Kamala tree as an indicator of the presence of Asian elephants during the dry season in the Shivalik landscape of northwestern India

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A B S T R A C T

The availability of forage resources during the dry season is often a critical factor in determining the distribution and movement of large herbivores. It has long been suspected that the Kamala tree (Mallotus philippinensis) can serve as an indicator of the distribution for Asian elephants during the dry season in northwestern India. However, there is little direct evidence in support of this speculation, especially at a large landscape scale. Here, we predicted the distribution of Kamala trees in the Shivalik landscape of northwestern India based on topographic and bioclimatic variables, as well as satellite-derived vegetation indices and forest canopy height data using a presence-only ecological niche model. We used the area under the receiver operating characteristic curve (AUC) and true skill statistic (TSS) to validate the model.

We then examined the relationship between the occurrence probability of Kamala trees and the presence of Asian elephants with data collected during dry seasons between 2010 and 2014 using logistic regression models. Our results showed that the probability of occurrence of Kamala trees was predicted with good accuracy (AUC = 0.88 and TSS = 0.51). The logistic regression models showed that the presence of Asian elephants can be adequately predicted by the occurrence probability of Kamala trees. This result suggests that the distribution of Kamala trees is a good indicator of the presence of Asian elephants during the dry season in the Shivalik landscape. These findings may have major implications for the conservation of Asian elephants, especially in designing wildlife corridors and mitigating human-elephant conflicts.

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1. Introduction

Prior to the industrial revolution, Asian elephants ranged in areas stretching from Iraq to southern China (Sukumar, 1993; Gangwar et al., 2014). Asian elephants have disappeared from ~95% of their historical range, and are currently restricted to parts of Southeast Asia and the Indian Peninsula. A recent estimate for the global population size of the Asian elephants is between 38,500 and 52,500 individuals according to Sukumar (2003) and updated by the IUCN/SSC Asian Elephant Specialist Group in 2004 (Sukumar, 2006). India has the largest surviving population of these elephants, ~50% of the global population of the species (Sukumar, 2006). The Shivalik landscape in northwestern India supports approximately 1246 elephants in its limited area. However, this population has been declining over the past decade, more than 134 elephants succumbed in the wild from 1987 to 2004 (Joshi et al., 2009b). Fragmentation of their habitats, increasing demand for forest products, permanent conversion of forest to agricultural land, rapid urbanization and infrastructure development, and illegal hunting are considered the main drivers of the loss of these elephants and their habitats. These drivers continue to pose a critical threat to the remaining population (Joshi and Singh, 2007; Joshi et al., 2009b; Joshi, 2013; Alamgir et al., 2015; Madhusudan et al., 2015).

Asian elephants are mega herbivores and they can consume up to 150 kg of plant matter per day (Vancuylenberg, 1977). Their forage requirements are particularly high during the dry season when...
they migrate due to high energy demands (Joshi and Singh, 2008b). Therefore, the availability of food resources is a major determinant of the habitat carrying capacity and affects the distribution of Asian elephants in a given area. These elephants are generalist feeders and are less discriminating than other herbivores in the selection of food plants. Asian elephants may feed on over a hundred plant species in an area. However, plants from just a few botanical families may account for most of their total intake, of which tree species in the majority, accounting for 56%–74% of the totally forage species (Pradhan et al., 2007; Joshi and Singh, 2008a; Mohapatra et al., 2013). This is evident during the dry season, when green herbaceous fodder with relatively high palatability and nutrient concentration dries up (Sukumar, 1990). In northern India and the lowland of Nepal, evergreen Kamala tree (Mallotus philippinensis) constitutes an important diet of Asian elephants during the dry season (Pradhan and Wegge, 2007; Pradhan et al., 2007, 2008; Joshi and Singh, 2008a; Joshi et al., 2009a). These trees represent 42% of elephant food according to systematic sampling along fresh elephant tracks (Pradhan and Wegge, 2007; Pradhan et al., 2008). Therefore, the distribution of Kamala trees is hypothesized to be a good indicator of the presence of Asian elephants during the dry season.

