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Modelling of Habitat Suitability Index for Muntjac (*Muntiacus muntjak*) Using Remote Sensing, GIS and Multiple Logistic Regression

Imam EKWAL[1], Hussain TAHIR[2], Mary TAHIR[3]

[1] *Mekelle University, Department of Biology, Corresponding author, Mekelle, ETHIOPIA*

[2] *Mekelle University, Department of Geography & Environmental Studies, Mekelle, ETHIOPIA*

[3] *Jamia Millia Islamia University, Department of Geography, New Delhi, INDIA*

E-mail: ekwalimam@rediffmail.com, ekwalimam01@gmail.com

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A B S T R A C T

Habitat degradation and loss has been widely recognized as the main cause for the decline of wildlife population. Evaluating the quality of wildlife habitat can provide essential information for wildlife refuge design and management. The purpose of this study was to produce georeferenced ecological information about suitable habitats available for muntjac, *Muntiacus muntjak* in Chandoli tiger reserve, India (17º 04' 00" N to 17º 19' 54" N and 73º 40' 43" E to 73º 53' 09" E). Habitats were evaluated using multiple logistic regression integrated with remote sensing and geographic information system. Satellite imageries of LISS-III of IRS-P6 of study area were digitally processed. To generate collateral data, topographic maps were analysed in a GIS framework. Layers of different variables such as: Landuse land cover, forest density, proximity to disturbances and water resources and a digital terrain model were created from satellite and topographic sheets. These layers along with GPS location of muntjac presence/absence and multiple logistic regression (MLR) techniques were integrated in a GIS environment to model habitat suitability index of muntjac. The results indicate that approximately 222.39 km² (75.4%) of the forest of tiger reserve is least suitable for muntjac, whereas, 29.53 km² (10.02%) is moderately suitable, 22.12 km² (7.5%) suitable and 20.70km² (7.0%) is highly suitable. The accuracy level of this model was 97.6%. The model can be considered as effective enough to advocate that forests of this area are most appropriate for declaring it as a reserve for muntjac conservation, ultimately to provide prey base for tiger.

1. INTRODUCTION

An understanding of the relationship between spatial distribution of animals and their habitats plays an important role in conservation and management of threatened species [1]. Remote sensing and GIS (RS and GIS) can be used as tool for getting information about the habitat preference of the wildlife species. RS and GIS also help in monitoring areas of land for their suitability to endangered species, through integration of various habitat variables of both spatial and non-spatial nature [2]. The outputs of such models are usually simple, easily understandable and can be used for the assessment of environmental impacts or prioritization of conservation efforts in a timely and cost-effective manner [3, 4].

Indian muntjac (*Muntiacus muntjak*) is the smallest deer of the Indian subcontinent, popularly known as barking deer. It has soft, short, brownish or greyish hair, sometimes with creamy markings. The male Indian muntjac has small antlers which attain 15 cm in length and have only one branch. This species prefers rain forests, monsoon forests and hilly areas with dense vegetation and is omnivorous, feeding on fruits, shoots, seeds, etc. Indian muntjacs are regarded as extremely solitary animals and are a favourite food source for large Asian predators like leopards, tigers, pythons and crocodiles. The Indian muntjac is found throughout India, Nepal, Malaysia, southern China, and Taiwan. In spite of their wide distribution in southern Asia, muntjac population in India is sparse due to hunting for food and habitat loss. Therefore, they are listed as endangered species and kept under Schedule-III of Wildlife Protection Act of India [5]. Long-term survival and conservation of this herbivore depends on the availability of preferred plant species for food. Hence, protection of the historically preferred habitats utilized by muntjac is a significant factor in conservation biology. Muntjac is a prey base of large carnivores and symbol of wilderness and well being of the ecosystem so that by conserving them and their habitat, the entire ecosystem can be conserved, which is ultimately beneficial for man‘s own survival. Therefore, it is important to evaluate the suitable habitat available for muntjac for their better conservation and management. The present study is a small effort in this direction. The habitat suitability of muntjac was investigated within Chandoli tiger reserve.

