating habitat suitability map through statistically justified machine-based technique.

1.2 Remote Sensing

Remote sensing is defined as acquisition of information about the condition and / or the state of target at earth's surface by a sensor that is remotely located. All objects above absolute zero temperature radiate electromagnetic energy by virtue of their atomic and molecular oscillations. The total amount of emitted radiation increases with the body's absolute temperature and peaks at progressively shorter wavelengths. These principles form the basis of remote sensing, widely used for acquiring information about the earth surface (land and ocean) and atmosphere using sensors onboard aircraft or ballons (airborne) or satellites (spaceborne). The basic of this technology is, however, to detect, measure and record electromagnetic radiation reflected or emitted from the intercepted target. The intent for sensing electro-magnetic radiation is that each and every objects in nature has its unique reflectance or emittance properties. These spectral properties, if ingeniously exploited, can be used to distinguish one object from the other or to obtain information about shape, size and other physical and chemical properties.

At present there are different types of sensors designed to sense the reflected or emitted energy in different bands of electromagnetic spectrum. Advancement of the sensor capability to record energy from small possible ground resolution cell has revolutionized the application potential of this technology. Optical sensors that detect solar radiation in visible and near infrared wavelength regions form image resembling photographs taken by a camera high up in space. The remotely sensed data, thus acquired, contains both spatial (Size, shape, pattern etc characteristics) as well as the spectral information enabling data interpretation more efficient and amenable for further spatial and spectral analysis.

Remote sensing has been used extensively in wide variety of disciplines, but it is not a discipline or exclusively a subject itself. Digital image processing aids to manipulate and analyze image data products produced by remote sensors which otherwise do not reveal any information in its raw form. Thus it generates information in the form of knowledge where application of this knowledge in desired pursuits is the ultimate objective. Remote sensing data is effectively used to gather information on shapes, sizes and total variations of the different kinds of land use/land cover features viz. human settlement, forests, denuded area, wetlands, grasslands, hills etc. Animals have no specific reflectance values that can be recorded by specific sensors placed in the satellite. However, animals are habitat specific. Habitat, which is a composition of several climatic factors, altitude, geographical extent and various cover composition, can be mapped out with reference to these habitat attributes. Information obtained through remotely sensed data about different physiographic characteristics, climatic factors, and land use pattern along with prior knowledge of the area under study and limited field study together can give reliable information on macro and microhabitats. Depending upon the desired precision of study, it can be precisely known that a particular part of earth's surface has particular habitat type. Hence, prediction of the animal species that are expected to occupy those habitat types can also be made precisely.

1.3 Geographic Information System (GIS)

GIS is a system of hardware and software used for storage, retrieval, mapping and analysis of spatial and non-spatial data. Spatial features are stored in a coordinate system, which refers to a particular place on the earth. Spatial data and associated attributes in the simiar coordinate system can then be overlaid together for mapping and analysis. It provides ample opportunities to integrate, analyze and generate scenarios based on human knowledge and geospatial parameters. Combination of remote sensing and GIS has made tasks of planning and decision making much easier (Kushwaha *et al*., 2000). GIS has been playing increasingly important role in the conservation biology and wildlife management because they provide an efficient means for modeling potential distribution of the species and habitat (Davis *et al*., 1990 ; Kushwaha *et al*., 2000). The usefulness of GIS technology is now limited due to data availability, quality and the reliability of habitat preferences model than by the technological obstacles. Habitat evaluation normally requires integration of various habitat variables of both spatial and non-spatial nature (Sawarkar, 1986) that can be effectively managed and analyzed through GIS technology for automating the application of HIS models. It is hence considered inevitable tool which integrates tremendous capacity for data analysis and management.

1.4 Rhinoceros unicornis in Chitwan National Park

Worldwide destruction and conversion of natural habitats to other uses have inevitably threatened the species supported by those habitats. The prerequisite for ensuring the perpetual persistence of the elements that comprise biodiversity is to develop the basic information required for their effective management. Obviously, this information should incorporate data base on the distribution, biology and habitat requirements of species in danger.

Greater one-horned rhinoceros represents one of the most endangered species of large mammals in the world. Historically, the rhinos were distributed in the floodplain and forest tracts in Brahmaputra, Ganges and Indus river valleys.

