ANALYSIS OF THE ONE-HORNED RHINOCEROS (*Rhinoceros unicornis*) HABITAT

IN THE ROYAL CHITWAN NATIONAL PARK, NEPAL

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This study analyzes the remaining suitable habitat of the one-horned rhinoceros, *Rhinoceros unicornis*, in Royal Chitwan National Park of Nepal. An April 2003 Landsat image was classified into eight land cover types: wetland, sand, water, mixed forest, sal forest, agriculture, settlement, and grassland. This image was converted into habitat suitability maps using cover, food, and water. The rhinoceros prefers grassland habitat with oxbow lakes and closed canopy during the monsoon season. Nominal values of five parameters were used to create a map of habitat suitability index. The map was categorized into four habitat classes: highly unsuitable, unsuitable, moderately suitable habitat, and suitable. Landscape metrics, patch metrics and class metrics associated with habitat were determined through the use of FRAGSTATS.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

Background

Wildlife habitat management is becoming increasingly vital around the globe, especially in poor and developing countries where indiscriminate deforestation continues. The demand by an ever-growing population in such countries causes rapid depletion of natural resources thereby posing a potential threat to wildlife.

The total land area of Nepal is 14.72 million ha, and about 8.24 million ha was covered with forest prior to 1978 (Forest Resources of Nepal 1999). The forest area has been depleted rapidly from 56 % (8.24 million ha) in 1978 to 39.6% (5.83 million ha) in 1996, as indicated by photo point analysis (Juwa 1998), and is decreasing at the rate of 1.7 % annually. The major cause for declining forest habitat is human population growth. In addition, illegal logging and clearing for cultivation are also potential contributors to the losses.

The unprecedented and increasing loss of forest, exponential human population growth (2.23% per annum), and urbanization has warranted conservation efforts of endemic flora and fauna preservation in Nepal. Due to its unique topographical features (the plains or *terai* lying just above 100 m from sea level and soaring up to 8,848 meters; Mt. Everest, the highest point on earth), Nepal harbors a variety of ecosystems that support a vast range of vegetation and wildlife. Nepal, along with its international partners, has been taking active part in conservation measures for the last three decades, and this has been achieved through the creation of parks and reserves in various parts of the country. Such areas are set aside and managed to protect particular

plant and animal species or assemblages of species, habitats, and groups of habitats. However, some areas are designated as park or reserves based on high - profile species only or because they form a habitat for endangered species or are unique natural landscapes. The study site for this project – Chitwan Valley is one such habitat, because it houses the one-horned rhinoceros.

Objectives

The major objective was to analyze the habitat available to the *Rhinoceros unicornis* (one-horned rhinoceros) in the Royal Chitwan National Park (RCNP), Nepal. This project has the following specific objectives – 1) to develop land cover map emphasizing vegetation of RCNP, using a landsat ETM (Enhanced Thematic Mapper) Image, 2) use habitat evaluation procedures (HEP) and generate habitat suitability indices (HSI), and 3) to determine the spatial distribution of current suitable habitat area for rhinos by using FRAGSTATS.

Research Questions and Hypothesis

The main research questions are -1) how much habitat for the one-horned rhinoceros remains in the RCNP and 2) what is the spatial structure of this habitat. The main hypothesis is that the major vegetation types that constitute one-horned rhinoceros habitat can be classified in a LANDSAT ETM image.

Historical Distribution of Greater One-Horned Rhinoceros

The one-horned rhinoceros was once widely distributed throughout the

Brahamaputra, Indus and the Ganges plains of South Asia (Figure 1) but indiscriminate poaching and unprecedented habitat loss have nearly pushed them to extinction. They are now restricted to small isolated populations on the Indian sub – continent, mainly in India and Nepal (Laurie 1978). The current estimated wild population of the greater one-horned rhinoceros is about 2,400 individuals with, Kaziranga National Park of India harboring the highest population of 1,100 individuals.
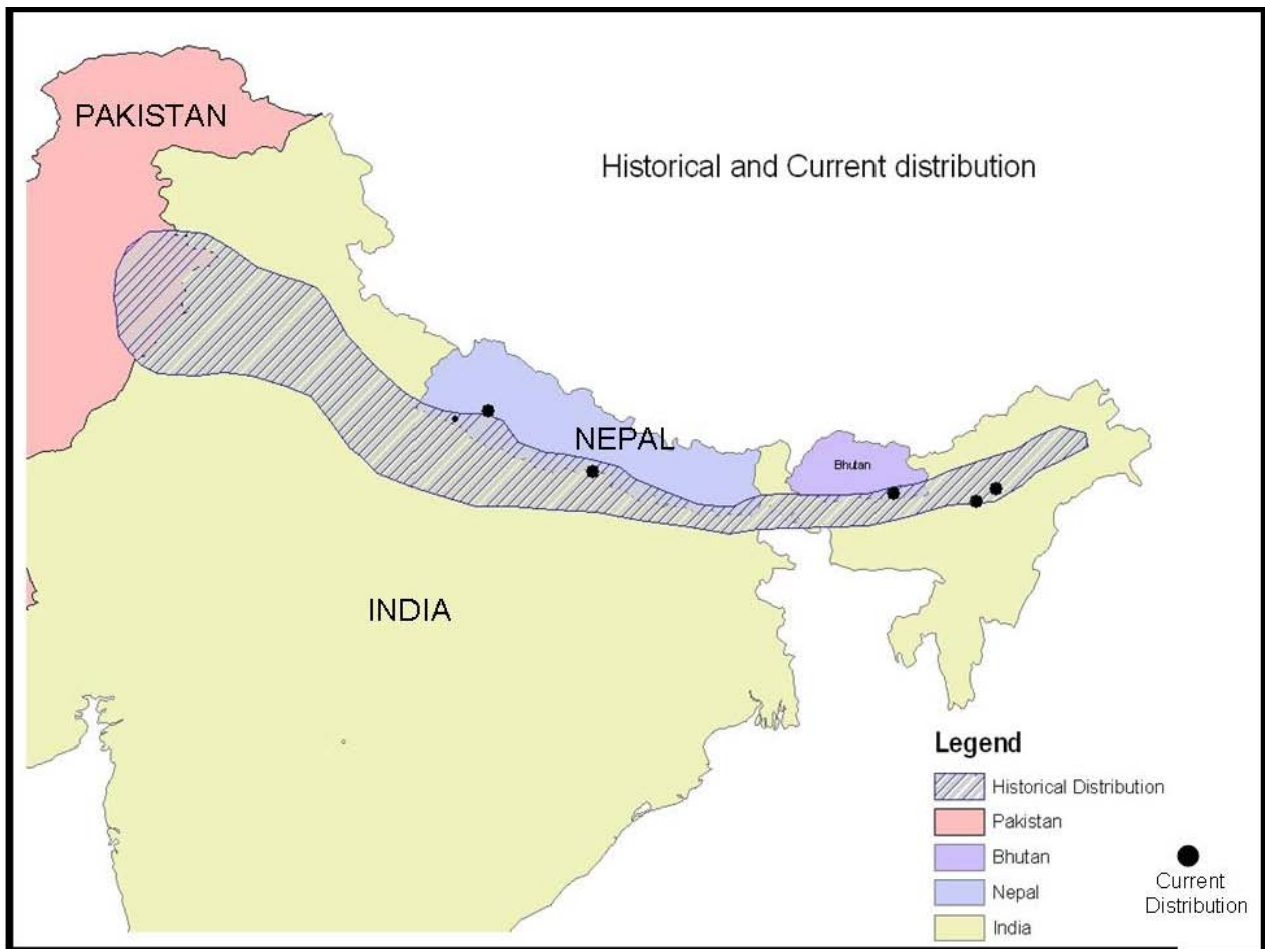
Figure 1. Historical and current distribution.

In the southern lowlands of Nepal, a free ranging population of 1,000 individuals survived until the1950s. Control of malaria was followed by the massive destruction of their habitat – alluvial floodplains, adjacent swamps and forests; that triggered a drastic

decline of the population. Consequently, only small populations of less than 100 individuals were reported to have survived in the floodplains of major rivers – the Reu, Rapti, and Narayani. Fortunately, these prime habitats of 932 km^2 were declared as a National Park in 1973, and the rhinos were regarded as property of the Nepal government. This reduced poaching and other illegal activities significantly. And as a result, the population has increased; nearly 600 individuals wander the floodplains today (Dinerstein and Price 1991, Khan et al. 1995) and marking this as one of the most successful conservation stories in the world.

CHAPTER 2

METHODOLOGY AND WORK PLAN

Tools Used

Geographic information systems (GIS), remote sensing, habitat evaluation procedures (HEP), R Console and FRAGSTATS were used to document the quality and quantity of habitat available for one-horned rhinoceros.

Study Area

The study area, Royal Chitwan National Park (RCNP), is located in the lowlands of Nepal along the southern border of India at an elevation of 120 to 200 m above sea level. The park consists of 93,200 ha or 932^2 km of riverine and deciduous forests, alluvial floodplains, swamps, oxbow lakes, grassy meadows and grasslands. Geographically, the park lies from 83° 41' to 83° 49' east longitude and from 27° 18' to 27° 41' north latitude.

RCNP is bordered to the northeast, northwest and west by privately owned land used primarily for agriculture and on the southeast by another wildlife reserve, Royal Bardia National Park, which is regarded as ideal habitat for wild elephants. The study site is one of the low plain areas of the Chitwan district that lies in the inner part of the Terai region situated between the Middle Hills and the Siwalik Mountains. Numerous intermittent and perennial water channels link the surrounding landscape to the park.

The principal habitat used by one-horned rhinoceros, tall grasslands, occupies approximately 15 % of the total park area (Dinerstein 2003). The dominant tall grass species that comprise this habitat is *Saccharum benghalensis* and *Narenga*

porphyrocoma. Rhinoceros feed on the young shoots of this grass along with other grass species such as *Imperata cylindrica, Chrysopogon aciculatus (*Kuro in Nepali), *Eragrostis* spp., and others. The three species are short grasses and are usually 5 cm in height and are found inside the tall grassland. However, the rhinoceros feed only on the young shoots of the fourth grass species, *Imperata cylindrica* but are all intensively grazed by the rhinoceros. Among the grass species, rhinoceros seek out *Saccharum spontaneum* as it is most nutritious and this type of grassland accounts for only 5 % of the total park area (Dinerstein 2003). The riverine forest association is composed of *Trewia nudiflora* (Bhelur in Nepali), *Bombax ceiba* (Simal in Nepali), *Acacia catechu*, and *Dalbergia sisoo.* Another tree species *Shorea robusta* (Sal in Nepali) covers nearly 70 % of the park area.

This region of Nepal is known for a hot summer and devastating monsoon season followed by short winter season. The climate is sub – tropical, with the temperatures rising to approximately 37° C on a typical summer day. Mean annual precipitation is 2.4 m with 90% of it falling during the period of May to September. The changing of river course, inundation of nearby agricultural lands, and drowning of wildlife during this period are regular occurrences.

Loss and fragmentation of habitat are inextricably related or linked even though they differ markedly in the severity of impact they impose upon the wildlife. For wildlife species, loss of habitat has detrimental effects on their survival or may even become the cause for their extinction. However, fragmented habitats may still contain enough of the original features such as sufficient life or habitat requisites to sustain small or viable populations of some species. For example, the study site, Chitwan (Figure 2), has

undergone drastic changes in the last three decades since the establishment of the park, in terms of human population density, and conversion of surrounding landscapes or topography including other natural assets to agricultural land. It contains the last intact fragments of biologically important habitat types (mosaic alluvial grasslands and riverine forests) with a few other protected areas located at the foothills of the Himalayas. As stated earlier, it is bordered on northeast, northwest and west by private lands that are comprised of 36 village development committees and these villages support over 250,000 people (His Majesty's Government of Nepal 1994).

In 1996, about 750 km^2 of the land between the park boundary and villages was demarcated officially as buffer zones and remarkably almost 60% of the land remains forested, while the remaining is degraded severely. This buffer zone has become another fragmented habitat for the wildlife of Chitwan especially wild elephants, rhinos and tigers. The incidents of crop raiding and human causalities caused by the wild animals are common in these parts. Also, these buffer zones were set aside to fulfill the need of firewood, fodder and grazing land for the villagers thereby diminishing to some extent, the magnitude of human impact on the park. Nevertheless, the perpetual population growth and need for more agricultural lands are chronic problems that will continue to be of concern to wildlife guardians of Chitwan.
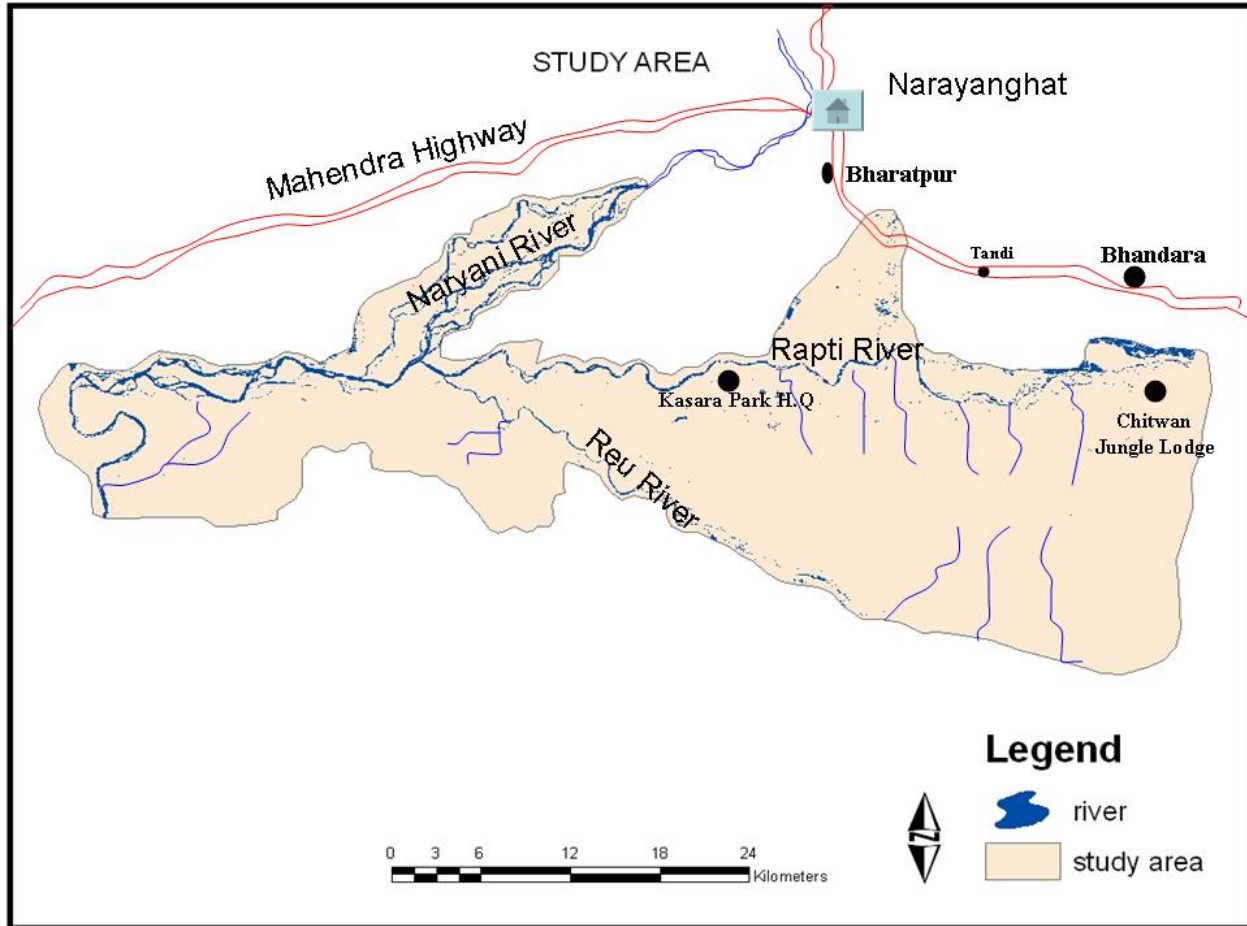
Figure 2. Royal Chitwan National Park (study area).