Habitat evaluation is the first step towards meaningful wildlife conservation [6]. Geospatial technology including: remote sensing, geographic information system (GIS) and global positioning system (GPS) along with a habitat suitability index (H.S.I.) model provide an efficient and low-cost method for determining habitat quality [7]. Use of satellite imagery, geographical information systems (GIS) and statistics may assist in quantifying available habitat for animal species [8]. A suitability index provides the likelihood of how much area is suitable for a particular species. The higher the values the better are the chances that a particular location is suitable for the occurrence of that species. In this model, regression is used on several environmental parameters to calculate an index of species occurrence [9, 10].

The concept of wildlife habitat analysis started with the development of habitat evaluation procedure (HEP). Firstly developed in 1976, the HEP has been modified since then after detailed assessments and there are now many habitat evaluation models. The US Fish and Wildlife Service has developed as many as 157 habitat suitability models for large number of fish and other wildlife in the past 20 years [11].

Encouraged by the results, Lyon [12] used LANDSAT image classifications in predictive modelling for nesting sites of American kestrel *(Falco sparverius)*, whereas in the same year Harris [13] used visual LANDSAT image classification as an effective tool in re-introduction programme of the white oryx *(Oryx leucoryx)*. In 1984, Bright [14] used remotely sensed data along with other ecological parameters to assess the habitat of elk *(Cervus Canadensis)*. Homer et al. [15] created a model that accurately predicted suitable habitat for sage grouse *(Centrocercus urophasianus)* whereas, in 1994, Andries et al. [16] used SPOT remotely sensed data to extract landscape characteristics for spatial modelling of barn owl habitat. The geospatial technology can also be used in quantifying the suitable habitat for herbivore species through predicting modelling [17, 18]. In 1997, Brian and West modelled elk calving habitat in prairie environment using GIS and remote sensing techniques [19]. Use of remote sensing and GIS for modelling potential available habitat is becoming popular among ecologists [20] and many studies have used this geospatial technology to create predictive models of distribution and specific habitats for individual species [21]. Whereas, Beutel et al. considered that the available habitat modelling technique needs some improvement, therefore, in 1999 they reviewed that how wildlife habitat modelling techniques can be improved for better and accurate prediction [22]. Furthermore, Store and Jokimaki [23] used geographic information system, integrated with habitat suitability index and multi-criteria evaluation approach to produce georeferenced ecological information about the habitat requirements of different species. On the other hand, Kummerle et al. used maximum entropy models to analyze herd range maps and habitat use data from radio-collared bison to identify key habitat variables and map European bison habitat across the entire Carpathian eco-region [24]. Similarly, Jordan et al. tested the use of H.S.I. scores as predictors of abundance of blue-winged teal in Ohio, USA and find it be reasonably well [25].

Impressed with potentiality of remote sensing and habitat modelling techniques, Indian researchers also used geospatial technology wisely. In India, the use of geospatial technology for analyzing the habitat suitability index started during the late 1980s. In 1986, Parihar et al. evaluated habitat of Indian one-horned rhinoceros using remotely sensed data from LANDSAT [26], while Roy et al. used this technology for habitat suitability analysis of *Nemorhaedus goral* [27]. Similarly, Porwal et al. analyzed suitable habitat for muntjac (*Cervus unicolor*) in Kanha National Park using remote sensing data [28]. The geospatial technology was widely used by Kushwaha and his colleagues for habitat suitability analysis of various wild animals. In 2000 they analyzed suitable habitat for rhinoceros in Kazhiranga National Park [29] and for mountain goat in Rajaji National Park [30]. In 2004, Kushwaha1and Hazarika used Landsat-TM imagery and IRS-1D, LISS-III imagery to assess the habitat loss of elephant in Arunachal Pradesh and Assam, India [31]. Recently, Kalra and Unial have used remote sensing and GIS for the habitat evaluation of Great Indian Bustard and Lion in desert National Park and Palpur Kuno proposed Lion Sanctuary, respectively [32] [33]. A further improvement in H.S.I. technique was record after application of multiple logistic regression (MLR). MLR is a relatively new statistical technique for predictive modelling. Binomial logistic regression is a form of regression that is used when the dependent variable is dichotomous and independent variables are continuous. For MLR statistical analysis, statistical package for the social science (SPSS) has been used [34]. MLR applies maximum likelihood estimation after transforming the dependent variable into a logit variable. This way the multiple logistic regression estimates the probability of a certain event occurring. Habitat models using presence–absence data (dichotomous dependent variable) and multiple logistic regressions is useful in formalizing the relationship between environmental conditions (independent habitat variables) and species habitat requirements, thus quantifying the amount of potential habitat available.