Formerly extensively distributed in the Gangetic plain today it is restricted to parts of south Asia and South East Asia in Nepal and West Bengal in the north, the Duars, and Assam of India (Fig. 1). Kaziranga national park, prime habitat of rhinoceros, after initiation of conservation programme, realized five-fold increase in rhino population between 1959 and 1985 and after that no significant population increase has been recorded (Kushwaha *et al*., 2000). This trend has been attributed to the habitat extent and condition of the park. Similarly, chitwan population in Nepal, declined to about 100 in sixties (Caughley, 1969; Pelinck and Uprety, 1972). However, effective conservation measures adopted through the establishment of national park in 1973 the rhino population of the chitwan increased to about 270-310 by 1975 (Laurie, 1978). By 1988, the population rose to 358 (Dinerstein and Price, 1991), 466 in 1994 (Yonzon, 1994) and 544 in 2000 (Rhino count, 2000). Result of the Rhino count 2005 shows that the population of endangered greater one-horned rhinoceros in Chitwan national park has dropped from 544 in 2000 to 372 i.e. 31percent decline in five years. The recent census in 2008 has shown satisfactory population status of 408 individuals. This unpredictable population structure demands mapping habitat suitability for rhinoceros in the area to identify the amount of area that has been actually used by the species. At the same time the area that could be potentially used by the species is also very important for enhancing its suitability.

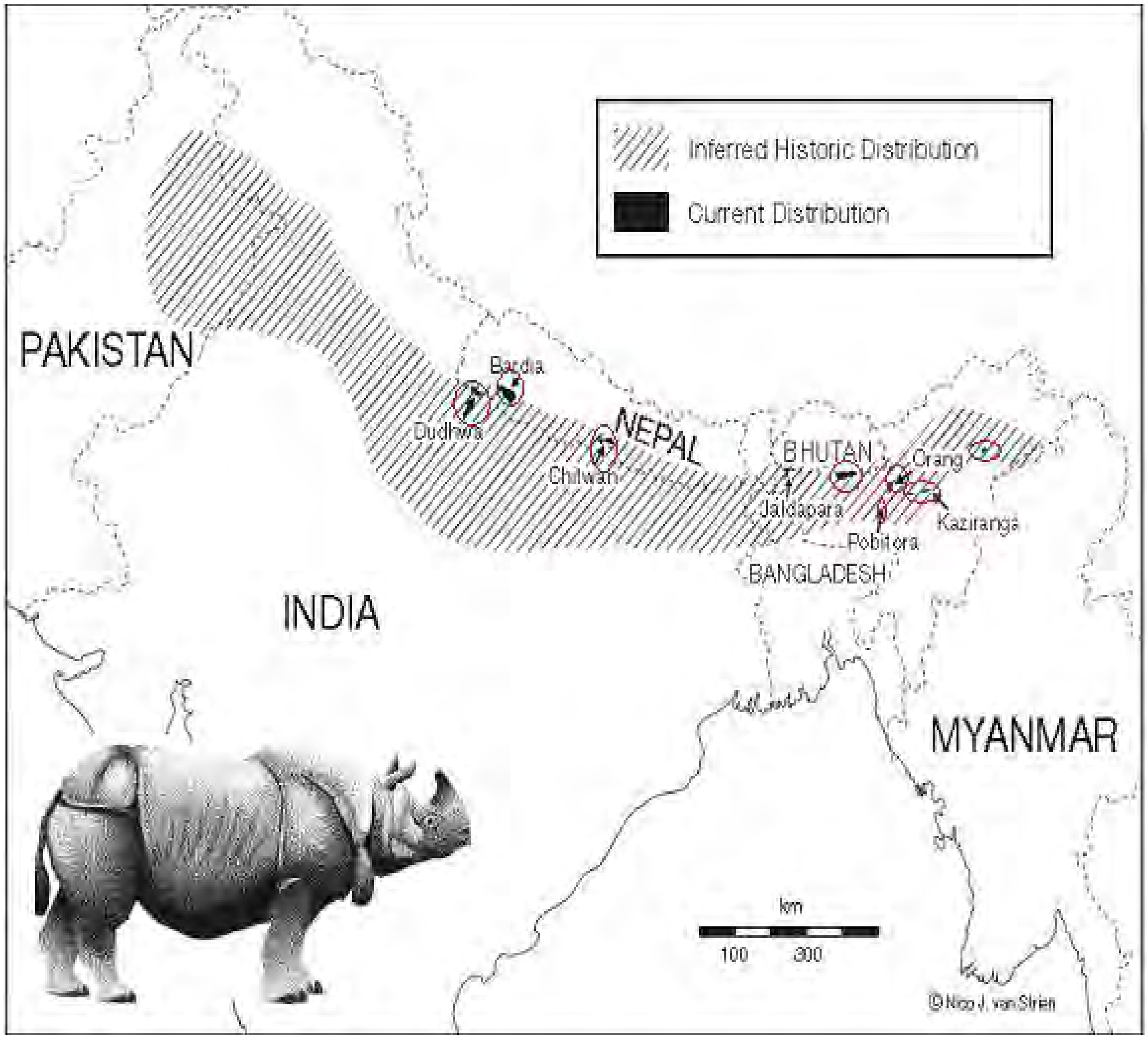


Figure 1. Greater one-horned rhino : Historic and present distribution (Source: Asian Rhinos: Status Survey and Conservation Action Plan, 1997)

