India's national animal 'Tiger' despite being accorded the highest protection under Schedule I of the Wildlife (Protection) Act of India, 1972, has been forced to lose ground in recent decades (John Singh et al., 2010; Jhala et al., 2011). In Terai Arc Landscape, conservationists are working to restore, reconnect, and manage wildlife corridors to link 12 important wildlife reserves and national parks that harbour wild tigers across the 49,000 km² area (Wikramanayake et al., 2004; Dinerstein et al., 2007). The goal is to manage tigers as a meta-population in which dispersal between core refuges can help to maintain genetic, demographic, and ecological integrity. The Corbett National Park has the highest density of tigers (17.8 ±1.4/100 km²) in the world and serves as a source from where tigers are likely to disperse both westward as well as eastward to maintain the populations in the Rajaji National Park and Pilibhit Forest Division. However, the population outside the Tiger Reserve (TR) is also of great significance with the Ramnagar FD having a density of approximately 15 tigers per 100 km² with evidence of breeding individuals (Jhala et al., 2011). The tiger population of Corbett and Ramnagar currently forms a single unit with important connectivity provided by the Kosi River which flows between Corbett Tiger Reserve (CTR) and Ramnagar Forest Division (RMR FD) and certain stretches of forests along the river. Tiger crosses the river for prey and maintains their territory. Habitat is a sum total of the environmental condition of a specific place occupied by wildlife species or a population of such species. All species have specific habitat requirements, which can be described by habitat factors. These factors were connected to the critical characteristics of the habitat, such as vegetation, soil and the spatial structure of landscape elements. Urbanization, industrialization, infrastructure development projects, agriculture, grazing, deforestation, wildlife trade, and poaching continue to create tremendous stress on pristine natural habitat and wildlife. Remote sensing and Geographic Information System (RS and GIS) can be used as a 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 the integration of various habitat variables of both spatial and non-spatial nature (Davis and Goetz, 1990). 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 (Kushwaha et al., 2004 and Zarri et al., 2008). As a result, the information acquired from RS data when supported by field evidence of the presence of animal and biotic disturbances has been used for wildlife habitat suitability analysis (Roy, 1993; Roy and Ravan, 1994). Consequently, a habitat suitability model is developed primarily based on the distribution of animals compared to the availability of habitat parameters (Buk, 2004). The present study was carried out using the RS and GIS to predict and model the habitat suitability of tiger (Panthera tigris tigris) and its prey sambar (Rusa unicolor), chital (Axis axis) and wildboar (Sus scrofa) species in the Kosi - Corbett river Corridor for better conservation.
MATERIALS AND METHODS

Study area: The Kosi corridor includes part of Almora Forest Division, Sarpduli Range of Corbett Tiger Reserve (CTR) and Kosi Range of the Ramnagar FD. Broadly, this corridor connects CTR with the forests of Ramnagar FD and administratively comes under Nainital and Almora districts of Uttarakhand (Table 1, Plate 1).

Satellite data: The digital image of Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) were used. The imaging consisted of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9. New band 1 (ultra-blue) is useful for coastal and aerosol studies. New band 9 is useful for cirrus cloud detection. The resolution for Band 8 (panchromatic) is 15 meters. Thermal bands 10 and 11 are useful in providing more accurate surface temperatures and are collected at 100 meters. Approximate scene size is 170 km north-south by 183 km east-west.

SRTM (DEM): The Shuttle Radar Topographic Mission (SRTM) Digital Terrain Model (DTM) with 30 m resolution, downloaded from the www.srtm.usgs.govt. website, was used to generate the slope, aspect and elevation data layers.

Software and equipment: ERDAS Imagine 14 and ArcGIS 10.3 were used for the processing of satellite data and GIS work. Equipment like binoculars (8 x 40), camera (Canon 700 D with lens 55-300 mm), and Global Positioning System (GARMIN e_trex vista) were used for the field data collection. GPS was used for recording locations of tiger and its prey species (sambar, chital and wild boar). Maxent modelling was used to generate the habitat suitability maps and calculate the predictable habitat of the tiger encountered taking into account the closeness to water availability, habitat type, slope, aspect and prey species, etc.

Study Area Extraction: The boundary of the study area was delineated taking Kosi river as a center and make an area of interest (AOI) for image analysis.

Field Work and Ground Data Collection: An extensive field survey was undertaken and the ground point collection such as direct sighting, pugmark, claw mark on bark of tree, kill of prey and scat were undertaken to obtaining information about the accessibility of the area, the patterns, and distribution of vegetation type, recording of location of tiger presence and its prey sambar, chital, wildboar sighting.