Probably due to this, multiple logistic regression, integrated with remote sensing and GIS has gain momentum in different parts of the world for predictive and habitat suitability index modelling. Palma et al. used logistic regression to analyse Iberian lynx habitat and its distribution [35]. On the other hand, Hirzel et al. [36] assessed habitat suitability models using multiple logistic regression in Bern Alps (Switzerland) for virtual species, whereas, Bio et al. [37] used binomial logistic regression for predicting the plant species distribution in lowland river valleys of Flanders (Belgium).

In 2004, Keating reviewed application and interpretation of logistic regression and suggested that improvement is needed in this method to be used as an important tool for wildlife habitat-selection studies [38]. Later on, Dendoncker et al. used multiple logistic regression (MLR) for modelling of land use suitability maps [39]. In 2007, Flantua et al. combined palynological GIS and multiple logistic regression, and developed a predictive model for Columbian savanna, which can be used in reconstructions of past and future land-cover distributions under changing climatic conditions [40]. In the same year, De La et al. achieved habitat suitability analysis to outline potential areas for conservation of the grey wolf (*Canis lupus*) using geospatial techniques [41].

In India recently, Kushwaha et al. [3], Singh [42], Braunisch et al. [43] and Zarri et al. [4] have used multiple logistic regression to analyze habitat suitability for *Cervus unicolor* and *Muntiacus muntjac* at Ranikhet, muntjac in Binsor Wildlife Sanctuary, tiger in Corbett Tiger Reserve, edge effect on two population of capercaillie *(Tetrao urogallus)* and Nilgiri laughing thrush *(Garrulax cachinnans)* in Western Ghats respectively. Similarly, Imam [44] and Imam, et al. [45] used multiple logistic regression, remote sensing and GIS for evaluating the suitable habitat for tiger in Chandoli national park respectively. On the other hand Singh and Kushwaha improved the logistic regression technique and used it for wildlife habitat suitability modelling of muntjac and goral in the Central Himalayas, India [46]. Similarly, Alam used this method for habitat suitability analysis of striped hyena *(Hyaena hyaena)* in Gir National Park and Sanctuary, Gujarat, India [47]. In most of the cases the presence/absence data of animal species are used along with multiple logistic regression for habitat suitability analysis.

2. STUDY AREA

Chandoli tiger reserve is situated mainly along the crest of the North Sahyadri Range of Western Ghat, Chandoli tiger reserve (CTR) and lies between Koyna and Radhanagri sanctuaries. It contains pristine patches of semi-evergreen forests, harbouring among other endangered species, the Indian giant squirrel. Origins of the Warna river and almost the entire catchments of the reservoir is protected the PA. Though the reservoir submerged very good patches of forests, it is now playing an important role in providing effective natural protection to the rest of the remaining forests by isolating them. This PA along with others mentioned above was primarily declared to protect catchments of the dam, as well as to conserve biological diversity of the region. There are few remaining dense forest patches left in Northern area. The location of CTR is 17° 04' 00" N to 17° 19' 54" N and 73° 40' 43" E to 73° 53' 09" E (fig. 1). The tiger reserve lies within the districts of Satara, Kolhapur, Sangli and Ratnagiri.

The reserve is situated in the biogeographic province of Western Ghats along the crest of the Sahyadris. The topography of the entire reserve is undulating, with steep escarpments, often with exposed rock. The average elevation is 816.5 mean sea level (msl), with the lowest point at 589 msl and the highest point at 1,044 msl. A distinct feature of the sanctuary is the presence of numerous barren rocky lateritic plateaus, locally called the *sadda*. These are usually flat to slightly inclined and have tremendous amount of loose scattered laterites. Devoid of any perennial vegetation these have overhanging cliffs on the edges and numerous fallen boulders. The geological foundation of the area is Deccan trap, the soils are mostly lateritic on the plateau and reddish brown, of mixed origin, on the hill slopes. The area has a moderate climate with maximum temperature of 38°C in summer and a minimum of 7°C in winter, meanwhile annual rainfall is 3,500 mm (recorded at Chandoli village).