Rhinos are solitary as a rule, though several may occupy the same patch of jungle. Its food chiefly comprise of grass. They inhabit the alluvial flood-plain vegetation of sub-tropical climates where water and green grass is available all year round (Prater, 1971). Laurie (1978) claimed that rhinoceros in chitwan reach highest densities in areas with the greatest vegetation diversity based on his study that included qualitative assessment of vegetation diversity. However, Dinerstein 2003 presents that the highest densities do not relate to degree of vegetation diversity but to the abundance of *S. spontaneum*. Saccharum is staple in rhinoceros diets and it normally exceeds 50 percent of the diet each month (Jnawali, 1986). *S.*

spontaneum is exceptional among the common tall perennial grasses of Chitwan in that new shoots sprout soon after cutting, grazing, burning, or inundation by floods. Monsoon floods are therefore most influential component of Chitwan's disturbance regime (Dinserstein, 2003), that supports maintain grassland habitat.

1.5 Remote Sensing and GIS in Habitat Suitability Analysis

Until recently many conventional techniques have been applied for collecting data on natural resources. Relatively many ground-based studies have been carried out on habitat and corridor use by the wild animals (Bhat and Rawat, 1995; Hobaugh, 1984; Johnsing and Joshua, 1994; Mishra and Johnsingh, 1996; Rodgers, 1990; Saxena, 1986; Tiwari, 1986). The role of remote sensing has been emphasized in quick appraisal of habitat attributes, identification of new sites for protected areas and current status of corridors (Kamat, 1986 and Panwar, 1986). In number of cases remote sensing can supplement or partially replace tedious ground survey methods. Moreover, ground methods have limitations as whole area can not be accessed in one go in many of cases and the information collected may not be as accurate as is possible through remote sensing aided by limited ground survey (Kushwaha and Roy, 2002).

Remote sensing not only provides spatial data but also allows us to compare temporal variations in the spatial data, essential for wildlife management. Wildlife managers have been using topographic maps to generate management and other maps of their interest (Leopold, 1933). Although technically complex, the remote sensing techniques have revolutionized the process of data gathering and map making. Wildlife habitat mapping is similar to any type of land cover mapping (Lindgren, 1985). Both biotic and abiotic surface features including vegetation composition and/or density and landforms can be mapped and interspersion of habitat components, the extent of habitat types and the distance to other critical habitat components can be measured (Best, 1984). Remote sensing can thus be applied to wildlife habitat inventory, evaluation and wildlife census besides merely map making activities.

The geospatial technology, including remote sensing and geographic information system, is found to be time and cost effective assessment of natural resources (Kushwaha *et al*., 2004 and 2000). Remote sensing coupled with ground based methods provides timely and accurate information on all the three basic parameters used for habitat evaluation (Kamat, 1986). Kushwaha and Unni (1986) demonstrated that remote sensing data when with ground information can serve as an important input in quick assessment, evaluation and monitoring of wildlife habitats. Few studies using remote sensing and GIS techniques carried out recently on the habitat suitability analysis of Indian mammals such as *Nemorhaedus goral* (Roy *et al*., 1995); C*ervus unicolor* (Porwal *et al*., 1996); *Rhinoceros unicornis* (Kushwaha, 1997) and *Elephus maximus* (Rout *et al*., 2000) have emphasized the usefulness and efficiency of these disciplines in wildlife management techniques.

Many studies to date have used remote sensing and GIS for wildlife habitat analysis and their suitability evaluation. For habitat assessment of elk (Brian and West 1997 and Bright, 1984), reindeer (George *et al*., 1977) and kangaroo (Hill and Kelly, 1987) remote sensing and GIS technologies were used extensively. Rees *et al*. (2002) used Landsat and ETM+ imagery for mapping of land cover change in a reindeer herding area of the Russian Arctic. Mongkolsawat and Thirangoon (1998) used satellite imagery and GIS to evaluate wildlife habitat suitability mapping, mainly for Asian elephants in Thailand. Similar studies have been carried out by Foley (2002), Zhix *et al*. (1995) and Polce (2004). Pertaining to the Indian context the works of Roy *et al*. (1995), Porwal *et al*. (1996) and Kushwaha *et al*. (2000 and 2004) and Rout et al. (2000) are noteworthy.