Biology and Spacing Behavior

The daily routine of a rhinoceros can be broken down into two major activities - feeding and thermoregulation. The duration and nature of these activities change with season and availability of food. They spend more time thermoregulating during hotter summer months and browsing and foraging (Owen –Smith 1988) during cooler months. The following picture was taken during my field visit to Chitwan in summer 2004. We found five rhinos basking in the sun in an oxbow lake located inside the Icharni jungle. (Figure 3)

Figure 3. Rhinos wallowing in an oxbow lake in RCNP (Photo by K.P Limbu and Vivek Thapa)

Adaptation to heat stress for ungulates native to subtropical and tropical is essential for survival. The presence of sweat glands in white rhinoceros (Cave and Allbrook 1958), retention of heat by the two African rhinoceros species and heat - radiating pinnae in African elephants are some of the physiological adaptations of the large herbivores to promote heat dissipation. The study of normal rectal temperature of the one-horned rhinoceros in captivity suggest that these may not be the strategy for heat control since their normal rectal temperature are between 36 and 39° C throughout the year (Dinerstein 2003). Instead this species wallow to regulate heat (Laurie 1978), which is another adaptation feature. It is a process of immersing the body in water, usually an oxbow lake, combined with rolling in mud. The primary function of wallowing is assumed to be heat regulation, but social communication by scent – marking and evading insect bites may also encourage this activity (Dinerstein 2003). Additionally,

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they forage at nights and use dense shade during the hot season to evade overheating (Owen – Smith 1988).

Unlike other ungulates or large animals such as tigers, elephants, and Indian bison, the rhinoceros differs markedly in spacing behavior. Annual mean home range of dominant adult breeding males is 4.3 km^2 and of female is 3.5 km^2 (Dinerstein 2003). And the home range varies according to the season. The reason for such a small home range is the available prime habitat in Chitwan. The availability of lush green grassland, riverine forest and wallowing sites in Chitwan limit the travel of the greater one-horned rhinoceros. If these features are absent or more widely distributed, they travel greater distances like the other ungulates.

Using the above information, the following identifiable habitat requisites for one-horned rhinoceros will be employed in this thesis: food, wallowing sites and cover. These will correspond to tall-grass and other grass species, water, and forest as identifiable habitat variables according to the following reasons:

1. The tall grass *Saccharum spontaneum* is the primary diet of rhinos of Chitwan in all seasons (Jnawali and Wegge 1993), although they browse on other grass species too. These grass species grow abundantly on the alluvial soils of Chitwan. Seasonality of moisture regime, formation of new shoots and growth of mature stems are important variable in determining their abundance (Dinerstein, 2003). These requisites are met by presence or absence of grass in a pixel. (Figure 4)

Figure 4. Grassland of Royal Chitwan National Park.

    2. Rhinos require wallowing or resting sites to meet their thermoregulatory requirements (Laurie 1978). These are oxbow lakes; usually located in midst of the grassland and such sites are associated with tall grassland and water bodies. This requisite is met by one-model variable – water. (Figure 5)

Figure 5. Oxbow lake near Rapti River.

3. During monsoon season, rhinos seek refuge in the upland forests to avoid drowning and to feed on the fruits of *Trewia nudiflora* that is one of the tree species of mixed forest. The floodplain vegetated with grassland and the upland forest is usually separated by thick stands of mixed forest. This habitat requisite is represented by canopy closure or forest (Figure 6).

Figure 6. A typical sal forest of RCNP.

Data Acquisition and Field Visit

In order to analyze the actual habitat of the rhinoceros, the most important data source of this project was to acquire an image of the Royal Chitwan National Park (RCNP). Fortunately, only one image was required for the entire project, although a small portion of the southeast side is missing. Precaution was taken while retrieving the image from U.S. Geological Survey (USGS) to select for a recent, cloud free image with highest reflectance. As discussed earlier, Chitwan vegetation is in full bloom during the months of March until May before the summer begins followed by monsoon. Another important source was topographic maps at scale of 1:125000 bought in Nepal.

A field survey was conducted in the months of May and June 2004, and June 2005. The second visit lasted for only five hours to the areas of the unknown pixels. A

total of 847 GPS (global positioning system) points were collected from various parts of the park. Each and every point or site visited was accompanied with notes of soil texture, soil moisture regime, and plant composition and elevation data. Digital and disposable cameras were used to take photographs of each site visited. An excel file was created with the GPS points and were imported as a shape file and then again imported into Arc Map for further analysis. Simultaneously, hyperlinks to the digital photos were added along with vegetation descriptions included as attributes to the points for easier reference during classification. The GPS points were overlaid on the map (Figure 7).
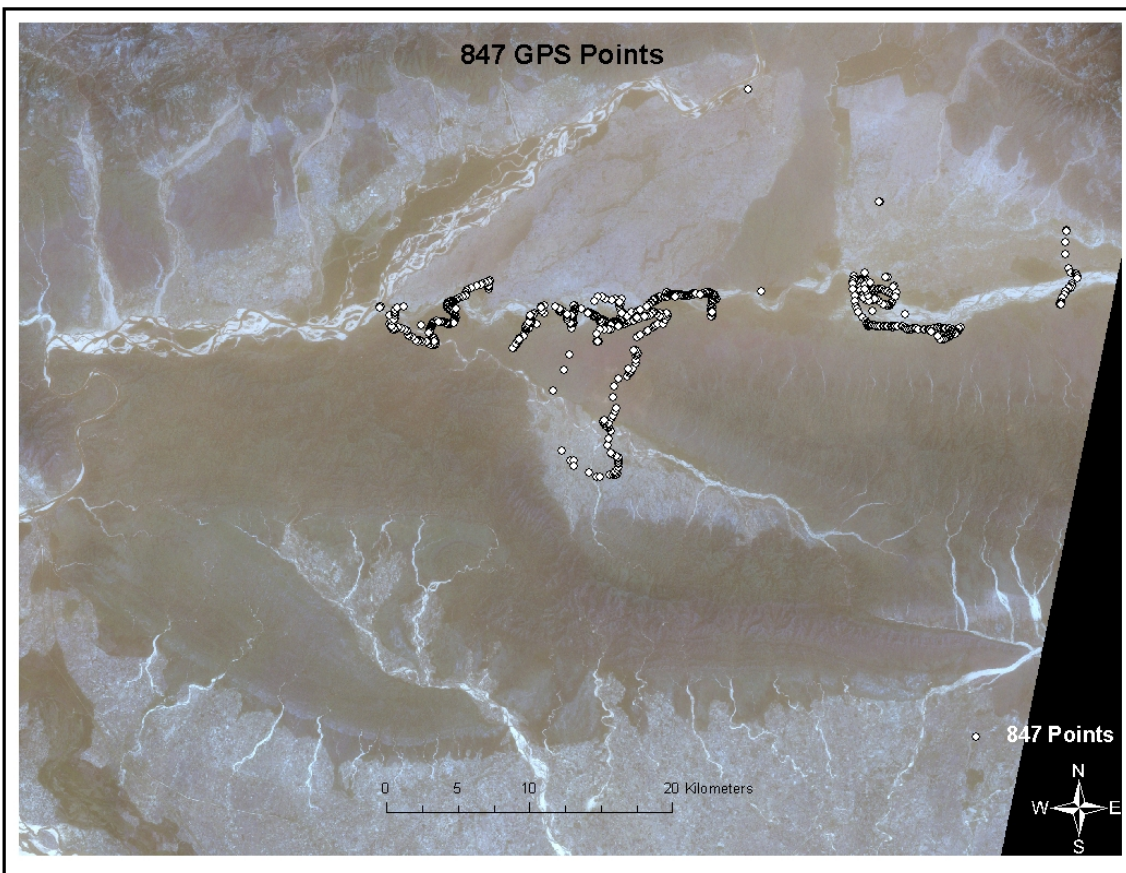
Figure 7. 847 GPS points on the subset image.

Geometric Correction and Subset Image

For georectification of the subset of the raw image, geographic coordinates were collected from topographic maps (12 points). The coordinates of the topographic maps were in latitude and longitude that had to be converted into Universal Transverse Mercator (UTM) system in order to correlate with the image coordinates. The points were then saved as ASCII file to import into the ERDAS IMAGINE. Then the points were imported to Arc Map as X, Y coordinates along with GPS points of the same locations. The two points for nearly all the locations matched fairly well as shown in Figure 8.
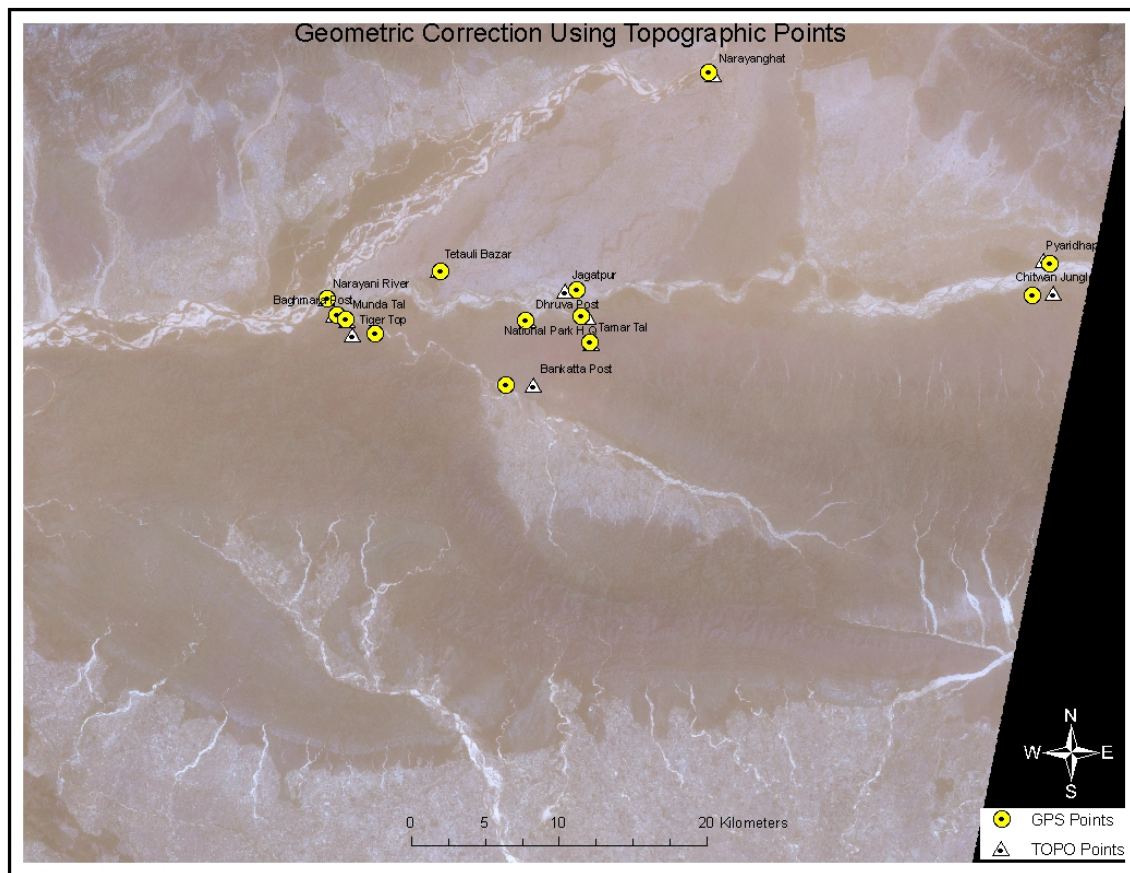
Figure 8. Georectification of the subset image.