Image Interpretation: The image feathers on the satellite data were interpreted for vegetation type using various image elements viz. tone, texture, patterns, shape, size, shadow, location and association. Various forest type categories were classified, correlated and interpreted using on-screen visual interpretation. Maps were prepared using Universal Transverse Mercator (UTM) projection and WGS-84.

Image Verification: After interpretation of satellite image, image verification was carried out through personal knowledge of the field. The vegetation type of the study area was marked on the satellite image during ground truth collection and geo-coordinates were taken by using GPS.

Database Creation: Habitat suitability analysis requires the generation of the accurate database on various life support system as well as potential distribution factors in the habitat. Five maps were required for habitat analysis using GIS. Digital database of the study area, vegetation type, slope, elevation, and aspect were prepared in a GIS environment. All the input map layers were co-registered with sub-pixel accuracy. A specific GIS model will be followed for the assessment of habitat suitability of tiger in the study area (Fig. 1).

Analysis: The field database was geostatistically analyzed to understand the habitat used by the animal and its prey species. This was carried out using the Maximum Entropy Model (MaxEnt).

Maximum Entropy Method (MaxEnt): MaxEnt is a recently introduced modelling technique, achieving high predictive accuracy and enjoying several additional attractive properties. The performance of MaxEnt is influenced by a moderate number of parameter. The data available for this problem typically consists of a list of geo-referenced occurrence localities, i.e., a set of geographic coordinates where the species has been observed. In addition, there are data on a number of environmental variables, such as elevation, slope, aspect, etc. They have been measured or estimated across a geographic region of interest. The maximum-entropy principle is explained...
here, the unknown probability distribution, which we denote $\pi$, is over a finite set $X$ (which we will later interpret as the set of pixels in the study area). We refer to the individual elements of $X$ as points. The distribution $\pi$ assigns a non-negative probability $\pi(x)$ to each point $x$, and these probabilities sum to 1. Our approximation of $\pi$ is also a probability distribution, and we denote it $\hat{\pi}$. The entropy of $\pi$ is defined as $-\sum_{x} \pi(x) \ln \pi(x)$.

The predictors that affected the tiger occurrence in the model are the presence of prey species especially sambar (48.7%) and sal mix forest. The occurrence of the tiger was more with low aspect, elevation, and slope. According to jackknife training gain, the contribution of aspect and elevation were not preferred by a tiger while other variables like forest type and riverine area were favorite. The study area was divided into 9 different habitats (Table 2) and the forest type map was developed (Plate 3B). The SRTM was used to generate the map of aspect (Plate 3A), elevation (Plate 3C), and slope (Plate 3D). Various environmental variables and animal presence points were used as points into the MaxEnt model to generate the habitat suitability maps for tiger and its prey species. Receiver Operating Characteristic (ROC) curve for wild species in this corridor was prepared. The occurrence of the tiger was more with low aspect, elevation, and slope. The AUC for training data for the study were 0.809 for chital, 0.0818 for wild boar, 0.746 for sambar and 0.800 for tiger (Fig. 2).

As per the response curves, the chital, wild boar and sambar preferred elevation areas in lower slopes but prey species did not prefer high dense forest (low NDVI) thus the habitat suitability map produced in the present study is very similar to the map produced by Ghosh (2013) for habitat suitability of tigers in Indo-Bhutan Manas Tiger Conservation Landscape (IBMTCL).

The performance of MaxEnt is influenced by a moderate number of parameters (Phillips, 2006).

**RESULT AND DISCUSSION**

First, the false color composite map of the study area was prepared (Plate 2). It was also used to identify environmental variable associated with the tiger occurrence in the study area using MaxEnt. The Area under the Receiving Operator Curve (AUC) for training data for the study was analyzed for tiger. The predictors that affected the tiger occurrence in the model are the presence of prey species especially sambar (48.7%) and sal mix forest. The occurrence of the tiger was more with low aspect, elevation, and slope. According to jack knife training gain, the contribution of aspect and elevation were not preferred by a tiger while other variables like forest type and riverine area were favorite. The study area was divided into 9 different habitats (Table 2) and the forest type map was developed (Plate 3B). The SRTM was used to generate the map of aspect (Plate 3A), elevation (Plate 3C) and slope (Plate 3D). Various environmental variables and animal presence points were used as points into the MaxEnt model to generate the habitat suitability maps for tiger and its prey species. Receiver Operating Characteristic (ROC) curve for wild species in this corridor was prepared. The occurrence of the tiger was more with low aspect, elevation, and slope. The AUC for training data for the study were 0.809 for chital, 0.0818 for wild boar, 0.746 for sambar and 0.800 for tiger (Fig. 2).