Kushwaha *et al*. (2000) followed overlay approach of the area-based modeling and created habitat suitability map for rhinoceros in Kaziranga National Park, India. Hazarika and Saikia (2005) used six different periods imagery from different sensors with varied spatial resolutions as Landsat TM and ETM+ with 30m spatial resolution, IRS 1C LISS III with 23.5m and ASTER with 15m resolutions and used Erdas Imagine's Expert classifier to assess the rhino habitat suitability in the same area. Parihar *et al*. (1986) used panchromatic black and white photograph taken by kate 140 camera system and Landsat MSS images of Kaziranga for habitat assessment of five mammalian species. They used grid based habitat suitability schemes on the classified image and generated habitat suitability map. Kushwaha *et al*. (2004) employed Principal component Analysis (PCA), Discriminant Function Analysis (DFA) and Binomial Logistic regression to understand the habitat use pattern and model suitable habitat of *Cervus unicolor* and *Muntiacus muntjak* in forests of Kumaon Himalaya, India. Foley (2002) used spectral signature box classifier and logistic regression models for classifying suitable elephant habitat in Tarangire National Park, Tanzania. The study revealed that logistic regression model is a useful method because its predictive power can be evaluated based on the resulting logistic regression correlation (D^2) value and would likely be very useful when analyzed with a larger number of significant parameters.

At a simple level, a habitat model is a numerical representation of a species' habitat preferences. It may be used to make inferences about a species habitat requirements and likely response to environmental change, or it may be used to predict a species abundance, density, carrying capacity or probability of occupying a location based on its environmental attributes. The primary use of habitat modeling in conservation planning is in predicting the spatial distribution of suitable habitat for species of interest in a landscape. Many habitat modeling methods are available that may be more or less applicable depending on the type of biological and environmental data available, the species of interest and the end use of the model. There are several detailed reviews and comparisons of wildlife habitat modeling methods in the literature (Franklin 1995; Manel *et al*. 1999 a & b; Elith 2000; Guisan & Zimmerman 2000; Ferrier *et al*. 2002a; Zaniewski *et al*. 2002).

1.6 Rationale

Wilderness area for rhinos continues to shrink and fragment due to multiplicity of natural phenomena as well as ever increasing anthropogenic pressures. Rhinos are in critical demographic crisis; primarily by over-exploitation through poaching for rhino horn and other products and secondarily by loss of habitat due to expanding and developing human populations (Foose and Strien, 1997). Revised IUCN categories and criteria, approved by the 40th meeting of the IUCN council has rated vulnerable to the parameters viz. population reduction, population estimate and probability of extinction. However extent of occurrence has been rated to be endangered. Consequently greater one-horned rhinoceros status falls under endangered category with special emphasis put to in-situ conservation with adequate protection measures (Foose and Strien, 1997). In-situ conservation, in turn, is directly dependent on its habitat parameters that decide whether the site is suitable for rhino conservation demanding habitat suitability analysis for the species.

The target of the modeling effort here is to identify sites where a species might occur (Scott *et al*., 1993) with the help of a MaxEnt modeling technique that makes use of classified imagery and presence only dataset (Philips et al. 2005).

Habitat suitability modeling is a tool for predicting the quality or suitability of habitat for a given species based on known affinities with habitat characteristics.

Habitat evaluation is the first step towards meaningful wildlife conservation and management. Realizing the afore mentioned facts this study was taken up to evaluate rhino habitat in Chitwan National Park, that has been serving as a potential site for rhino conservation in perpetuity. RS and GIS based study was designed to analyze the application of these advanced technologies in the field of wildlife conservation for ultimate conservation objectives. This study thus used remote sensing data for generating habitat type map and using raw data variables in the modeling process, while geographic information system (GIS) was effectively employed for spatial data integration and modeling.

Chapter 2 Chitwan National Park

Chitwan National Park is situated in Indo-Nepal border in lowland southern Nepal (Fig. 2). It lies between 27°18'-27°41' N latitude and 83°41'-83°49'E longitude covering 932 km^2 of riverine and deciduos forests, alluvial floodplains, churia range, swamps, oxbow lakes and grasslands. The entire park is 120-200 meters above mean sea level where maximum temperature reaches around 36°C while minimum temperature falls down to about 9°C. The Narayani River and Rapti River constitute the northern boundary of the park's bufferzone and park respectively. while the southern boundary is formed by Reu River. It shares its eastern boundary with Parsa Wildlife reserve that is contiguous to Valmiki Tiger Reserve in India, forming an important transboundary area for wildlife conservation.