Vegetation Classification

ETM (enhanced thematic mappper) data collected on April 12, 2003 (scene

7142041000310250 path 142/ row 41) were used for the study (Figure 9) to derive land cover types. This particular image was selected to allow optimum discrimination of vegetation types.
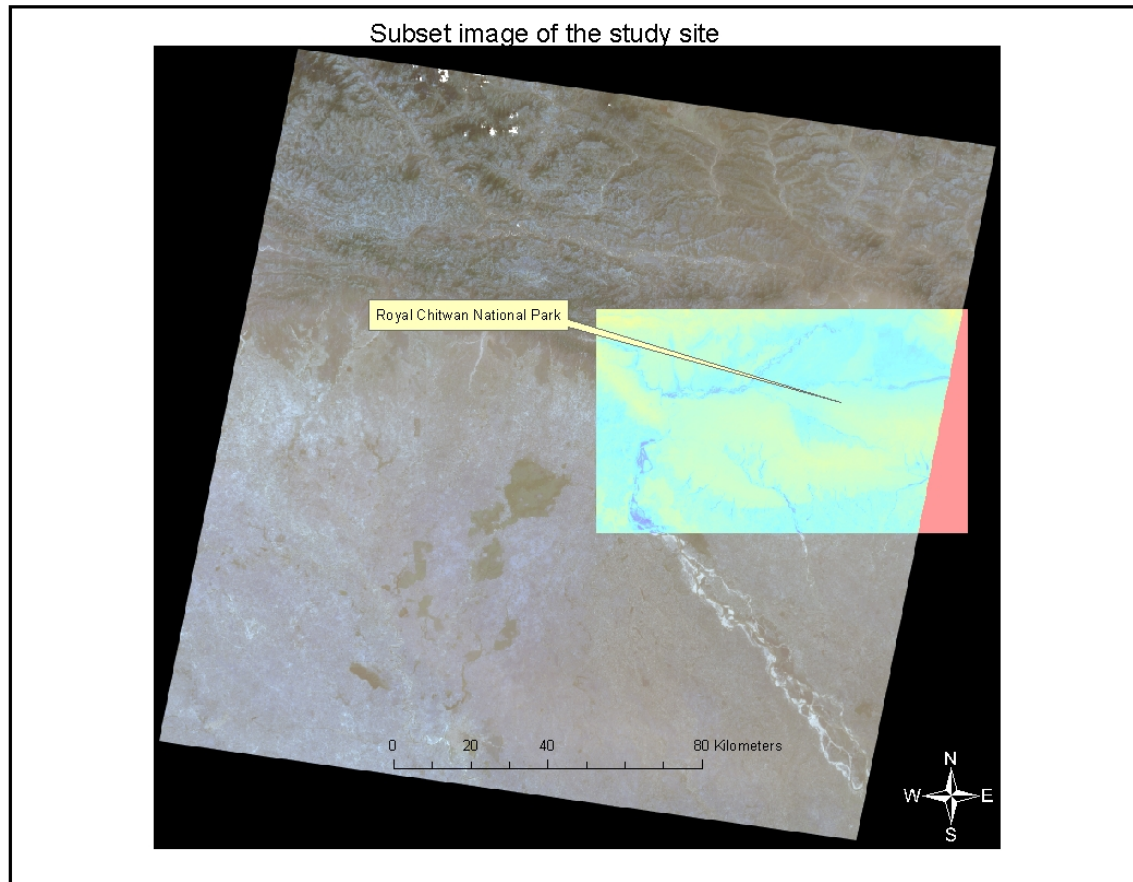
Figure 9. Subset of the study site or RCNP.

The image was already projected to UTM coordinate system using a WGS – 84 datum and Zone 44. Since, photographic images are not evenly projected due to inherent inconsistencies (Hardison 2003); they usually require geo-rectification. However, DOQQs (digital quarter orthophoto quadrangle) or DEMs (digital elevation models) or other classified maps of the study area were not available in order to georectify the image. The DOQ is a computer- generated image of an aerial photograph that combines the image characteristics of a photograph with the geometric qualities of

a map. DEMs are digital files consisting of points of elevation that are sampled systematically at equally spaced intervals. First, I made a subset of the image to include only the area of interest or study site, to reduce the processing time thus enabling rapid analysis. There are two major types of classification procedures – unsupervised and supervised classification. The unsupervised classification technique trains the computer without any prior knowledge of an area to assign pixels to their respective classes known as spectral clusters. On the other hand, supervised classification techniques require the user to define spectral characteristics of known areas of land cover types and develop training sites. As stated earlier, due to the lack of availability of tested maps, I performed supervised classification only. Armed with knowledge of vegetation pattern of the study area along with 847 GPS points, I classified the subset into eight land cover types including water, settlement, sand, wetland, mixed forest, sal forest, agriculture, and grassland. Several attempts were made to classify pixels into one of the eight land cover types. Each attempt included the use of AOI (area of interest) tools, one of the many tools available in IMAGINE. A set of parameters was used in the seed properties dialog box. The number of pixels was set to 300 with four-neighborhood analysis, and Euclidian distance was set to 10. After selecting pixels from the known area, they were tested for reflectance properties by using the spectral profile dialog box. It is known that, for healthy vegetation pixels, one will observe a spike in bands 4 and 5 of electromagnetic spectrum. Vegetation is brighter in the near infrared band that is band 4. For bare land, settlement, any man made objects, and for sand, one can see a spike in the bands 5 and 6. For water, there is no reflectance in bands from 1 to 6. The confused classes were recoded to increase accuracy along with supervised (with areas

of known habitat) classification methods. The classification was continually refined until

an acceptable accuracy was obtained. The final thematic map depicting eight land

cover types is shown in Figure 10.

 In summary:

- I made two text files of 847 GPS points, one with 433 and the other with 414 points. I lost 22 points in the process.

- In ERDAS imagine, the 433 GPS points were laid over the subset Landsat image. The points were imported to the coordinate calculator dialog box. They were then saved as a.gcc file for further use. Using the function "region grow" available in ERDAS, a region having similar spectral values was grown and saved as signatures in the signature editor for further classification.

- With the saved signatures, supervised classification was performed on the image using Imagine to generate a classified image.

- The resultant classes were further grouped by category, and the suspicious classes were masked and reclassified. This masked classification was combined with the original output to create the final land cover map.

Once a land cover and vegetation map was generated by the supervised

classification procedures described in the above section, each pixel had a categorical

value for cover, water and food according to Table 1. The values or categories 1, 2, 3,

and 4 were considered for natural habitat value.

Table 1. Environmental variable for one-horned rhinoceros.

Value	Environmental Variables	Suitability Indices
0	Bare Ground (Sand, Gravel, Stones)	Not used
1	Grass (*S.spontaneum* and others)	Food
2	River, streams, oxbow lakes	Water
3	Mixed and Sal forest	Cover
4	Agriculture field	Food
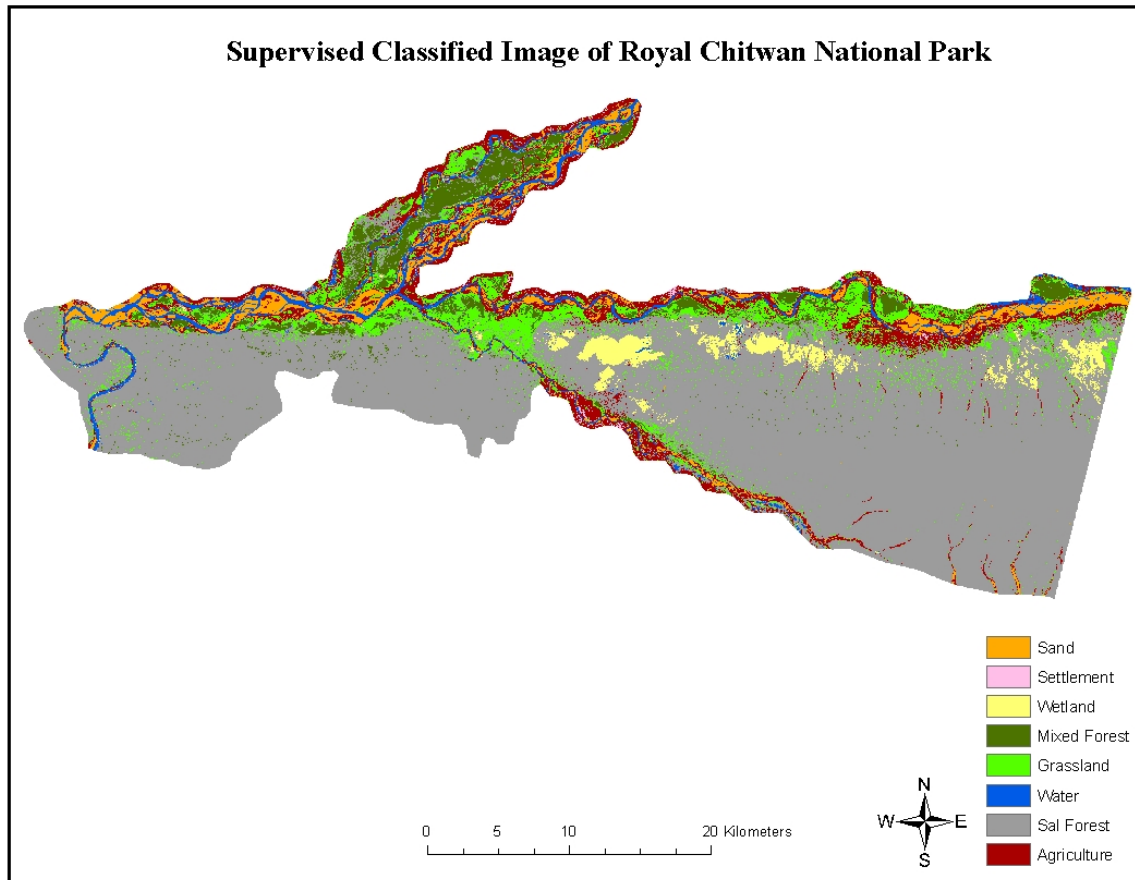
Figure 10. Supervised classified image of RCNP.

It is necessary to assess accuracy of any classified image in order to determine the quality of the information derived from remotely sensed data, and it is critical to know the measure of the quality if the data are used in some decision – making process (Congalton et al. 1999). Since, the results of this project will be used to make some decisions for managing habitat; I performed accuracy assessment as explained hereafter.

Accuracy Assessment

After classifying the subset image, series of accuracy assessments using

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different combination of GPS points and randomly created points were carried out.

Initially, 250 GPS points (reference points) and 50 random points created from the

classified image were used, because a minimum of 204 reference points should be

assessed to achieve 85 % accuracy with an allowable error of 5% (Jensen 1996).

According to Congalton et al. (1999), at least 50 reference points should be collected

per land cover class to calculate an error matrix. A stratified random sampling technique

was employed to locate 50 random points from the classified image for each land cover

class. The reference points were entered into the accuracy assessment function of

IMAGINE 8.7. According to Anderson et al., (1976), the minimum level of accuracy

acceptable for land use and land cover classification is 85%.

Four types of accuracy were assessed for the classified image. The four types

are - overall accuracy, producers, users, and kappa statistics. Overall accuracy is the

number of correctly identified pixels divided by the number of pixels in the error matrix.

Producer's accuracy (errors of omission) is the probability that a reference pixel is

calculated by dividing the number of correctly classified pixels in each category by the

total number of reference pixels in that category and this measures the accuracy of the

map's reflection for the land cover types. The user's accuracy, also called as errors of

commission, measures the probability of classified pixel on the map whether it actually

represent that class on the ground. It is calculated by dividing the number of correctly

classified pixels in each category by the total number of pixels in that category. Kappa

statistics yields a k_{hat} that measures overall accuracy by combining user's and

producer's accuracies (Jensen 1996). The k_{hat} statistic is a measure of agreement

between image data and classified data, and ranges from zero (no association) to one

(complete association or perfect agreement). If a negative value is calculated, a less than chance agreement is signified.

The results obtained from the first accuracy test were not satisfactory, even when the overall classification accuracy was 85%. I ran a second test and this time I used only the GPS points. The 433 points were used while performing supervised classification procedure and the remaining 392 points were used to test the accuracy of the classification. Some points were not used because they were not informative and I lost some other points during the process. After importing the classified image in the ERDAS, the 433 GPS points were imported as User Defined Points using the Edit menu of the accuracy assessment dialog box. Since, the class values of the classified image will be shown automatically when the show class values function is clicked on Edit menu. But the reference points will have to be manually input by the user. All the 433 GPS points were assigned the following numerical values that are obtained from the supervised classification. The values are shown in Table 2.

Table 2. Class values of the reference points.

	Class Names	Class Value
1	Settlement	6
2	Agriculture	18
3	Grassland	13
4	Sal Forest	16
5	Mixed Forest	11
6	Water	15
7	Sand	1
8	Wetland	10

These values were input manually accordingly in the accuracy assessment dialog box. Once all the reference points were assigned to one of the eight values, the accuracy test was run. In the report function of the accuracy assessment dialog box - error matrix, kappa statistics and accuracy totals were checked before the run was performed.

Habitat Suitability Index and GIS

GIS analysis is becoming increasingly useful to develop habitat suitability (HS) models for wildlife. These models can be used for ecosystem, environmental and sustainable land management. During the 1980s, the US Fish and Wildlife Service developed several HS models to evaluate impacts on fish and wildlife habitat due to water and land use changes. Habitat suitability index (HSI) models allow the presentation of wildlife together with other natural resources by recording or predicting the response of a species to its environment. For any HS model, the fundamental elements are environmental variables that are independent, the resulting dependent habitat suitability values and the classification functional values that link the two. Such models use habitat requisites such as food, cover, distance or proximity to water (environmental variables), and the functions provide a dimensionless 0.0 – 1.0 habitat suitability indices that are determined by combining or aggregating one or more of the requisites. Outside the US and some parts of Europe, HS models are rarely used or developed.

According to Dettki et al. (2003), there are two approaches to assess wildlife habitat – relationships. Process – oriented models assess plausible causal relationships or functional processes underlying habitat use and provide a more general

conceptual framework. In contrast, empirical models analyze data on habitat use and

habitat characteristics collected at specific sites. This project attempts to develop a

heuristic HS model for the greater one-horned rhinoceros that will be based on literature

review (United States Fish and Wildlife Services HSI models) and Moose (Dettki et al.