According to Champion and Seth [48] the forest types include, western tropical hill forests, semi-evergreen forests and southern moist mixed deciduous forests. Dominant species are anjani *(Memecylon umbellatum),* jamun *(Syzium cumini)* with associates Pisa *(Actinodaphe angustifolia)*, Katak *(Bridelia retusa),* Nana *(Lagerstroemia lanceolata)*, Kinjal *(Terminalia paniculata)*, Kokam *(Gravinia indica)*, Phanasi *(carallia brachiate)*, Ain *(Terminalia tamentosa)*, Amla *(Emblica officinalis)*, Umbar *(Ficus hispida)*, Harra *(Terminalia chebula)*, etc. Among grasses Bangala *(Andorpogon)*, Dongari *(Crysopogon fulvas)*, Kalikusli *(Hetropogon canturtus)*, Anjan grass *(Sanerus silaris)*, Karad *(Thimedo quadrivalvis)*, saphet-kusli *(Aristida funiculate)* and among bamboo species *Bambusa bambos* (Kalak) are the common. Warna River originates in the reserve.

Numerous other perennial and seasonal streams also drain into the reservoir, which are important sources of water.

In addition to the 19 perennial and 48 seasonal natural water sources, 3 artificial waterholes are also recorded.

Chandoli tiger reserve has very low number of wild animals and except for gaur (6 in number) no other animals were encountered. Koyna sanctuary is situated at about 25 km north to the Chandoli, while Radhanagri is in south.

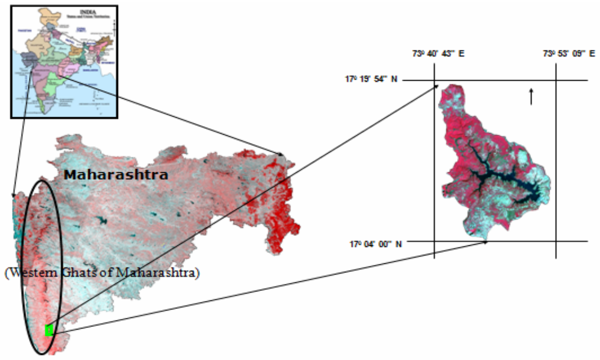

Fig. 1. Study area *(Chandoli tiger reserve, India).*

These PAs provide an important link of protected area and core forests between them.

3. METHODS

The study was started with collection of topographic maps of study area. Topographic maps (of 1:50,000 scale) were collected from wildlife wing of forest Department of Maharashtra (India) and with the help of forest officials the boundary of protected area was marked on these sheets. Since the study area was encompassed by four topographic maps, all topographic sheets were scanned separately and exported to *ERDAS IMAGINE* 8.7 in image format (.img) for mosaicing [49]. Before mosaicing, all scanned topographic maps were georeferenced to Geographic Lat-Long Projection to sub-pixel accuracy. The common uniformly distributed ground control Point's (GCP) were marked with root mean square error of one third of a pixel and images were re-sampled by nearest neighbour method.

After georeferencing, all topographic maps were mosaiced. Then this data was re-projected into UTM-WGS 84 projection for further analysis. After this, re-projected image was exported to *ERDAS IMAGINE* 8.7 and vectorized. The vector map was polygonized using a clean-build operation. A study area extent AOI was built around the tiger reserve boundary to produce a rectilinear map and area of PA was calculated for verification. Satellite data of Indian remote-sensing satellite-P6, linear imaging self-scanning satellite-III of 2005 of study area was acquired from National Remote Sensing Agency, Hyderabad, India.