Chitwan receives about 2400 mm of mean annual rainfall, 90% of which falls during four-month monsoon season (June-September), that serve as the source of ground water recharge, besides bordering rivers, aiding persistence of water in the pools even in dry season. However shallow ponds and lakes are dried off. The area of the park is a vast alluvial plain, between Narayani, Rapti and Reu rivers, interspersed with numerous rivulets, lakes and ponds. The rich and extremely fertile plain at the base of the Himalayas support luxuriant growth of forests and diversity of fauna.

Chitwan National Park predominantly comprises of S*horea robusta* forest with *Terminalia tomentosa*, *Terminalia belerica* and S*yzigium cumini* association. Beside these several patches of exotic and indigenous species like *Tectona grandis*, , *Acacia catechu*, *trewia nudiflora, Dalbergia sissoo* etc are also found in the park. Grasslands enriched by the fertile top soil annually washed due to monsoon flood from surrounding young mountain chains is an important feature of the park. Throughout the world, tall grasslands such as Chitwan are both rare and more threatened (Dinerstein 2003). Seidensticker (1976) portrays the ability of Chitwan's grasslands to support levels of ungulate biomass (wild and domestic) that exceed all other sites in Asia and rival some in East Africa (Eisenberg and Seidensticker 1976; Seidensticker 1976 sighted in Dinerstein 2003).

The park contains large mammalian species as Royal bengal tiger (*Panthera tigris tigris),* Great indian one-horned rhinoceros *(Rhinoceros unicornis), ,* Common leopard *(Panthera pardus),* Sloth bear *(Melursus ursinus),* Spotted deer *(Axis axis),* Hog deer *(Axis porcinus),* Barking deer *(Muntiacus muntjak),* Sambar deer *(cervus unicolor),* Wild boar *(Sus scrofa)* etc. Around 525 species of birds have been found in the park including endangered species as Bengal florican (*Haubaropsis bengalensis)*, White stork (*Ciconia ciconia),* Black stork *(Ciconia nigra)* etc. In addition to high ungulate and carnivore density and diversity of birds, Chitwan is home to endangered reptiles, including the rare and primitive crocodilian, the gavial, or Gharial (Maskey 1979); Mugger crocodile; golden monitor lizards; and soft shelled turtles (Zug and Mitchell 1995).

Figure 2. Location of Chitwan National Park

Chapter 3 Objectives

The major objective of this study is to model rhinoceros habitat suitability in Chitwan National Park using Remote sensing and GIS techniques. The specific objectives are as follows:

1. Mapping land use / land-cover of Chitwan National Park with special emphasis on features significant for rhino habitat study.
2. Spatial modeling for rhino habitat suitability.

The main research questions of the study are: 1) What is the spatial pattern of habitat that is suitable for rhinos in the park 2) How much habitat is potentially suitable for rhinos in the park and 3) Which of the habitat variables explains distribution of rhinos in Chitwan National Park.

Chapter 4 Data, Software and Equipment

Remote sensing satellite data is a classical source of information on natural resources capable of recording continuum of resource status due to repetitive coverage. Image analysis and GIS software are basic for acquiring information from the remote sensing data and conducting further analysis.

4.1 Satellite Data

Landsat ETM+ data (Fig. 3) with ground resolution of 30.0 m false color composite (FCC) of Eight bands (Table 1) dated 13 December 1999 was used for rhino habitat features extraction and modeling purpose.

Table 1. Features of Landsat ETM+ sensor

Bands	Wavelenth	Resolution
Band 1	0.45 – 0.52	30
Band 2	0.52 – 0.60	30
Band 3	0.63 – 0.69	30
Band 4	0.77 – 0.90	30
Band 5	1.55 – 1.75	30
Band 6	10.40 – 12.50	60
Band 7	2.09 – 2.35	30
Band 8	0.52 – 0.90	15

Different band combinations of the landsat ETM+ data serve for easy separability of features of interest. For instance, below shown band characteristics are kept in consideration while selecting different band combinations for the respective feature identification in Landsat ETM+ image.

Band 1 (0.45 - 0.52 µm): provides increased penetration of water bodies and also capable of differentiating soil and rock surfaces from vegetation and for detecting cultural features.