2003), field observations (ground – truthing) and geographic data obtained from

topographic maps (scale 1:125000, Survey Department of His Majesty's Government of

Nepal in cooperation with the Finnish International Development Agency, FINNIDA). To

generate a valid HS index or habitat suitability map, both models should be assessed

simultaneously in the study. Use of GPS – collars or radio telemetric studies should be

extensively carried out for a long period of time along with expert knowledge of causal

relationship. Unfortunately, such studies are still lacking for one-horned rhino. Hence,

this project adopted a simpler process – oriented approach based on the identifiable

variables of grass, water and forest described above and applying neighborhood

analysis, which is one of many GIS operations. I made flow diagram of the process –

oriented model as shown in Figure 11.
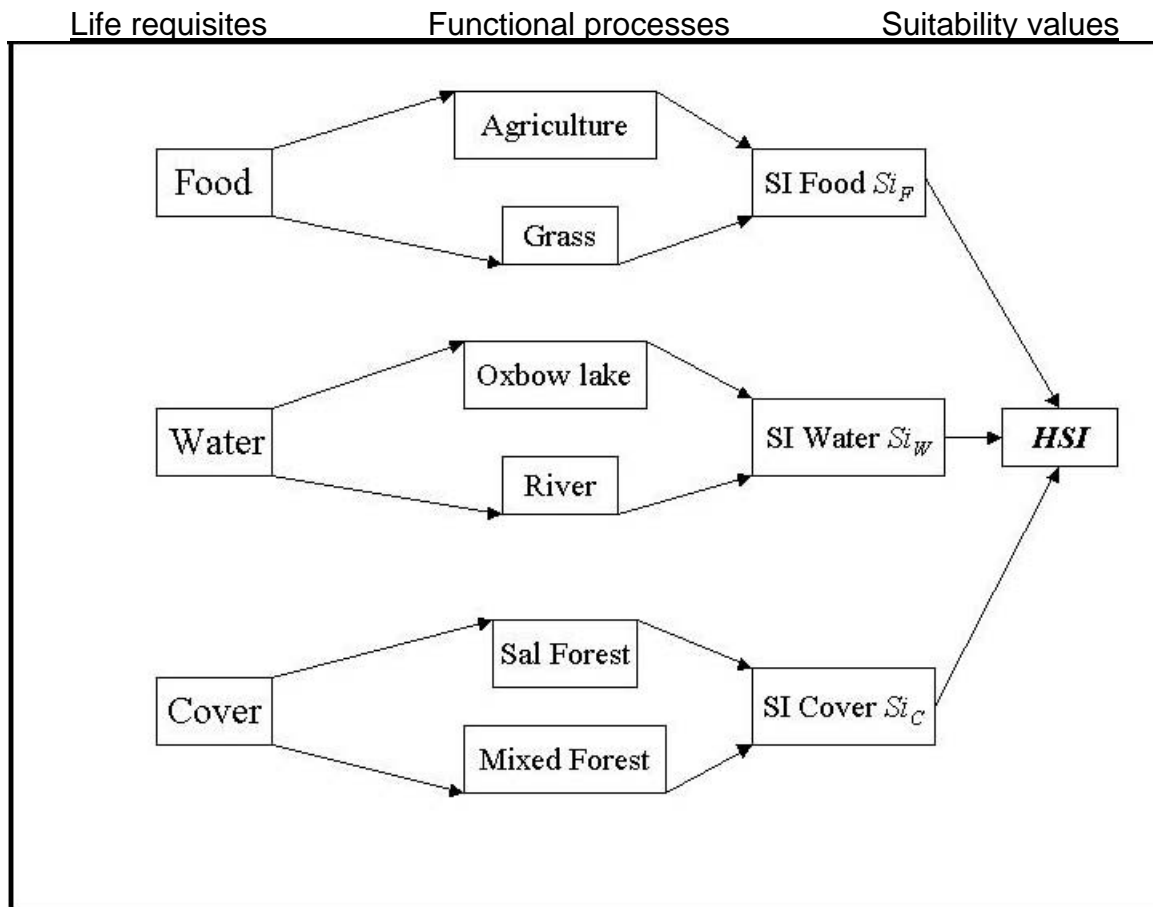
Figure 11. A flow diagram describing the life requirements, the variables used in the functional processes of the conceptual, process – oriented model to calculate habitat suitability index (HSI) for one-horned rhinoceros. (Adapted from Dettki et al., 2003)

Neighborhood analysis is a focal function that uses surrounding cells to assign value to a particular cell. In other words, the Neighborhood Statistics function computes a statistic based on the value of the processing cell and the value of the cells within a specified neighborhood. For example, it can be used to find the most dominant species in a neighborhood – majority – or to see how many species are located in the neighborhood.

Using neighborhood analysis, for each target pixel the number of pixels of each category of rhinoceros was counted in the neighborhood surrounding the target pixel and divided by the total number of pixels in the neighborhood. The neighborhood size

was initially set at 3x3 cells or 90 m x 90 m but different combinations were explored to decide which size to select. The set of 5x5 cells or 150 m x 150 m was selected for the neighborhood analysis. I selected this set because I thought this set would select average amount of pixels for one neighborhood as 3x3 cells would be too small while 7x7 would be too large.

Denote by Ni the proportion of pixels of the *ith* category in the neighborhood while *ith* being food, water or cover. For each category suitability index (Si) was defined by a linear function with threshold saturation as follows

$$Si = AiNi \ \text{ when } Ni \leq Ti$$
$$= 1 \ \text{ when } \ Ni > Ti$$

where Ai is the slope or coefficient and Ti is a threshold. For example, if the threshold for i=1, food, were $T1$=0.4 then the slope is $A1$=1/0.4. The thresholds values were assigned based on literature review and varied to find reasonable values. The supervised classified image was used to derive food, water and cover values ranging from 0 to 1. For food, I reclassified the values assigning 0 to all other values and 1 to those that had food in them. Similarly, I reclassified water and cover and made three maps as shown in Figure 12.
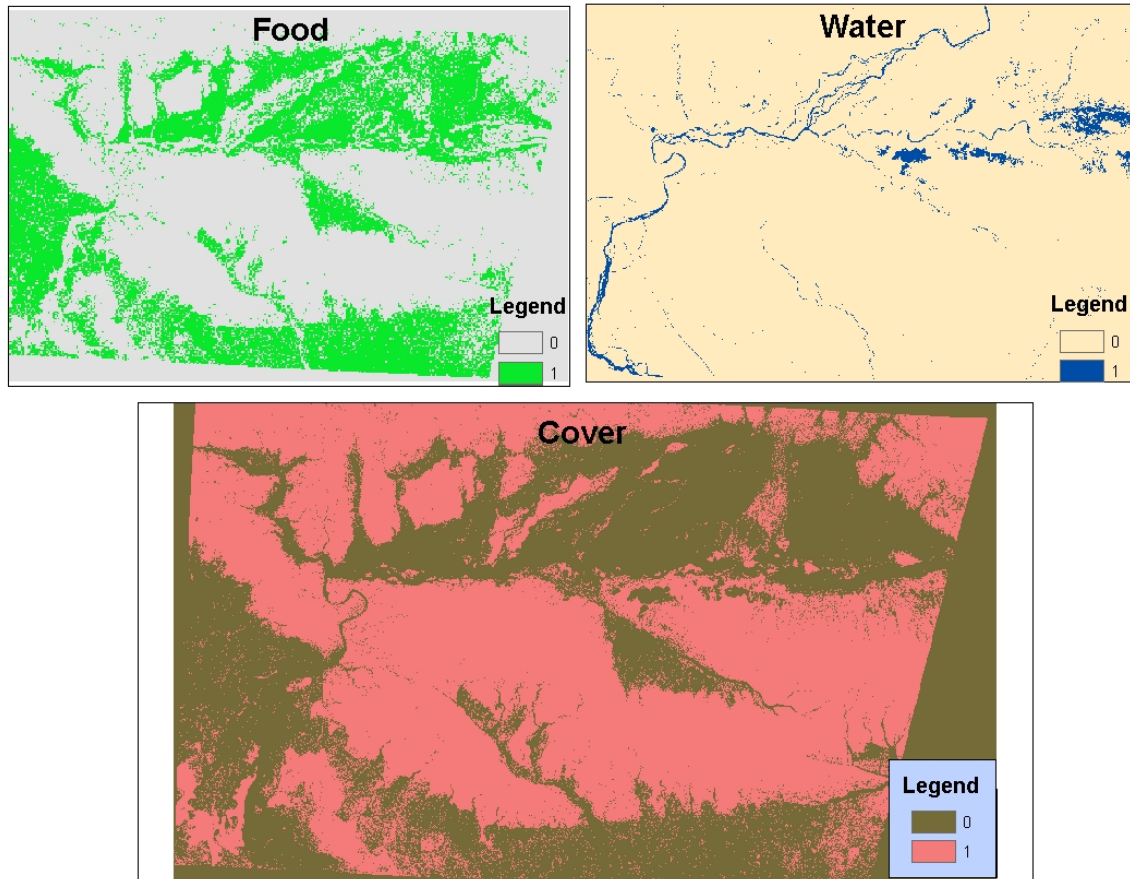
Figure 12. Food, water and cover map.

In the cover map, sal and mixed forest represent cover and have the value of 1 while rest of the classes has values of 0. Similarly, in the water map, lakes, oxbow lakes, wetlands and rivers have value of 1 and on the food map; grassland and agriculture have values of 1.

Neighborhood analysis was performed on the above maps. After calculating the neighborhood statistics, suitability indices for food, water and cover were explored using different combinations of decimals ranging from 0.0 to 1.0. For example,

1. *Si* for food = 0.4

2. *Si* for water = 0.4

3. *Si* for cover = 0.2

In other words, if 40 % of the pixels in the neighborhood contain water or food, then the threshold value would be 1 and for cover, only 20 % of the pixels should contain mixed and sal forest to have the threshold value of 1. Further combinations were used to achieve a higher suitability index as explained later.

The above suitability indices were then combined into a single equation that, in turn, was used to calculate a habitat suitability index (HSI) for rhinoceros habitat scaled to produce an index value between 0.0 (unsuitable habitat) and 1.0 (optimal habitat). To combine the three Si, the HSI equation was weighted arithmetic mean of cover suitability and the weighted geometric mean of food and water suitability.

$$HSI = b \, (S_1{}^a \, S_2{}^{1-a}) + (1 - b) \, S_3$$

where, a and $1\text{-}a$ are the weights for the geometric mean of food and water, respectively, and b, and $1\text{-}b$ are the weights of the arithmetic mean of the combined food-water and cover. The parameters a and b were assigned according to the literature review. The resultant HSI map with the above combination is shown in Figure 13.
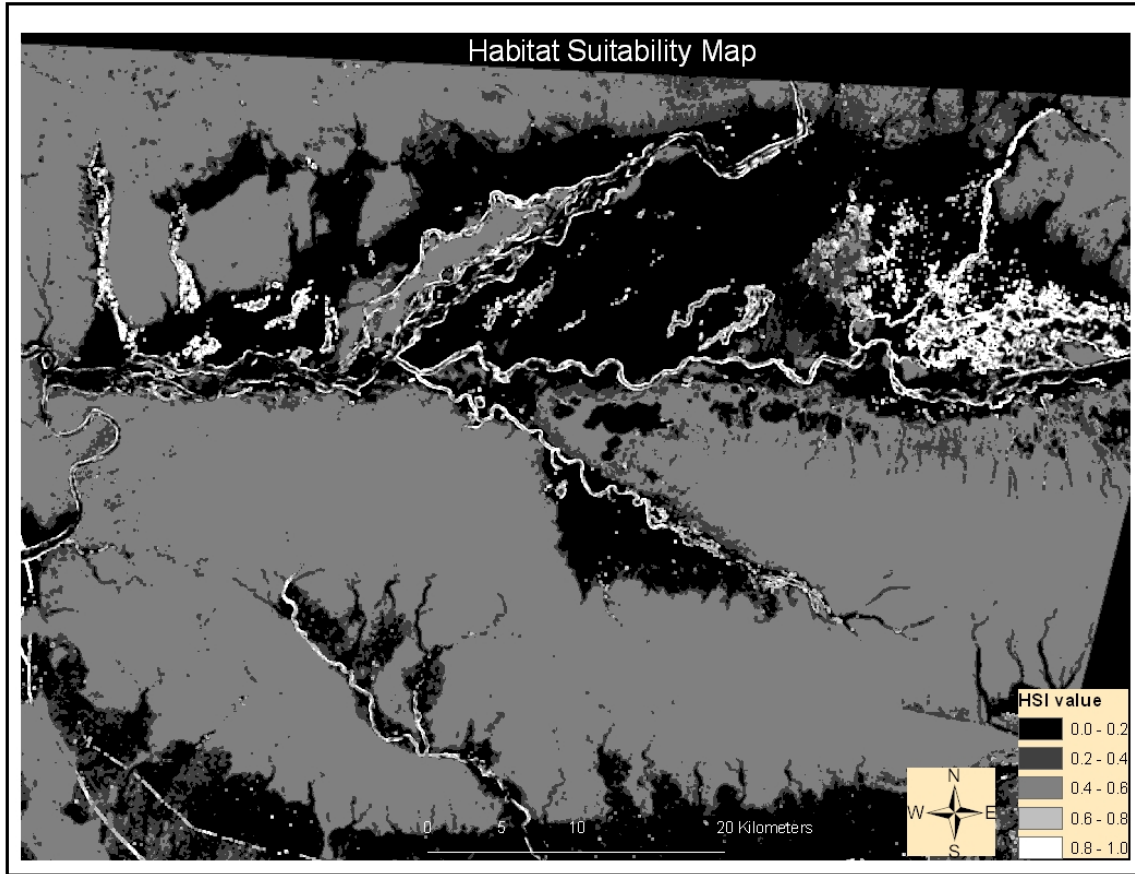
Figure 13. The suitability index value map for process – oriented model.

Sensitivity Analysis

The parameters used here such as *a, b, Tw, Tf* and *Tc* are uncertain parameters that require sensitivity analysis to examine the effect of change on one another. I assigned the best-estimated value or nominal value for each parameter as shown in Table 3.

Table 3.Two levels for five parameters.

Parameter	Nominal	Nominal + v
Tw	0.5	0.6
Tf	0.5	0.6
Tc	0.2	0.3
a	0.6	0.7
b	0.7	0.8

Then, each parameter was varied or perturbed above the nominal value and here v is

the percent change to impose on the parameter. Depending on the number of

parameters, I used two levels for five parameters. For example,

Suppose, the total level is denoted by *m,* then

$m = 2$, two levels that are nominal, nominal + v

If number of runs were denoted by *n*, then the full factorial combination would be as

follows

$n = \text{m}^{\text{p}}$ or $2^{5} = 32$

The full factorial design of thirty-two combinations was developed as shown in Table 4.

Table 4. Full factorial of two levels and five parameters.

	p.Tf	p.Tw	p.Tc	p.a	p.b		p.Tf	p.Tw	p.Tc	p.a	p.b
1	0.5	0.5	0.2	0.6	0.7	**17**	0.5	0.5	0.2	0.6	0.8
2	0.6	0.5	0.2	0.6	0.7	**18**	0.6	0.5	0.2	0.6	0.8
3	0.5	0.6	0.2	0.6	0.7	**19**	0.5	0.6	0.2	0.6	0.8
4	0.6	0.6	0.2	0.6	0.7	**20**	0.6	0.6	0.2	0.6	0.8
5	0.5	0.5	0.3	0.6	0.7	**21**	0.5	0.5	0.3	0.6	0.8
6	0.6	0.5	0.3	0.6	0.7	**22**	0.6	0.5	0.3	0.6	0.8
7	0.5	0.6	0.3	0.6	0.7	**23**	0.5	0.6	0.3	0.6	0.8
8	0.6	0.6	0.3	0.6	0.7	**24**	0.6	0.6	0.3	0.6	0.8
9	0.5	0.5	0.2	0.7	0.7	**25**	0.5	0.5	0.2	0.7	0.8
10	0.6	0.5	0.2	0.7	0.7	**26**	0.6	0.5	0.2	0.7	0.8
11	0.5	0.6	0.2	0.7	0.7	**27**	0.5	0.6	0.2	0.7	0.8
12	0.6	0.6	0.2	0.7	0.7	**28**	0.6	0.6	0.2	0.7	0.8
13	0.5	0.5	0.3	0.7	0.7	**29**	0.5	0.5	0.3	0.7	0.8
14	0.6	0.5	0.3	0.7	0.7	**30**	0.6	0.5	0.3	0.7	0.8
15	0.5	0.6	0.3	0.7	0.7	**31**	0.5	0.6	0.3	0.7	0.8
16	0.6	0.6	0.3	0.7	0.7	**32**	0.6	0.6	0.3	0.7	0.8

The R Console is an integrated suite of software facilities for data manipulation, calculation, and graphical display. It is statistical system that use S language and used mostly for single piece of data analysis. Four different sets were used for the analysis accompanied with set of graphs to facilitate interpretation. The four sets of parameter combinations are shown in Table 5, and the results are illustrated in Figures 14 – 17.