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Table 1: Details of Kosi - Corbett Corridor of Uttrakhand

<table>
<thead>
<tr>
<th>Name of Linkage</th>
<th>Connectivity between forest division</th>
<th>Forest type</th>
<th>Village / khatia fall in the corridor</th>
<th>Anthropogenic pressure</th>
<th>Frequency of use by key wildlife species</th>
<th>Major threat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mohan - Kumeria</td>
<td>Corbett - Ramnagar Forest Division</td>
<td>Tropcal dry deciduous</td>
<td>Kumeria and Khunkhet</td>
<td>RAMNAGAR - RANIKHET Road NH 121</td>
<td>Elephant herd 2-10 Tiger 2-3 Many Ungulate herd</td>
<td>IMPCL factory Mohan Grazing pressure by cattle</td>
</tr>
<tr>
<td>Sunderkhal - Mohan</td>
<td>Corbett - Ramnagar Forest Division</td>
<td>Sal forest and tea plantation</td>
<td>Chuklam, Mohan, Amarpur, Deviachaur &amp; Sunderkhal</td>
<td>RAMNAGAR - RANIKHET Road, Garhiya temple</td>
<td>Elephant herd 2-10 Tiger 2-3 Many prey species</td>
<td>Encroachment, Lopping, Grazing pressure by cattle, Fuel wood collection</td>
</tr>
<tr>
<td>Bijrani- Dhikuli</td>
<td>Corbett - Ramnagar Forest Division</td>
<td>Tea plantation</td>
<td>Aamanda, Ringora</td>
<td>Forest depot, Mazar at Ringora and Heavy Traffic on NH 121</td>
<td>Elephant herd 2-10 Tiger 2-3 Many Ungulate herd</td>
<td>pressure by cattle Uncontrolled development in the corridor area &amp; Increasing number of resorts in the vicinity</td>
</tr>
</tbody>
</table>

Table 2: Forest type of study area

<table>
<thead>
<tr>
<th>S No</th>
<th>Forest Type</th>
<th>Area (in sq km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sal forest</td>
<td>74.00</td>
</tr>
<tr>
<td>2</td>
<td>Sal mix forest</td>
<td>125.06</td>
</tr>
<tr>
<td>3</td>
<td>Teak forest</td>
<td>11.34</td>
</tr>
<tr>
<td>4</td>
<td>Riverine grasses</td>
<td>04.64</td>
</tr>
<tr>
<td>5</td>
<td>Agriculture</td>
<td>2.168</td>
</tr>
<tr>
<td>6</td>
<td>River bed</td>
<td>12.87</td>
</tr>
<tr>
<td>7</td>
<td>River</td>
<td>2.05</td>
</tr>
<tr>
<td>8</td>
<td>Settlement</td>
<td>2.07</td>
</tr>
<tr>
<td>9</td>
<td>Scrub land</td>
<td>5.71</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>239.94</td>
</tr>
</tbody>
</table>

Table 3: Estimates of relative contributions of the environmental variables for Habitat Suitability of tiger

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percentage contribution</th>
<th>Permutation importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sambar avg</td>
<td>48.7</td>
<td>4.2</td>
</tr>
<tr>
<td>Aspect</td>
<td>23.4</td>
<td>19.5</td>
</tr>
<tr>
<td>Forest Type</td>
<td>19.3</td>
<td>19.1</td>
</tr>
<tr>
<td>Elevation</td>
<td>4.3</td>
<td>44.5</td>
</tr>
<tr>
<td>Forest Density</td>
<td>2</td>
<td>3.4</td>
</tr>
<tr>
<td>Chital_avg</td>
<td>1.7</td>
<td>7</td>
</tr>
<tr>
<td>Slope</td>
<td>0.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Wild boar avg</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 1: GIS model approach for habitat suitability of tiger

digital techniques by several other earlier workers (Roy et al., 1986), Kushwaha and Madhavan Unni, (1986), Parihar et al., 1986), Singh, (1986). Every species were the product of their habitats (Riclefs, 1973). But During this study, we found that some dominant component of the habitat of physical variables can be used to quantify the habitat.

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REFERENCES


Figure 2: The AUC for training data of different wild animals
Figure 3: Response curves for Tiger in the Corbett - Kosi river corridor
Plate 3 B: ASPECT

Plate 3 C: ELEVATION

Plate 3 D: SLOPE

Plate 4: Habitat Suitability Map for Tiger in the Corbett Kosi river corridor