The satellite data was imported into *ERDAS IMAGINE 8.7* software in an image format for geometric correction. In order to use these data in conjunction with other spatial data, it is needed to georeference the distorted data (raw data) to a coordinate system. The LISS data was co-registered with already rectified enhanced thematic mapper (ETM) satellite data of 1999 considering it as a reference coordinate system and reprojected in terms of Universal Transverse Mercator World Geodetic System - 84 (UTM WGS-84). Distortion was corrected using ground control points (GCP) and appropriate mathematical models. In the present study about 20 well distributed prominent features were considered as GCPs. The precision was measured through root mean square error (RMSE). The well distributed 20 GCPs improved the image rectification accuracy and brought the RMSE value as low as 0.2, which is below 1 pixel and can be considered sufficiently accurate [50]. Since study area lies in two scenes of 095-60 and 095-61 (of L1SS III), both images were treated separately and after rectification, these scenes were mosaiced together using a model present in *ERDAS IMAGINE 8.7* software.

From the mosaic data, a subset of area of interest (AOI) was made for further analysis. Image was displayed as a False Colour Composite (FCC) using three bands (3, 2, 1) and colour prints were taken to the field for ground truthing. The Landuse land cover map of an area can give pattern of land utilization and also helps in evaluating the earth surface. Therefore, it is important to prepare land use land cover map. Satellite data (imageries) was used for creating False Colour Composite (FCC) that served as the basis to develop the Landuse land cover map. The Landuse land cover map was prepared through digital analysis of satellite data using supervised maximum likelihood classification technique. The study area was categorized into eight classes of land cover viz. Evergreen forest, *Malkiland forest* (secondary/rejuvenated forest), Scrub, *Sada* (laterite rock), Grass land, Agriculture, Sand and River (water).

Forest crown density map provides information on the crown cover of the forest, which is an indicator of forest status. Normalized difference vegetation index (NDVI) was used to prepare a forest density map that was categorized into four canopy density classes: <10% (non forest), 10-40% (open), 40-70% (medium) and >70% (dense).

The normalized difference vegetation index is calculated by the formula: NDVI = (IR–R)/(IR + R), where IR = infrared light and R = red light. The ratio gives a number from minus one (–1) to plus one (+1). An NDVI value of zero means no green vegetation and close to +1 (0.8–0.9) indicates the highest possible density of green leaves [51]. The group of pixels having NDVI values from 0 to 0.3 were categories under canopy density class of <10%, 0.3-0.5 as canopy density class of 10-40%, and 0.5-0.7 were categorised as 40-70%, whereas, the group of pixels having NDVI value 0.7-0.9 were kept under the canopy density class of >70%). The field survey was carried out for the period of 15 days from the 18th to the 30th October 2005. Ground truthing was done by matching the tone, pattern, texture association, shape and size of the features from the FCC for a particular habitat with the help of GPS location.

To analyze the habitat use by wild animal species present in the tiger reserve, opportunistic transects were used to collect data on presence/ absence of the wild species as forested area was not accessible due to its high density, under growth and absence of tracks and roads. A total of 312 points locations of wild animal‘s presence/absence were recorded with the help of GPS. Slope, aspect, elevation, and distances to roads, settlements and drainage were not recorded, as they would be more accurately derived through data post-processing in a GIS framework.

It is important to quantify forest fragmentation, because spatial structure of habitats in which an organism lives, influence their population dynamics and community structure [52]. Anthropogenic activities can disrupt the structural integrity of landscapes and is expected to impede, or facilitate organism‘s movement across the landscape [53]. Therefore, much emphasis has been placed on developing methods to quantify landscape patterns, which is considered as prerequisite to the study of pattern-process relationships [54, 55].

The Landuse land cover map was used as input for landscape analysis to derive indices such as Patch cohesion, Contagion index, Proximity of patches, Aggregation index and Patch size density using ―FRAGSTATS [56].

Habitat suitability analysis requires generation of accurate database on various life support system as well as potential disturbance factors affecting the habitat. As mentioned above, satellite imagery was used to create variables like Landuse land cover map and Forest crown density map; whereas, continuous surfaces of distance from settlement and drainage were generated from topographic map for proximity analysis. Elevation, Aspect and slope layers were created from digital elevation model (DEM). Distance variables like settlements and drainage were log transformed to enforce normality. All the input layers (table 1) were co-registered with sub-pixel accuracy.

Table 1. List of input database layers created for muntjac habitat suitability modelling.