Band 2 (0.52 - 0.60 µm): it is sensitive to water turbidity differences; it highlights the turbid water. Because it covers the green reflectance peak from leaf surfaces, it is capable of separating vegetation (forest, croplands with standing crops) from soil. In this band barren lands urban areas and roads and highways have appeared as brighter (lighter) tone, but forest, vegetation, bare croplands, croplands with standing crops have appeared as dark (black) tone.

Band 3 (0.63 - 0.69 µm): senses in a strong chlorophyll absorption region and strong reflectance region for most soils. It discriminates vegetation and soil. But it hardly separates water and forest. Forest land and water both appear as dark tone.

Band 4 (0.77 – 0.90) and **Band 5 (1.55 – 1.75):** shows high reflectance in healthy vegetated areas. It is helpful to compare flooded areas and red vegetated areas with the corresponding colors in the 3,2,1 combination to assure correct interpretation.

Band 7 (2.09 - 2.35 µm): is capable of discriminating land and water sharply. Band 7 has strong water absorption region and strong reflectance region for soil and rock. Urban area, croplands, highways, bare croplands appear as bright tone and water body, forest appear as dark tone.

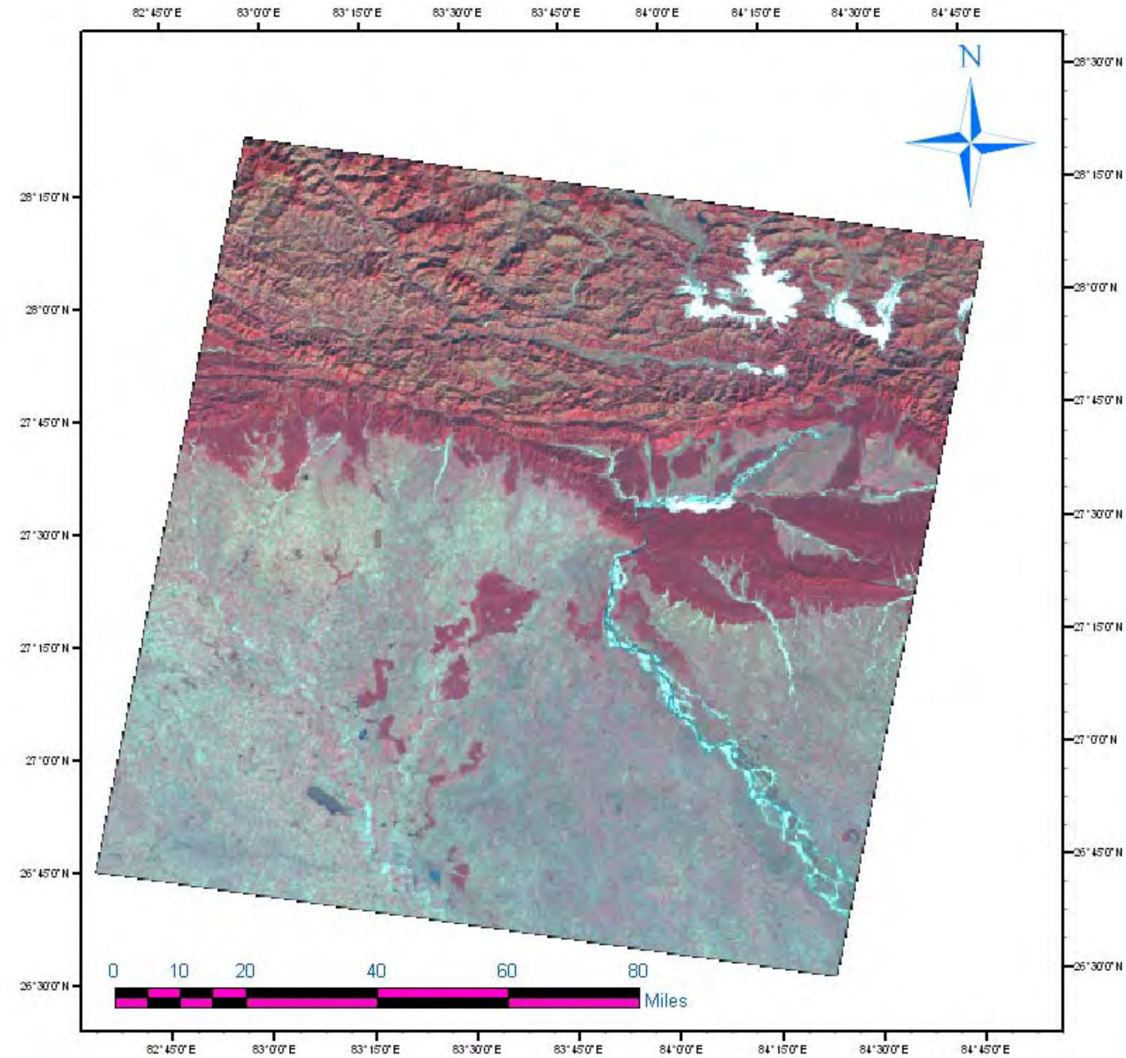


Figure 3. Landsat FCC of the study area (P 142, R 41)