Table 5. Four sets of parameter combinations.

Set	p.Tf	p.Tw	p.Tc	p.a	p.b	Set	p.Tf	p.Tw	p.Tc	p.a	p.b
4	0.6	0.6	0.2	0.6	0.7	32	0.6	0.6	0.3	0.7	0.8
8	0.6	0.6	0.3	0.6	0.7	32	0.6	0.6	0.3	0.7	0.8
3	0.5	0.6	0.2	0.6	0.7	32	0.6	0.6	0.3	0.7	0.8
5	0.5	0.5	0.3	0.6	0.7	32	0.6	0.6	0.3	0.7	0.8
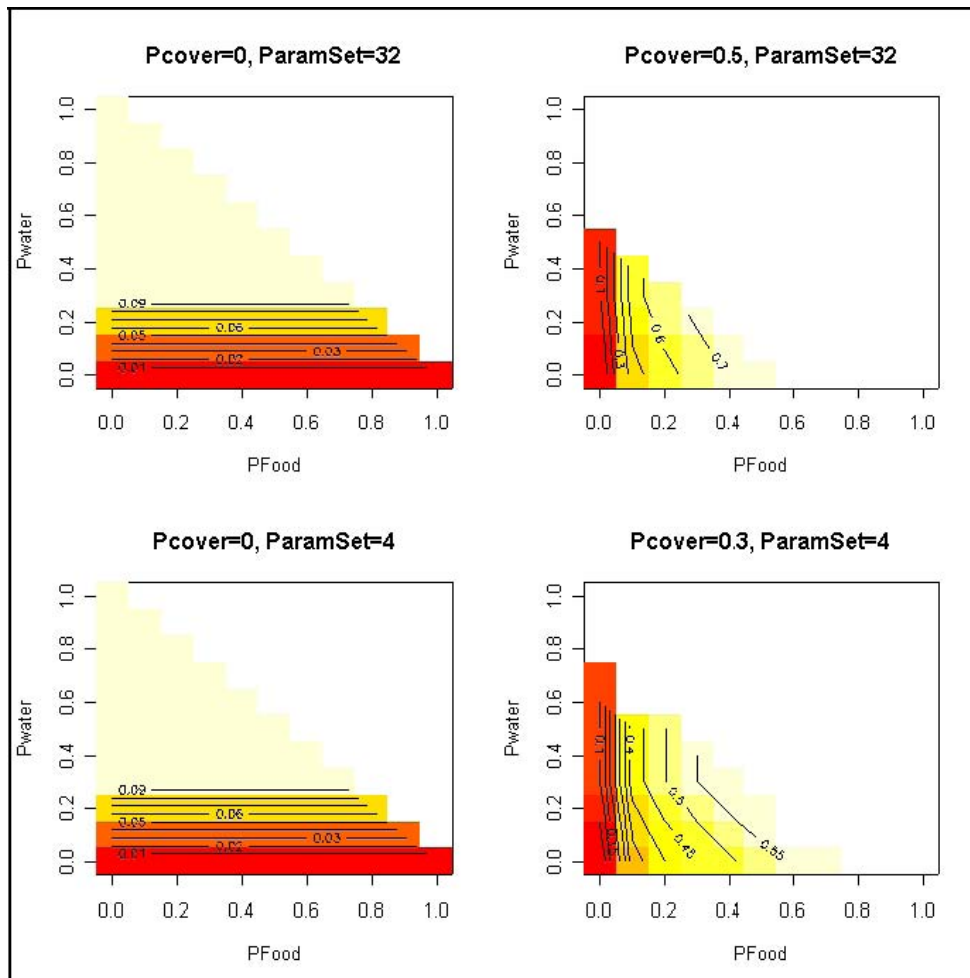
Figure 14. Paramset 4 and 32 with Pcover 0.3 and 0.5.

The red portion of the graph shows the low suitability value while the yellow color shows higher suitability values. In this set of parameter combinations, threshold value of food and water is 60 % with 0 % cover. It yields low suitability value of 0.09 for both sets. But with increased cover from 0 to 0.5, there is increase in suitability value to 0.55 and 0.7 respectively.
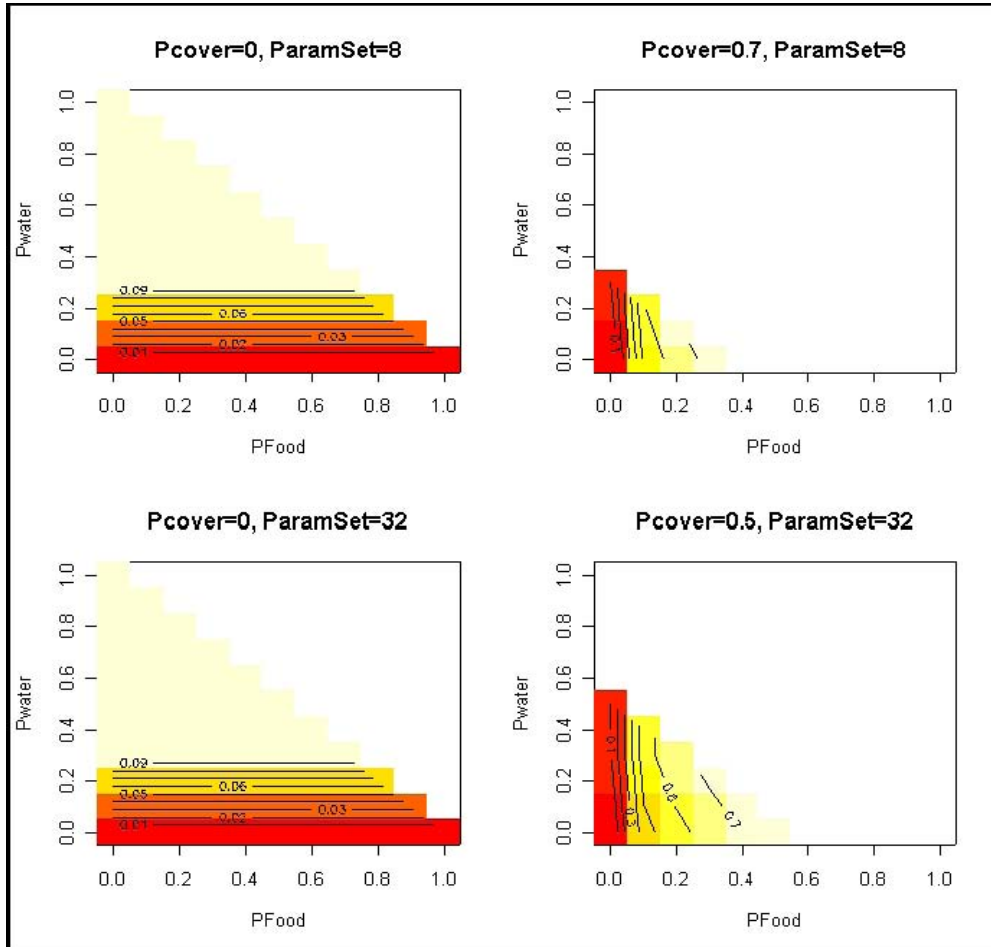
Figure 15. Paramset 8 and 32 with Pcover 0.5 and 0.7.

With this set of parameter combinations, effect of increased cover is exhibited clearly. For set 8, increased cover of 70 % reduces suitability value to less than 0.4. And for set 32, suitability value is 0.7 with 50 % cover indicating the effect of cover 32, suitability value is 0.7 with 50 % cover indicating the effect of cover.
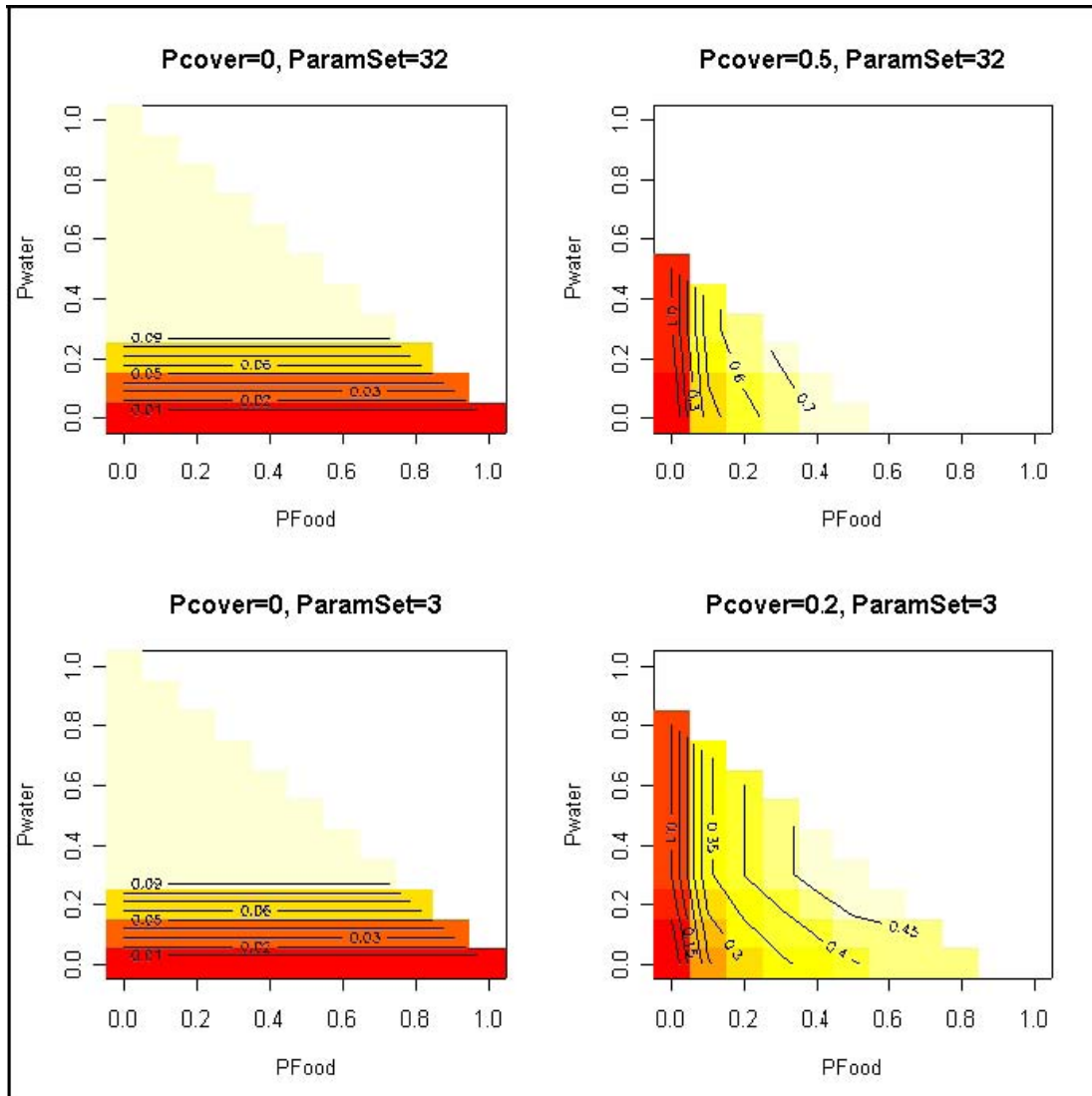
Figure 16. Paramset 3 and 32 with Pcover 0.2 and 0.5.

Using same parameter set 32 with set 3, it yields previous result of cover effect on suitability index. But even with low cover threshold for set 3, there is low suitability value of 0.45 and this may be due to the difference in geometric and arithmetic mean for set 3. Food has lower weight for set 3 than set 32. Also arithmetic weight for cover is higher for set 3.
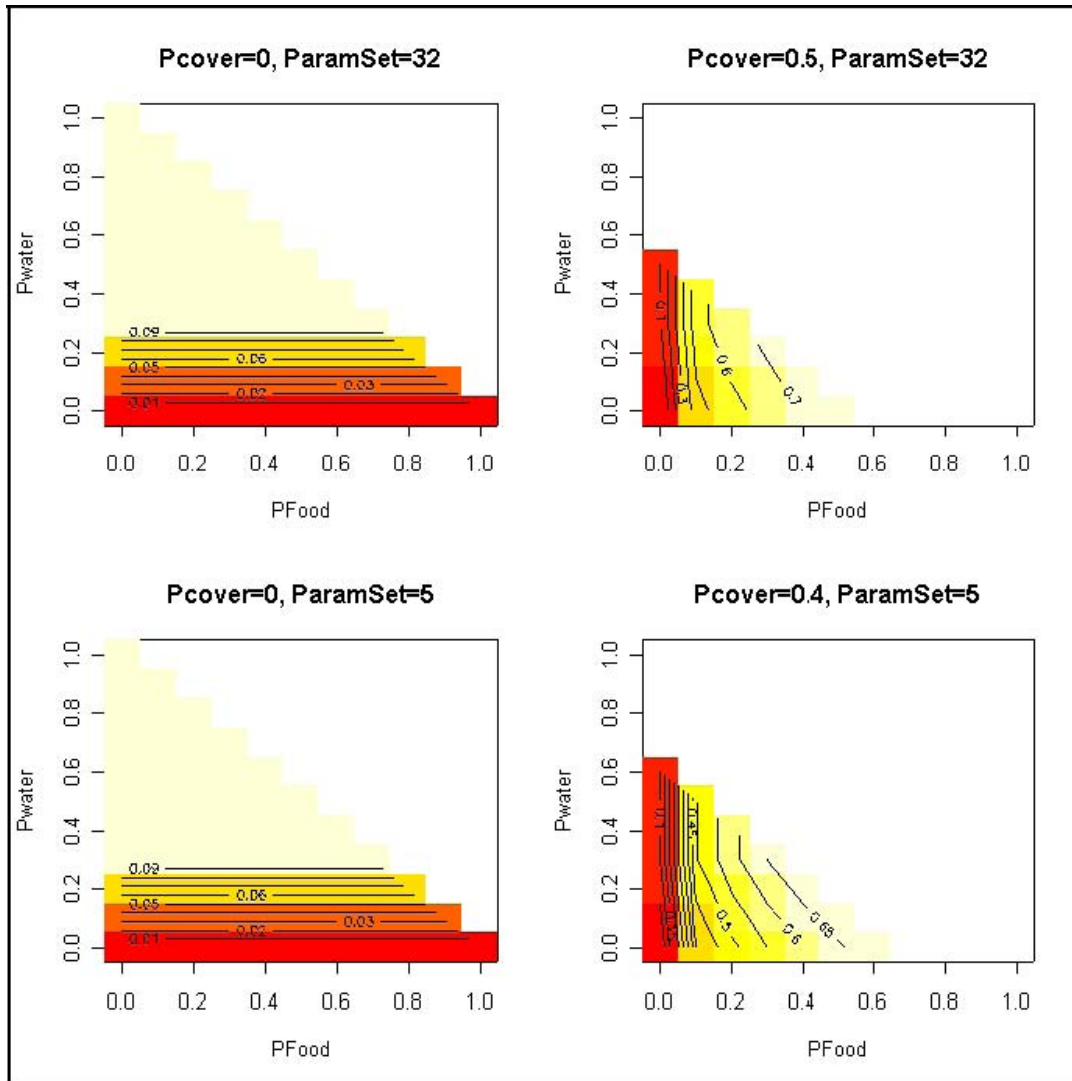
Figure 17. Paramset 5 and 32 with Pcover 0.4 and 0.5.