SN	Name of layers	Format layers	Source	File type	Software used
1	Aspects	Polygon	GIS derivative	Image file	ERDAS Imagine 8.7
2	Slope	Polygon	GIS derivative	Image file	ERDAS Imagine 8.7
3	Elevation	Polygon	GIS derivative	Image file	ERDAS Imagine 8.7
4	Drainage	Line	Topographic map	Shape file	ArcView 3.2a
5	Settlement	Point	Topographic map	Shape file	ArcView 3.2a
6	Road	Line	Topographic map	Shape file	ArcView 3.2a
7	Forest type	Polygon	Satellite imagery	Image file	ERDAS Imagine 8.7a
8	Forest density	Polygon	Satellite imagery	Image file	ERDAS Imagine 8.7a

4. RESULTS AND DISCUSSION

4.1. Muntjac H.S.I.

Distribution of animal species is largely determined by the availability of preferred forage and other environmental factors such as elevation, slope, distance from water, aspect and so on. Kushwaha et al. [3] and Zarri et al. [4] used these variables for habitat suitability analysis of tiger and Nilgiri laughing thrush respectively. Therefore, these factors (given in table 1) were also considered for muntjac habitat suitability index analysis.

After preparation of layer maps (table 1), modelling process for habitat suitability index for muntjac was started (fig. 2).

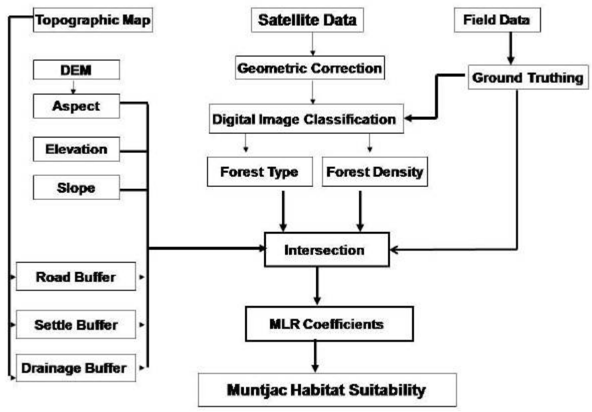

Fig. 2. Paradigm of muntjak habitat suitability analysis.

GPS locations of muntjac‘s presence/absence obtained from the field survey were transferred into ArcView 3.2 [57] and were attached as attributes to all the locations. All the independent variables were transferred into raster themes and used for further analysis. Values for Landuse land cover map and forest canopy density were recorded and specified as categorical variables. The points of animal detection were then intersected with all the input layers to produce the habitat use-environmental variables matrix. This worksheet was employed for further statistical analysis. Here, cases of animal sightings were taken as Boolean (presence/absence) and multiple logistic regression was run for H.S.I. modelling. Multiple logistic regression is a form of regression which is used when the dependent is a dichotomy and the independents are continuous variables, categorical variables, or both and computer software uses following formula for analyzing the probability:

$$\ln(ODDS) = \ln\left(\frac{\hat{Y}}{1-\hat{Y}}\right) = a + bx$$

where, $\hat{Y}$ is the predicted probability of the event which is coded with 1 (presence) rather than with 0 (Absence), $1-\hat{Y}$ is the predicted probability of the other decision, and x is predictor variable.

Initially all layers (variables) mentioned above were considered while developing the habitat suitability index for muntjac, but finally except for Landuse land cover map and fragmentation indices others were neglected as they were influencing the results towards biasness. The coefficients derived from multiple logistic regression (table 2) were used as weight for variables to integrate all layers in GIS domain (as shown below) to arrive at the probability/suitability map.

Formula of H.S.I. for muntjac = {exp (LULC(sada) * (-0.001) + LULC(grassland) * (-0.917) + LULC(water) * (-2.350) + LULC(scrub) * (-0.860) + LULC(agriculture) * (-1.130) +LULC(malkiland forest) * (-0.142) + LULC(sand) * (-0.816) + LULC(evergreen forest) * (13.254) + CON * (-7.415) + AI * (0.089) + CONSTANT * (–18.471)}

{1 + exp (LULC(sada) * (-0.001) + LULC(grassland) * (-0.917) + LULC(water) * (-2.350) + LULC(scrub) * (-0.860) + LULC(agriculture) * (-1.130) +LULC(malkiland forest) * (-0.142) + LULC(sand) * (-0.816) + LULC(evergreen forest) * (13.254) + CON * (-7.415) + AI * (0.089) + CONSTANT * (–18.471)}

Where, exp = Exponential, LULC = Landuse land cover, CON = Contagion index AI = Aggregation index

Table 2. Co-efficients derived for muntjac using multiple logistic regression.