4.2 Software

Erdas Imagine Version 8.7 was used for image analysis, feature identification and information extraction. Spatial Analysis of the data was performed in Arc GIS 9.2 software. Spatial modeling was performed in Maxent. Beside these, use of MS Office package was also extensively used for numerical data processing, calculations and export/import operations.

4.3 Equipment

Garmin Global Positioning System was used for collecting ground truth information of the field and conducting presence survey of the target species.

Other accessories include:

Rangers compass

Binocular

Photographic camera

Desk Jet and Laser printers, Plotter

Measuring tape

Chapter 5 Methodology

Methods adopted for executing different tasks under this project are separately described in brief under respective headings in the following sections.

5.1 Data collection

The study included pre-field data collection, field survey and post-field data analysis. Primary data collected during field work and secondary information about the rhinoceros and the study area were extensively used for the study purpose.

5.1.1 Pre-field activity

Secondary data pertaining to rhino, its habit and habitat preferences were collected and duly analysed for aiding in interpretation of the modeling results. The sources of these secondary information comprised of published papers in different national and international journals on rhino and its habitat study, relevant unpublished research reports accepted by authenticated research institutes or Universities, wildlife related literatures / text books, official web sites of renowned organizations etc. Relevant publications on Chitwan National Park and rhino related research works were duly studied for incorporating field condition information for generating area specific rhino habitat suitability criteria applicable for Chitwan area.

5.1.2 Field Work

Field survey for the study was carried out between 6 December 2007 and 20 June 2008. It is indispensable for this study purpose. Ground truth data collection of representing feature types present in the study area was done for identifying training sites required to generate land use / land cover map of the area. Familiarization of the researcher to the study area is also essential for interpreting the modeling results and suggesting the management interventions for achieving the conservation objectives of undertaking habitat suitability modeling. The presence survey of rhinoceros was conducted collaborating with the Rhino Count 2008 Team of the Department of National Parks and Wildlife Conservation, Nepal.

Training points selection

Total 480 training points were selected covering entire 973 sq.km area of Chitwan National Park. Proportional number of points were collected from different land cover types viz- Grass lands, waterbodies, Dry sand/ barren land, Sal forest and riparian forest. While selecting training points the edges between different land cover types were avoided as far as possible in order to avoid training points consisting of mixed reflectance pixels.

Rhino Presence-only data collection

I collaborated with Department of National Parks and involved in Census team for collecting rhino presence locations. Thus all the Presence data were collected during Rhino Count 2008. Opportunistic search method was employed for this purpose. The census included total count of Rhinos in the national park and buffer zone area. Sweep operation was conducted on 25-40 elephants to locate rhinos in every patch of land cover types. The census also assumed that there was no missing and double counting of rhinos within the area to count every animals present in the park. Hence this method enabled me to use the data as presence-only data for subsequent MaxEnt modeling operation. Total 408 presence point locations were recorded by Garmin GPS and the habitat features of the location were noted for data analysis and interpretation.

5.1.3 Post-field work

This phase included organization of raw data collected during the field work, data analysis, image information extraction and finally modeling of rhino habitat suitability in the study area. Data organization and analysis are described in the following activities involved during post field work in separate sections.

5.2 Database creation

The GPS locations of 408 presence points were converted to UTM WGS 84 Zone 44 N projection similar to that of FCC. 36 points appeared as out of bound points and were rendered useless for including in the analysis. This may be due to wrong entry of data points during field work or other errors- instrumental or human. Thus 372 points were used for creating presence location shape file in Arc GIS and overlayed on FCC (Fig. 4) for portraying rhinos location in the park. This shape file was further transformed into .CSV file for using as a dependent variable in MaxEnt Program.