For this combination, suitability value increased to 0.65 for set 5 with 40 % cover. This again shows the effect of cover even with low geometric and arithmetic weights for set 5 than set 32.

Habitat Fragmentation

In recent years, study of landscape ecology has become important from the wildlife management point of view. As wildlife habitat degrades over time, it is necessary

to find the impact on the particular species and its surroundings. There are two perspectives to define the landscape – wildlife and anthropogenic perspectives. From the wildlife perspective, landscape is defined as an area that contains mosaic of habitat patches within which "focal" or "target" habitat patch is embedded. This perspective is also referred to as an organism – centered perspective and is based on how each organisms view or scale their habitat or surroundings. According to this perspective, the size of landscape varies with the size of different habitat patches or resource patches that are meaningful or crucial for the survival of phenomena under consideration (one-horned rhinoceros).

From the human perspective, the landscape corresponds to an area of land equal to or larger than, say, a large basin with an area of several thousand hectares. But for the management of wildlife populations, the later perception has limited utility since each organism scales the environment differently. And from an organism – centered perspective, the landscape could range in absolute scale from an area smaller than a single forest stand, for example – an individual log to an entire ecoregion such as RCNP. The final phase of this project was to use FRAGSTATS (McGarigal et al. 1994, McGarigal 2002) to compute different metrics that in turn would calculate percentage of fragmented habitats, area of the largest patch, and most importantly, the area of remaining suitable habitat.

In order to quantify landscape patterns for the one-horned rhinoceros and to meet one of the objectives of this research, I selected categorical or thematic map patterns. These represent the system property of interest as a mosaic of discrete patches and from ecological perspective; patches represent discrete areas of relatively

homogenous environmental conditions at a particular scale. The eight land cover

classes were used for the categorical map pattern analysis, and the goal was to

characterize the composition and configuration of the patch mosaic that constitute the

landscape. The thematic or categorical map was not utilized directly for computing

landscape composition and configuration. The map was initially used for deriving

suitability indices that were combined into the final HSI equation to extract suitable

habitats across the park area. I selected forty percentage thresholds for both food and

water and twenty percent for cover. I assigned 0.8 geometric weight (a) for food and 0.2

arithmetic weights for cover. These combinations yield HSI of 0.8. The final habitat

suitability map (HSI) was created using this information. The resultant HSI map pixels

had values ranging from 0 to 1 and I reclassified the values to four classes according to

habitat suitability. For example, if the pixels had values ranging from 0 to 0.2, it was

considered as highly unsuitable habitat and was assigned a value of 0, if the values

ranged from 0.2 to 0.4, it indicated unsuitable habitat and was assigned value 1, if the

values ranged from above 0.4 to 0.7, it exhibited moderately suitable habitat with class

value of 2, and finally the pixels having the value ranging from 0.7 to 1.0 were assigned

class value of 3 and they indicated suitable habitat.

Then the map was converted into ASCII file for further use in FRAGSTATS.

Various metrics that I have used are given in Table 6. The metrics were computed at

the patch, class and landscape levels. Different metrics at the different levels reflected

various configuration and composition of the landscape. Some metrics are redundant at

class or landscape levels and they were not used during execution process. Some

metrics provided good measurement of landscapes when comparing their different

sizes. For this project, from the organism – centered perspective, RCNP is considered as a single heterogeneous landscape that is comprised of mosaic of patches of varying sizes.

At patch level, metrics such as AREA, PERIM, GYRATE were selected to calculate area, density and gyration of individual patch. AREA measures the patch area in hectares; PERIM measure perimeter of individual patch in meters and the GYRATE calculates extent of the patch in meters. The 4 or 8-neighbor cell - rule affect this metrics. I used the 8-neighbor cell – rule for the entire execution. And to measure the shape complexity of the patch, SHAPE index was selected over PARA metrics because the later varies with the size of the patch while the former measures overall shape complexity of the patch. The core area metrics used were CORE, NCORE, CAI and ISOLATION/PROXIMITY. These metrics measure core areas, percentage of the patch that is comprised of core area, number of core areas that consider disjunct areas as separate patch and are useful from the organism - centered perspective. The core area index (CAI) approaches 0 when the patch does not contain any core area and approaches 100 when there are core areas. The patches that contain core areas are usually larger in size, shape and edge width. I made histograms of all the patch metrics to observe areas, perimeters, and shapes, extent of patch, isolation, and proximities of different patches.

To measure the proximity of patches, I specified the search radius to 90 meters from the focal patch. PROX is 0 when there are no similar patch types within the search radius indicating greater fragmentation and increases if the target habitat is less fragmented. And to measure the isolation of patches, ENN metrics was used that is the

distance from a patch to the nearest neighboring patch of the same type. It is based on shortest edge – to – edge distance of the patches. Also, the value of ENN depends on the selection of 4 or 8 – neighbor rule.

At class level, CA, PLAND, NP, LSI, LPI were used to compute area, area density, number of patches and the largest patch index. CA metric is useful in determining remaining target habitat type in a landscape. PLAND quantifies proportional abundance of each patch type and serve to measure landscape configuration. NP measure extent of fragmentation of patch types and depends on the use of 4 or 8

Table 6. Fragstats metrics at patch, class and landscape levels.

Statistic	Abbreviation
Patch Level Metrics	
Area Metrics/Density/Edge Metrics	
Patch Area	AREA
Perimeter of patch	PERIM
Patch extent	GYRATE
Shape Metrics	
Size of patch	PARA*
Overall shape	SHAPE, FRAC*
Core Area Metrics	
Core area	CORE
Number of core areas	NCORE
Index of core areas	CAI
Class level metrics	
Area/Density/Edge Metrics	
Class Area	CA
Percentage of class	PLAND
Number of patches	NP
Patch density	PD

(table continues)

Table 6 *(continued).*

Statistic	Abbreviation
Largest patch index	LPI
Shape Metrics	
Overall shape	PAFRAC*
Core Area Metrics	
Total core area	TCA
Percentage of core areas	PLAND
Number of disjunct patches	NDCA
Landscape Level Metrics	
Area/Density/Edge Metrics	
Extent of landscape	TA
No. And patch density	NP*, PD*
Largest patch index	LPI*
Diversity Metrics	
Patch richness	PR
Shannon evenness index	SHEI

*Statistics not analyzed due to their identical behavior at three levels.

neighbor cell rule. LPI reflects dominance of the largest patch in the landscape. As for

the core area metrics at class level, TCA, CPLAND and NDCA were used. These

metrics are redundant because they are similar to the ones used in patch level and the

only difference is, in the class level, everything is summed up. And at landscape level,

TA metrics was used to calculate extent of the landscape but NP and PD were not used

due to their little interpretive value. The metric LPI is redundant because it yields same

result as the class level LPI. Shape and contagion/interspersion were not used but

diversity metrics such as PR, SHDI and SHEI were used. Patch richness, PR measures

landscape composition but do not reflect relative abundance of patch types while

Shannon diversity metrics, SHEI measures even distribution of area among patches. In

other words, SHEI reflects evenness of patch distribution.

CHAPTER 3

RESULTS

Vegetation Classification

The overall accuracy of 69.90 % was achieved for the 2003 subset image. User's accuracy (errors of commission) ranged from 91.67 % for sand to 75.00 % for wetland and grassland and to 50.34 % for agriculture. Producer's accuracy (errors of omission) ranged from 96.05 % for agriculture to 52.54 % for mixed forest. Overall kappa statistics was 0.6275.

The overall classification accuracy for the 2003 image as shown in was lower than 85% minimum as suggested by Anderson et al. (1976). The reason for low accuracy could be the lack of previously tested data, mixed pixels, i.e., pixels that contain more than one category or classes, and similar vegetation patterns because Chitwan valley has similar vegetation patterns from one end to the other end of the park. The vegetation pattern starts from the floodplain that is vegetated with sparse or pure stands of grassland to riverine forests (mixed forest) that lead to dense pure stands of sal forest.

Table 7. Errors of commission (User's accuracy) and omission (Producer's accuracy) and kappa statistics for classification of 2003 Landsat ETM image. Overall accuracy was 69.90%.

S.No	Classes	Producer's Accuracy	User's Accuracy	Kappa Statistics
1	Water	55.17%	94.12%	0.9365
2	Wetland	100.00%	75.00%	0.7441
3	Agriculture	96.05%	50.34%	0.3840
4	Settlement	0.00%	0.00%	0.0000
5	Sand	52.38%	91.67%	0.9119
6	Sal Forest	87.65%	84.52%	0.8049

(table continues)

Table 7 *(continued).*

S.No	Classes	Producer's Accuracy	User's Accuracy	Kappa Statistics
7	Mixed Forest	52.54%	81.58%	0.7832
8	Grassland	61.76%	75.00%	0.6621

Furthermore, dense grassland communities, especially near lakes and rivers, interrupt sal forest and mixed forest. In some areas of the park, grassland flourishes with other vegetation types such as ferns and shrubs. The composition of the forest, grass species and mixed forest tree species are similar throughout the park as well. This makes an accurate classification difficult because similar vegetation patterns mean similar reflectance values. As the similar vegetation pattern, the soil texture and the soil moisture regimes are also similar throughout the park area and outside the park. The soil is sandy and porous with less water holding capacity, but still it supports the communities of the similar vegetation patterns. The low user's accuracy for the grassland could have resulted because some of the pixels were incorrectly assigned to the agriculture category, a typical situation in such studies. The growth stage or the height of the crops and the grass could be similar at that time when this image was taken. Some of the paddy fields on the way to Basantapur and in the nearby villages are classified as grassland, but it is one of the short grass species that colonizes rapidly in the fresh exposed soil.

The agricultural land contains some of the settlement and grassland pixels. The urban areas of Chitwan consist of individual houses surrounded with agricultural land except in the city, Narayanghat that stands by the Narayani River. In the classified image, almost the entire city is classified as agricultural land. The largest wetland area

is actually the outlet of one of the major lakes, Tamar Tal (Tamar Lake). It is located on the lowlands, and, when the lake is inundated during monsoon season, the water overflows to this area. The second visit to the field was to confirm the vegetation and the location of this area.

The second fieldwork revealed secondary succession of grassland in the outlet. While one side of the outlet was covered with marshy vegetation, the other side flourished with grassland. The marshy vegetation would eventually convert into grassland that would serve as additional habitat for the one-horned rhinoceros. The area or the lake could have overflowed when this image was taken in the year of 2003. The spectral profiles of these pixels also exhibit the nature of vegetation that is submerged in water. Classification of sand, sal and mixed forest were satisfactory. It may be due to the fact that 70% of the park area is covered by sal forest and it was easy to create an AOI of the sal pixels. Similar to the sand, the selected pixels exhibited sharp spikes in bands 5 and 6. As for the forest, with literature review and knowledge of the study area along with nature of the spectral reflectance, the pixels were classified accurately.

New classification routines are needed that can tease apart detailed reflectance patterns that are essential to distinguish agriculture, grassland and settlement pixels. This need increases in field identification of these classes and use of higher resolution imagery is also another promising alternative. I converted the classified GRID image into vector polygons and symbolized each class to give them a more natural look as shown in Figure 18.
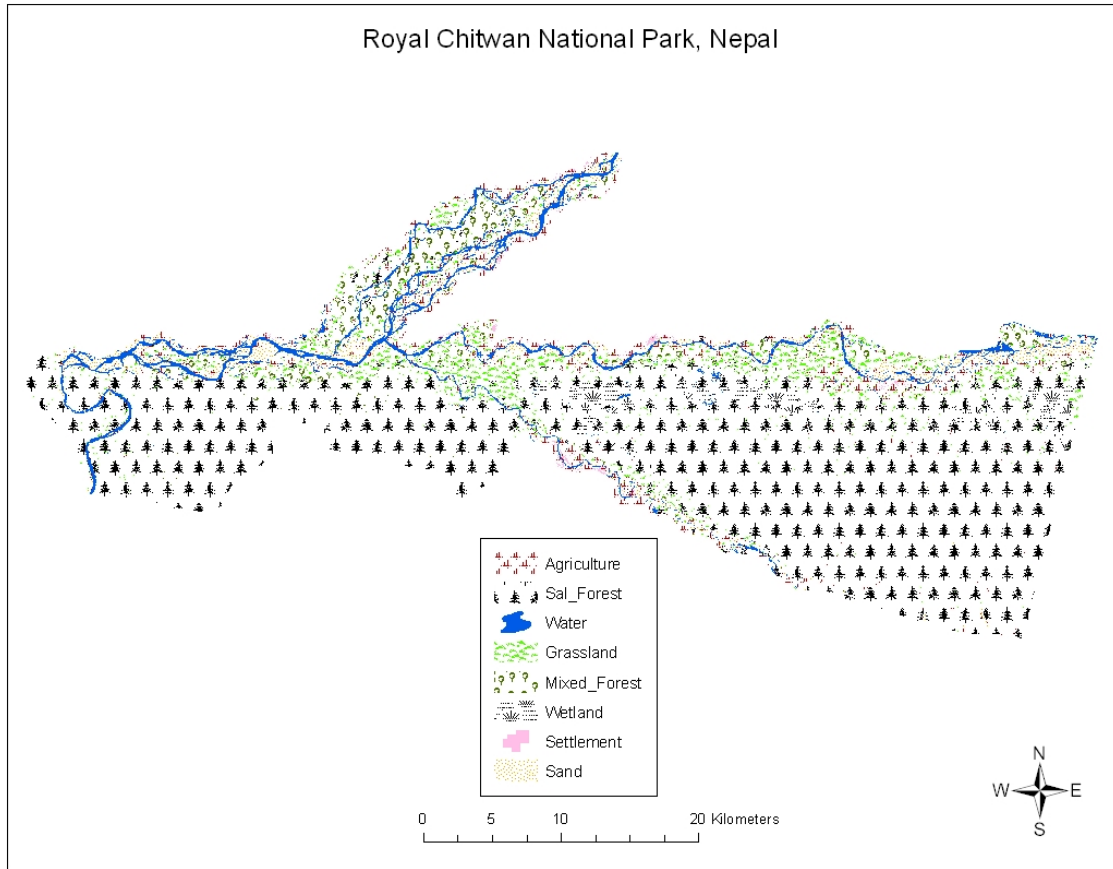
Figure 18. Symbolization of 8 classes.