Variables	Co-efficient
Landuse land cover(sada)	-0.001
Landuse land cover(grassland)	-0.917
Landuse land cover(water)	-2.350
Landuse land cover(scrub)	-0.860
Landuse land cover(agriculture)	-1.130
Landuse land cover(malkiland forest)	-0.142
Landuse land cover(sand)	-0.816
Landuse land cover (evergreen forest)	13.254
Aggregation Index	0.089
Contagion Index	-7.415
Constant	-18.471

The estimated log-odds image was then logit transformed to produce the intended probability map. As the log-transform squashed lower values and exaggerates higher values, the classification accuracies had been calculated at cut-off of 0.5. The output map was sliced to ―not suitable at value lower than 0.5 and ―suitable at values higher than that. Suitability map was further categorized into four classes of ―highly suitable, ―suitable, ―moderately suitable and ―least suitable. Predicted probability value of 0.004 - 0.673 was categorized as ―least suitable habitat for muntjac, 0.673 - 0.764 as ―moderately suitable, 0.764 - 0.830 as ―suitable and 0.830 - 0.892 as highly suitable, respectively. The model, ― habitat suitability map of muntjac, is given in figure 3. For muntjac the overall classification accuracy of 97.6% was observed with probability cut off value at 0.5 (table 3).

Table 3. Classification Accuracy for muntjac.

Observed	Muntjac Predicted Absent (0)	Muntjac Predicted Present (1)	Percentage Correct
Absent (0)	232	3	98.7
Present (1)	3	7	70
Overall Percentage			97.6

The results revealed that for muntjac 20.70 km^2 (7.02%) of forest area was most suitable, 22.12km^2 (7.5%) moderately suitable, 29.54 km^2 (10.02%) less suitable, whereas 222.4 km^2 (75.44%) was least suitable (table 4).

The modelling revealed that only 14.52 % of study area is suitable for muntjac and these are confined along with dense forests, however these habitats are highly fragmented.

Table 4. Area under different categories of suitability for Muntjac in Chandoli tiger reserve, India.

Name of species	Highly suitable habitat (km^2)	Suitable habitat (km^2)	Moderately suitable (km^2)
Muntjac	20.70	22.12	29.53

It is a well known fact that the presence or absence of a species in a particular habitat can result from the size and structure of the fragments and also from the characteristics of the surrounding landscape [4].

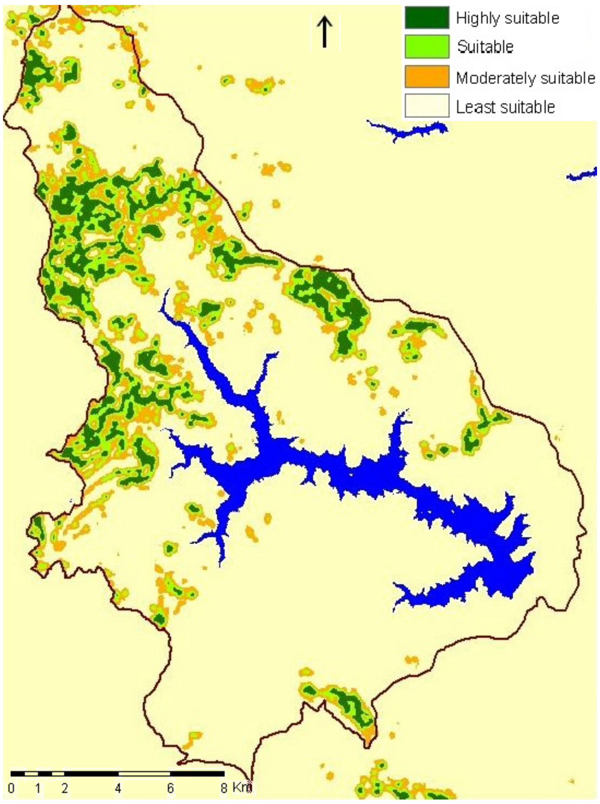

Fig. 3. Habitat suitability map of Muntjac.