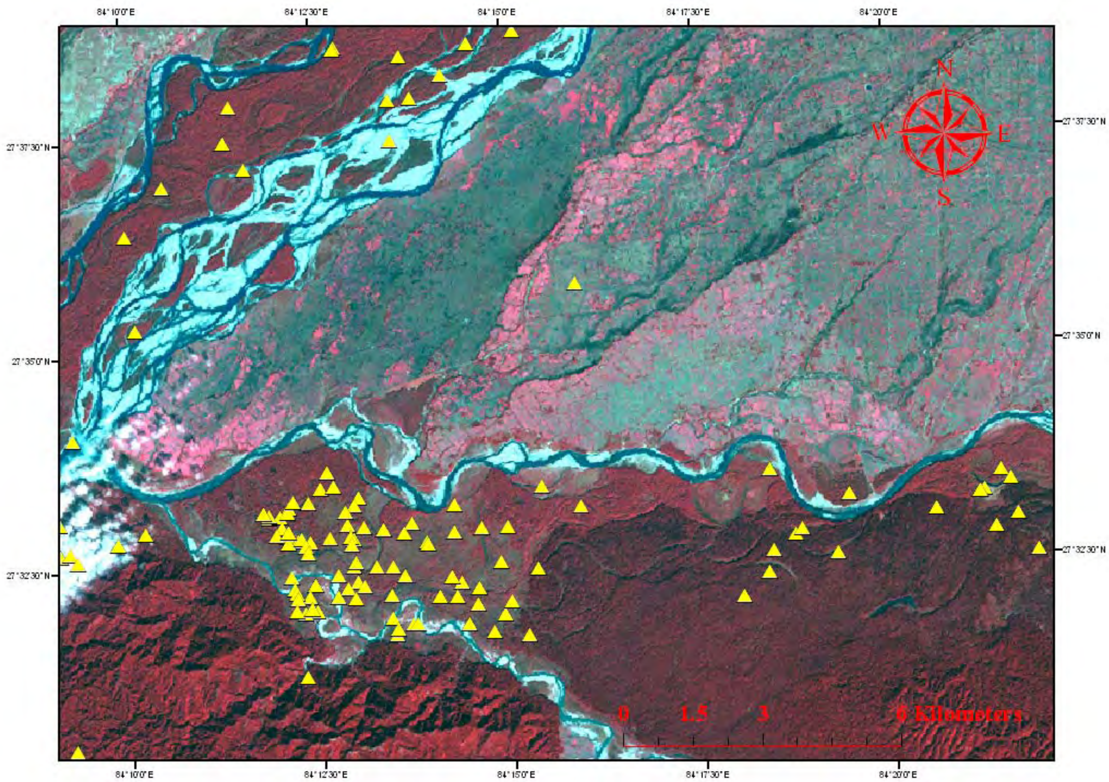


Figure 4. Map showing Rhinos presence locations

I used Erdas Imagine 8.7 software for image processing and analysis. The Landsat ETM+ FCC with 30m ground resolution was used to prepare the land use/ land cover map of the study area. I selected the bands 1,2,3,4,5 and 7 of same resolution (30m) and layer stacked for further analysis. Thermal band (Band-6) with 60m resolution and Panchromatic band (Band-8) with 15m resolution were excluded to stack in the FCC. This operation was carried out to reduce data redundancy due to resampling of bands with different resolutions insignificant contribution thermal and panchromatic for vegetation analysis in this study. I selected larger Area of Interest (AOI) beyond national park boundary to examine the modeling result in landscape level. Study area from the entire Landsat FCC was extracted by sub setting procedure in *Erdas Imagine 8.7* Software. I used supervised classification technique, maximum likelihood decision rule for image classification. For effective use of land cover map in the modeling process, I defined cover classes that were relevant for rhinos. I established a classification scheme to classify image into six land cover classes- Sal forest, Grass land, Riverine forest, Sand bank/ Barren land, Water bodies and Agriculture/Settlement. The burnt grassland cover type had similar spectral reflectance with agriculture/Settlement that rendered problem in discriminating grasslands and agricultural areas. I recoded the agricultural/settlement area that appeared as grassland with the help of expert knowledge and my experience of the study area. Water bodies are an important life requisite for rhino. It was very important to detect all the waterbodies for including in the further analysis. However, classifying 30m resolution image could not separate smaller waterbodies viz. small ponds, lakes, streams, rivulets etc. Moreover, eutrophication of the water bodies might have influence in rendering inseparability of small water holes spectrally. Therefore, I digitized the waterbodies that were not picked up in image classification and then merged with the classified image using ARC INFO. Continuous surfaces of distances from all land cover types were created using Euclidean distance algorithm available in spatial Analysts Tools in Arc GIS. These distance layers were then converted to ASCII files using conversion tools (Raster to Ascii) available in Arc GIS Toolbox. All the distance files in Ascii format were used as continuous predictor variables and the land use/ landcover Ascii file was prepared for input as categorical predictor variable.