Sensitivity Analysis

I explored various combinations of parameters using the R console to examine the effect of change on each other. With process – oriented model for modeling habitat suitability, I found a distinct spatial pattern, with high values of HSI along the water bodies and low values in the inland areas (Figure 13). For the development of habitat suitability indices, I have used numbers such as 0.5, 0.6, 0.7, and 0.8 but not lower than 0.5 for parameters P1 (food), P2 (water), a, and b. But for cover, I have used values lower than 0.5 such as 0.2 and 0.3. The number corresponds to the behavior and the habitat use of the one-horned rhinoceros. Areas that contain abundant water associated with tall grassland and oxbow lakes will make optimal habitats for these animals. They

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use sal forest to seek refuge during monsoon and mating season. They eat fruits of one species of the mixed forest named *Trewia nudiflora.* I used this information while assigning values to the parameters.

As seen from the sensitivity analysis test, all the parameters were interdependent. The value of 0.5, 0.6 for food and water and vice-versa produced high suitability values associated with 20 or 30 % cover. And increased cover lowered the suitability values that supports the above statement that forest are used less frequently. But in combinations where no cover was used showed significant reduction in the suitability index test and that proved the necessity of cover for a suitable habitat. This test also showed that if an area has more water than food or vice versa, it will have a lower suitability value indicating the unsuitable nature of the habitat. Hence, for an optimum habitat, it should have a combination of 0.5 (food), 0.6 (water) and vice –versa along with 20 – 30 % cover of mixed and sal forest.

Habitat Fragmentation

At patch level, moderately suitable habitat has the largest area and suitable habitat has the least area as shown in Table 8. The largest area for moderately suitable habitat accounts for the inclusion of farmland that is located in the vicinity of the park, because they were included as food during the habitat evaluation procedures. The unsuitable habitat area is small in comparison to the area of highly unsuitable habitat, the former is the calculation of settlements and the later is of sand and gravel. All the four habitat types have extensive perimeter sizes indicating intensity and distribution of edges across the landscape.

Table 8. Habitat metrics at patch level.

LID	Area(ha)	Perimeter(m)	Gyration(m)	Shape	Core(ha)	NCORE	CAI(%)	ENN(m)
0	0.09-50824	120-433400	15-36267	1-22.19	0-19615	0 - 458	0-88	67-60
1	0.09-4536	120-551760	15-10936	1-20.44	0-1451	0 -133	0-32	85-60
2	0.09-66478	120-421180	15-22432	1-14.83	0-51317	0 - 229	0-91	120-60
3	0.09-4211	120-351180	15-4262	1-13.52	0-1677	0 -124	0-40	60-60

Gyration metrics also suggest the extensiveness of the patches. The shape metrics increased from 1 to almost 23 indicating the increasing irregularity in patch shapes, because the metric is 1 when the shape of the patch is almost square and increments above 1 exhibit complex shapes of the patches. I made charts of shape complexities for the four habitat types. For moderately and unsuitable habitat, most of the patches have square shape as indicated by the metric of 1 and the lowest for suitable habitat patches with only about 470 patches having the shape of 1. Besides, suitable habitat patches consist of range of diverse shapes further indicating convoluted shapes for this habitat.

Depending on the nature of the data format (raster file), I have specified edge depth of 90 meters and that means the edge mask used to mask cells along the edge of the patch to eliminate them from the "core" of the patch, will be 3 cells wide. The result for the number of disjunct core areas (NCORE) indicates availability of numerous areas that are not within edges of depth distance from the patch perimeter. The higher percentage of the core areas indicates the presence of a high number of core areas in each habitat type. For the suitable habitat, 40 % of the area consists of core areas. The result of the proximity metrics indicates that the patch has neighbors of the same patch type within the search radius of 90 meters and 0 values for some patches show their isolation nature. This indicates fairly fragmented distribution of patches. ENN metrics

further proves the fragmentation nature of the patches as it increases away from 0 while

closer to 0 indicates closer distance to its neighboring patch of the same type.

At class level, CA and PLAND metrics measure landscape composition. Highly

and moderately suitable habitat comprises about 40 % of the landscape while the

settlement is only 9 %. The suitable habitat is about 3.5 % of the total landscape. NP of

highly suitable habitat exhibits highly fragmented nature of this class followed by

moderately suitable habitat. About 15 % of the suitable is fragmented as calculated by

FRAGSTATS. LSI of the four classes indicates increased desegregation between the

patch types with the highest for the unsuitable habitat. The lowest value of CPLAND for

suitable habitat suggests it's increasingly smaller sized patches or more convoluted

patch shapes. Number of disjunct core areas (NDCA) also indicates patch shape

complexity. Values approaching 100 for COHESION metrics at all the classes indicate

higher physical connectedness of the patches.

Table 9. Habitat metrics at class level.

LID	CA	PLAND	NP	LPI	LSI	PAFRAC	CPLAND	NDCA	COHESION
0	284167.17	45.7	1649	40.34	33.67	1.26	38.42	971	99.94
1	57123.54	9.27	5002	0.73	112.61	1.38	1.59	2913	98.47
2	258795.99	41.62	8005	26.77	48.08	1.42	35.26	920	99.80
3	21722.67	3.49	1389	0.68	53.76	1.33	0.73	1185	97.95

Here, PAFRAC approaches 2 indicating shape complexities in all the classes

with the highest for unsuitable and moderately suitable habitat. In order to examine the

shape complexities, I made a histogram of all the pixels in respect to their HSI values as

shown in Figure 19. This figure reveals less than 100000 pixels have HSI value of 0.8

and even fewer have the HSI value of 1 indicating less than half of the analyzed area is

comprised of suitable habitat. NP or number of patches can be correlated with this
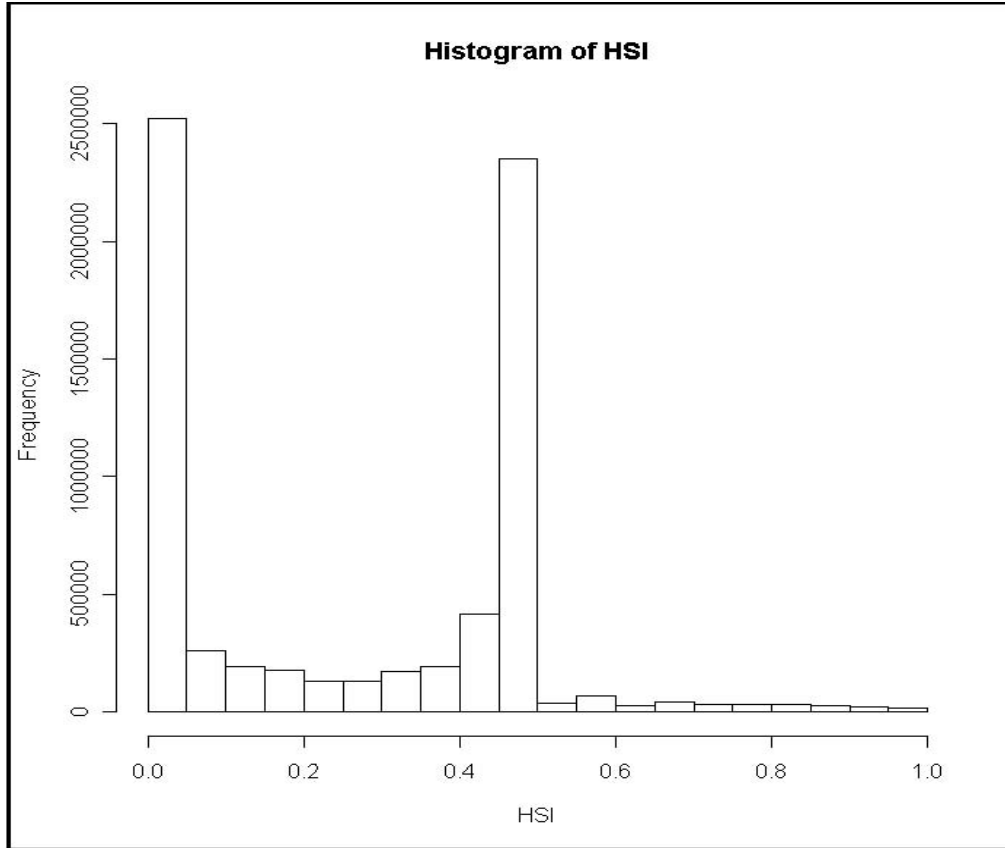
histogram.

Figure 19. Histogram of HSI of the pixels.

Figure 20. Shape complexity of patches for highly unsuitable habitat.

For very unsuitable habitat patches (Figure 20), more than 700 patches have shape value greater than 1 and increases there after indicating increase in shape complexity.
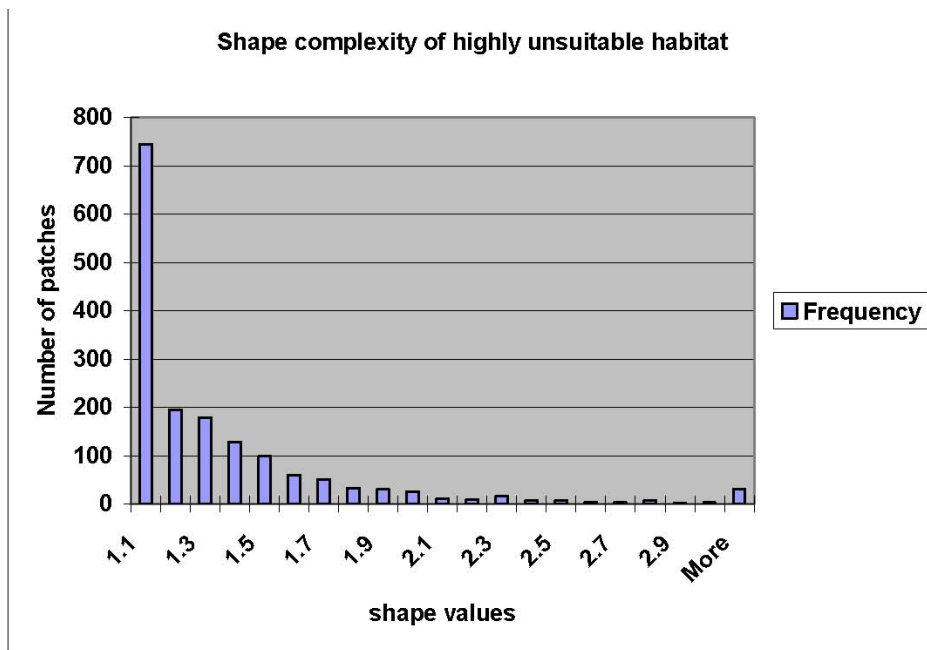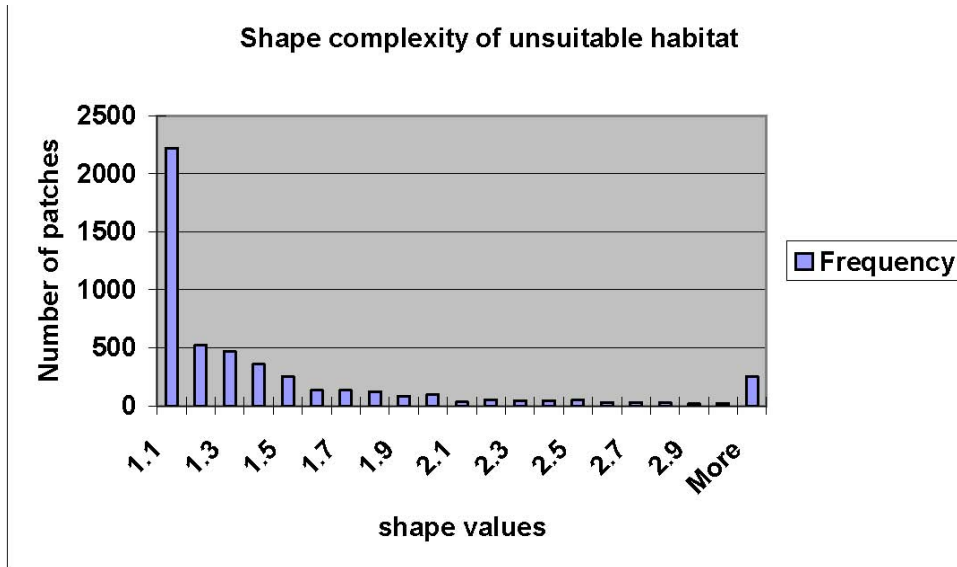

Figure 21. Shape complexity of patches for unsuitable habitat.