Therefore, population of muntjac in this reserve is very low [58]. The major portion of suitable habitats are lying in northern part of protected area, whereas in southern part only 3-4 small and fragmented patches of suitable habitats are present. It was observed during field visits that northern part of reserve was well protected and having corridor connectivity with other neighbouring forest areas and probably this may be one of the causes that these areas are suitable for muntjac.

Southern part of reserve is exposed to more anthropogenic activities and has more cattle grazing pressure than northern portion of the reserve. Before declaration of this forest as protected area, major portions of forests lying along river was owned by villagers as their private forests and while evacuating, villagers felled almost all privately owned forests and destroyed the natural habitats of wild animals. Probably this may be other reasons that southern part of reserve does not provide suitable habitat for muntjac. Karanth et al. [59] suggested that no doubt presence of forest cover negatively influence species extinction, but this factor alone is not sufficient to ensure persistence of many species.

Human population density positively influenced local extinction of animal species. At the time of establishment, there were 32 villages inside the protected area with a human population of 7,900, whereas, approximately 78 villages with a human population of 10,150 were present in the periphery (within 10km radius of PA) [60].

Karanth et al [61] provided evidence that protected natural reserve areas are critical for reducing the local extinction probabilities of most Indian large mammals and India‘s current fragmented network of relatively small protected areas (average size less than 300 km^2) does have high carrying capacities for large mammals. Probably these are the reasons that in spite of all pressure, local average extinction probability estimated for muntjac across a 100-year time-frame is 0.39 [61].

The study suggested that status of this forests area improved after declaring it as reserve, and privately owned forest which were destroyed almost completely, are rejuvenated and coming up as primary forests and evacuated village areas are sprouting in to grass lands [62]. Although very few wild animals were seen during the field visits, indirect evidences of their presence indicated that wild animals are thriving here after getting conservational attention. These developments are in line with recommendation of Karanth et al [61], that is creation of new protected areas and interconnection of existing protected areas will be required through conservation policy and management if many of mammalian species are to persist into the future.

Therefore, evaluation of new potential area for a particular wild species may be considered as one of the most important steps towards the conservation. Extensive field work, sound database, statistical treatment of data and modelling technique would be helpful in predicting the potentiality of a habitat for wild animals.

The study highlighted the role of Remote Sensing, GIS, GPS and geospatial technique in evaluation of wild animal‘s habitats with acceptable accuracy.

But it could be a better situation when this technology was also used for villagers resettlement programme. During field visits it was recorded that villagers resettled outside the protected area were not happy with the government and forest department’s approach. The village shifting programme was in haphazard manner and majority of households in the resettlement villages do not own any land that has had substantial effects on local peoples’ livelihoods and shelter. The lands allotted to villagers were not suitable for agriculture and even they were not happy with their village location. It could be better if forest department and government agency had used Remote Sensing and GIS technology in identification of suitable area for agriculture and resettlement for evacuated villages. This technology is widely used for this purpose, so that Civco et al. (63) used it for the quantification of urban landscape in north-east United States, whereas, Haack and Rafter (64) used Remote Sensing and GIS in analysing and modelling of urban growth pattern in Kathmandu valley and Xiao-fei et al (65) used it in identification of suitable land for rural settlement in hilly region of south-west China. Similarly Jat et al. (66) used this technology to model urban growth pattern in Ajmer (India). Furthermore, Evgeny and Vladimir (67) used geospatial technology to evaluate the state of urban resettlement in Orel region of Russian Federation using geospatial technique.

If Remote Sensing and GIS could have been used at the time of protected area establishment and village evacuation programme, then possibly complete felling of Malkiland forest could have been saved from villagers’ wrath. Therefore, it is opined that Remote Sensing and GIS is not only helpful in protected area establishment but also in rehabilitation of evacuated villages.

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