For patches of unsuitable habitat (Figure 21), more than 2000 patches have shape value greater than 1 and follow the same trend as the patches of very unsuitable habitat.
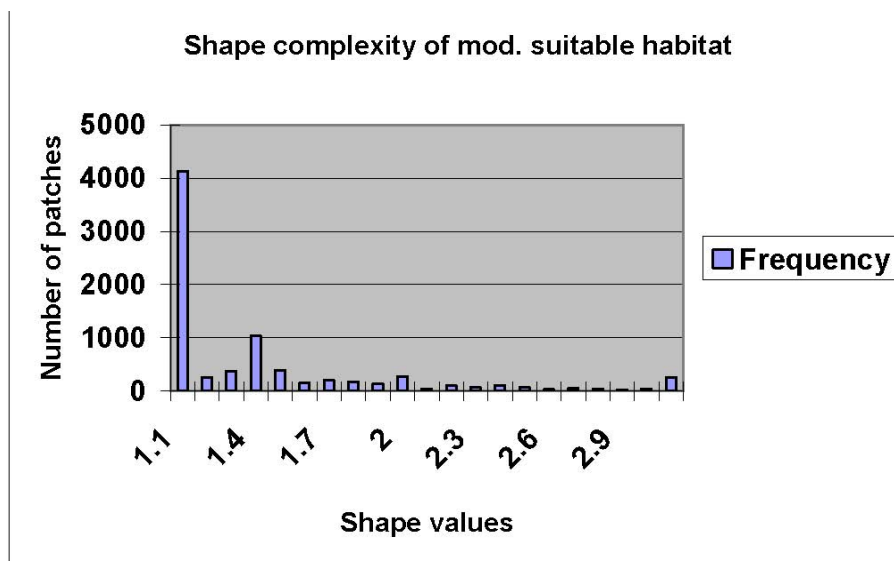

Figure 22. Shape complexity of patches for moderately suitable habitat.

There are more patches (Figure 22) that have shape value greater than 1 in this class. The patch shape size increases with fewer patches showing larger shape.
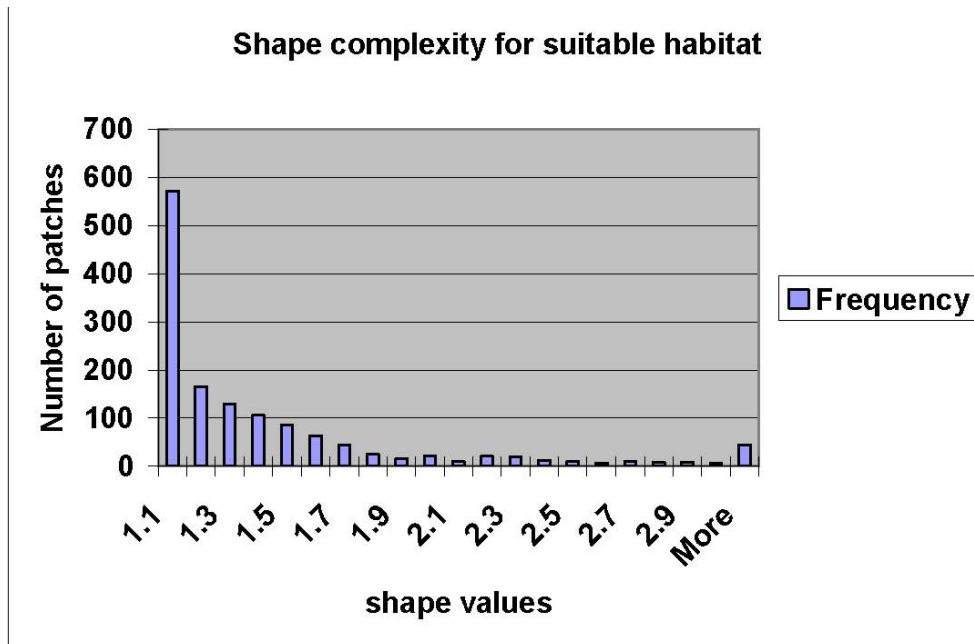
Figure 23. Shape complexity of patches for suitable habitat.

And finally, patches of suitable habitat (Figure 23), exhibits more diverse shape and sizes than the other habitats. Besides greater shape complexity, it also shows the fragmented nature of patches belonging to this class.

At landscape level, metrics such as TA, LPI, PR, SHDI and SHEI were used to calculate extent of the landscape, patch richness, diversity among the patches and how uniformly the patches are distributed across the landscape.

Table 10. Habitat metric at landscape level.

LID	TA	LPI	PR	SHDI	SHEI
Landscape	621809.37	40.3377	4	1.0592	0.7641

The total area of the landscape is 621809.37 hectares and about 40 percent of the total landscape area is comprised of largest patch that belongs to very unsuitable

habitat type. PR is the number of classes or patch types in a given landscape and for this project, there are four classes. The value of SHDI indicates increment in the number of different patch types. And SHEI value is greater than 0 indicating increasing even distribution of area among patches because when SHEI is 1, distribution of area among patch types is perfectly even or proportional abundances are the same.

For the four patch types or classes, at patch level, the decrease in area, perimeter, gyration and shape of the suitable habitat exhibited expected results. The area metrics at class level too supported the patch level area metrics. The percentage of the landscape occupied by the suitable habitat accounts for about 3.5 percent and suitable habitat has forty percent of food and water with twenty percent cover. The result of several metrics such as CORE, NCORE, PROX, ENN, NP, CPLAND, PAFRAC, and COHESION indicated fragmented nature of patch types across the landscape, especially patches of the suitable habitat.

Further result of perimeter – area fractal dimension (PAFRAC) indicated perimeter or edge complexity of the patches that is another measure for increasing shape complexities. More it approaches to 2, higher convoluted and plane - filling perimeters of the edges. With 1.4 and 1.3 PAFRAC metrics for moderately and suitable habitat, it exhibits increase in patch shape complexity, i.e. the shape of patches becomes more complex from a simple squares. Both value of landscape metrics such as Shannon evenness index (SHEI) and diversity index (SHDI) indicated approaching even distribution of area among patch types.

CHAPTER 4

DISCUSSION

Data Acquisition

An important part of this project was to retrieve satellite data for the study site.

Fortunately, only one image was required. I searched for vector data's of streams,

roads, and streets but, there were very few vector data's available at the time when this

project was underway and they were expensive. The most valuable data, land cover

types, soil profile, plant composition and density of canopy cover came from field study.

The image was classified with unsupervised method and it was used during the

field study. Field verification of land cover types proved to be the most effective method

and best suited to using a GPS unit as the device of choice.

Vegetation Classification

I had prior knowledge of the vegetation types that flourished in RCNP from

previous visits. With this and from literature review, I acquired sound knowledge of the

vegetation types and its pattern and came to know that the pattern is similar throughout

the park area. This would have been both problematic and useful during classification

process. Land cover types such as Sal forest, mixed forest, sand, and water was easier

to classify but was difficult to tease out the grassland, agriculture and settlement

accurately. Some of the pixels belonging to these classes were mixed due to similar

reflective nature of the pixels. Originally, I tried using unsupervised to classify but soon

switched to supervised method over it. If one has sound knowledge of the study site,

supervised method is more efficient for the vegetation classification.

After running the accuracy test with the reference points (GPS), I was confident

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that the classification was successful to some extent even with lower accuracy percentage of 70. For example, mixed forest nearby Sauraha and the grassland on its vicinity were classified almost accurately. I had little problem classifying sand, water and sal forest. As noted above, some pixels of settlement, agriculture and grassland got mixed and this may be due to the housing pattern of Nepal. Individual houses are usually surrounded by large tracts of agricultural land and in some cases, crops such as maize completely engulfs the house because most of the houses are one storey in height and are made from plant materials. And when these crops are still growing, they could resemble grasses. Grasslands near Tamar Lake are classified as mixed or sal forest and this may be due to the tall nature of these grasslands. With a height ranging from 6 – 8 meters, sometimes, they grow with small trees and shrubs and can completely overshadow them. In order to achieve more accuracy for the grassland, use of higher resolution imagery is recommended.

Habitat Suitability Index (HSI)

As stated in the objectives of this project, I have attempted to develop a heuristic habitat suitability model for the one-horned rhinoceros based on process-oriented approach. Generally, the HSI index provides suitability indices according to the habitat requirements of the target species. For one-horned rhinoceros, I selected three habitat variables to construct the HSI index and they were food, water and cover. Again, from the literature review, I knew their spacing behavior, biology and daily routine. If an area has all the three variables, then they won't travel afar. They spend most of their time foraging and wallowing depending on the season. Besides food and water, cover is also crucial for their survival. But forest or cover is not frequently used as food and water.

With this information in mind, I assigned thresholds accordingly. I considered a place with abundant water and food with some cover nearby would make a suitable habitat for them. I was also cautious while increasing or decreasing the threshold values for food and water. I tried assigning more values to water and vice – versa just to observe the effect on the suitability index and soon reached to conclusion that they have to have almost the same amount of food and water given some cover to make an ideal habitat. Since the parameters I was using were all uncertain, sensitivity analysis deemed important to study the effect of change on one another. This analysis exhibited the interdependency of the three variables and role of cover. About 20 % cover is enough for a good habitat and if the place has more cover then it would be unsuitable habitat for them.

As stated above, to validate the results of any suitability indices, rigorous field study involving home range, telemetric studies for years and habitat use is required. Here, I have applied habitat use to generate suitability index. As noted above this project merely attempted to examine whether such indices can be developed for the mega herbivore and after doing these procedures, it seemed feasible. I think sensitivity analysis produced some promising results such as effect of cover increase on the suitability index. At the same time, assignments of geometric and arithmetic weights and thresholds for the variables have opened a whole new area for arguments. For instance, how valid are the assigned weights and threshold values? What is the effect if geometric mean for suitability of water is lower than the food suitability? These scenarios were not explored in this thesis. However, I conclude this method will be effective and useful if used with data's are acquired in the manner explained above.

Habitat Fragmentation

To study the nature of fragmentation of RCNP, I used FRAGSTATS, a program that computes landscape metrics that measure landscape composition and configuration. More than a decade or so, RCNP has undergone drastic change both naturally and from anthropogenic activities. Naturally, the three rivers change course annually thereby creating new grassland habitats and floodplain. Anthropogenically, the rapid growth of population around the vicinity of the park has increased the pressure on the wildlife inside the park. The competition for the grass has increased dramatically along with other illegal activities such as logging and grazing cattle inside the park. With the help of FRAGSTATS, I attempted to explore the amount of remaining habitats and their connectivity.

I have considered RCNP as a single heterogeneous landscape with varying patch sizes. This landscape consists of areas outside and inside the park. I have included areas adjacent to the park because one-horned rhinos pay frequent visit to the agricultural filed located outside the park. To derive different metrics for different purposes, I used six of the eight available metrics and they are – area/density/edge, shape, core area, isolation/proximity, and connectivity and diversity metrics. I used these four metrics at patch, class and landscape level. The metrics were selected carefully because some of them yield same results at class and landscape levels. For example, total core area (TCA) calculates same statistics at class and landscape levels. Prior to selecting the metrics, landscape border, boundary and background were defined too. For this project, I selected no background and no border. In this case, all the cells are positive and the landscape boundary surrounds the entire grid. With this

selection, all cells are included in the total landscape area calculation. In the absence of background, the landscape boundary is treated like background for the calculation of core area metrics. With this selection of metrics, I ran FRAGSTATS.

At patch level, the area, perimeter, extent of the patch and shape of the patches seemed convincing. Even though shape metrics at patch level do not calculate complexity of the shapes but do give an idea of the shape of the patch. The value of 1 or greater for the shape metrics indicates maximum compact size of the patch, almost square. And at class level, all the metrics produced satisfactory results with 3.5 % of the remaining suitable habitat. This percentage could have been higher if the grasslands near Tamar Lake were classified correctly.

The moderately suitable habitat pixels had the value from 0.4 to 0.7 and suitable habitat pixels had values from 0.7 to 1.0. But If I had assigned all the pixels that had values from 0.5 to 1.0, the amount of suitable habitat would increase to 5 % or more with the missed grassland pixels included. Since, I have included areas located outside the park for entire calculation; the metrics for all habitat types has exhibited increased values that are logical. Recently, the forest area located between Narayanghat city and town Bhandara were included as suitable habitat for Bengal tigers and rhinos along with Asian wild elephants. This new habitat is connected to RCNP on the north – central side. It consists of similar vegetation pattern as RCNP with dense sal forest dotted with several lakes with grassland community growing along its edges. The classification procedures were able to identify fair amount of the grassland habitat of this area. FRAGSTATS produced results as I have anticipated such as shape complexity of different patches and fragmented nature of the suitable habitat. One can comprehend

the fragmented nature of grassland community just by observing the classified map. They are not connected to each other and are located in different areas. According to Dinerstein (2003), there are four subpopulations in four different regions of the area. His study also corroborates the fragmented nature of suitable habitat. Besides, one-horned rhinos of Chitwan valley do not travel far like the other large ungulates due to the availability of ample amount of food, water and cover. This reduces the need for migration and I suggest that connectivity of habitat is not critical for their survival. Even though, the results are reliable, there are some questions that are still left unanswered such as what is the carrying capacity of RCNP for the one-horned rhinoceros? How many subpopulations can it really support or how many individuals can actually thrive free of anthropogenic impact? These questions are vital from the wildlife management point of view. The area has obviously increased from 932 to 1,772 square kilometers as a result from the inclusion of 750 square kilometers of buffer zone and 90 square kilometers of Barandabhar forest. But we do not how many individuals can it sustain and for how long! This is another area of study open for future research.

CHAPTER 5

CONCLUSION

Habitat modeling is an aid to mitigate or resolve complex issues in co-management of large ungulates and forest resources. In this study, I examined one approach to model rhino-habitat resource-relationship. My aim was not to perform a formal model evaluation but to explore the assumptions of a conceptual, process – oriented HSI model based on expert knowledge. I could show that this approach is ecologically meaningful if the used environmental variables are selected based on the habitat requirements of the target species. And if the variables are correctly identified, they enable us to understand the effects of changes in the landscape to the model outcome. However, to validate this model, besides combining with empirical approach, I would require demographic data also.

The wildlife managers of Chitwan can find the results of this study valuable from the point of managing remaining and available habitats but again it needs constant monitoring of these habitats to ensure prolonged management. Presently, Nepal is thrust into troubled sea of political instability whose end does not appear to occur any soon. The obvious impact is on the wildlife of Chitwan valley, because it is located on *terai* or plain and is more accessible than other Himalayan parks and wildlife reserves. Just in the span of five years, about 200 one-horned rhinoceros have died, decreasing the population level to 378 from more than 550 individuals. The security posts have been reduced from 32 to 8, leaving RCNP more vulnerable to illegal activities such as poaching and logging. All these factors have contributed to the bleak future of *Rhinoceros unicornis* of Chitwan valley, Nepal. However, the tools developed in this

thesis could help in managing the remaining habitat and improve the deteriorating

condition of this mega herbivore.

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