The species distribution models (SDM) have been increasingly used to predict the potential species distribution by relating species occurrence data to environmental variables based on statistically and theoretically derived response surfaces. A variety of SDMs are available such as Maximum Entropy Model (MaxEnt). MaxEnt is a general-purpose machine learning method that calculates the occurrence probability of a species based on species presence-only data and environmental data (Phillips et al., 2006). It has been proven to work well in practice (Yang et al., 2013; Jiang et al., 2014; Matyukhina et al., 2015) because of its numerous advantages. For example, MaxEnt model is least affected by location errors of occurrence (Graham et al., 2008), it has good performance across all sample sizes (Wisz et al., 2008) and provides a continuous result that permits multiple classification (Phillips et al., 2006). Perhaps, most importantly, MaxEnt has become the default tool for modeling presence-only data on species distributions.

The objectives of this study were: 1) to predict the distribution of Kamala trees in the Shivalik landscape of northwestern India based on topographic and bioclimatic variables, as well as satellite-derived vegetation indices and forest canopy height data using presence-only ecological niche model MaxEnt; and 2) to examine the relationship between the occurrence probability of Kamala trees and the presence of Asian elephants during the dry season at a large landscape scale using a logistic regression model. We hypothesized that the distribution of Asian elephants is highly correlated with the occurrence probability of Kamala trees, which if so, could potentially be used as an indicator of the presence of Asian elephants during the dry season at broad spatial scales.

2. Materials and methods

2.1. Study area

The study area covers the Shivalik landscape of the Uttarakhand state and adjoining areas (Fig. 1). The landscape offers a natural habitat and western limit of Asian elephants (Joshi and Singh, 2008b). The area is situated between the lesser Himalaya and upper Gangetic plains (Joshi and Singh, 2007), making it a transient zone that has an important role in India biodiversity. It is characterized by typically low rolling hills, bisected by numerous rivers flowing from the Himalayas in the north to Gangetic plains in the south (Sivakumar et al., 2010). The climate of this area is typically subtropical, affected by the summer monsoon, which results in three distinct seasons. There is a cool dry season from November to March, a hot dry season from April to June, and a monsoon season from July to October (Williams et al., 2008).

2.2. Kamala tree presence data

The Kamala tree has a widespread natural distribution, from the western Himalayas, through India, Sri Lanka and southern China, and throughout Malaysia to Australia. It is sometimes gregarious but is more commonly mixed with other species both in forests.
Table 1
Environmental variables used for modeling the distribution of Kamala trees. The variables indicated with asterisk (*) have been used for the final model after a multi-collinearity test.

<table>
<thead>
<tr>
<th>Category</th>
<th>Variables</th>
<th>Abbreviation</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioclimatic</td>
<td>Annual mean temperature</td>
<td>Bio1</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Mean diurnal range</td>
<td>Bio2</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Isothermality *</td>
<td>Bio3</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td>Temperature seasonality</td>
<td>Bio4</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Max temperature of warmest month</td>
<td>Bio5</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Min temperature of coldest month</td>
<td>Bio6</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Temperature annual range</td>
<td>Bio7</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Mean temperature of wettest quarter</td>
<td>Bio8</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Mean temperature of driest quarter *</td>
<td>Bio9</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Mean temperature of warmest quarter</td>
<td>Bio10</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Mean temperature of coldest quarter</td>
<td>Bio11</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Annual precipitation</td>
<td>Bio12</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Precipitation of wettest month</td>
<td>Bio13</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Precipitation of driest month *</td>
<td>Bio14</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Precipitation seasonality *</td>
<td>Bio15</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td>Precipitation of wettest quarter</td>
<td>Bio16</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Precipitation of driest quarter</td>
<td>Bio17</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Precipitation of warmest quarter</td>
<td>Bio18</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Precipitation of coldest quarter *</td>
<td>Bio19</td>
<td>mm</td>
</tr>
<tr>
<td>Topographic</td>
<td>Altitude *</td>
<td>Altitude</td>
<td>m</td>
</tr>
<tr>
<td></td>
<td>Slope *</td>
<td>Slope</td>
<td>Degree</td>
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<tr>
<td></td>
<td>Aspect *</td>
<td>Aspect</td>
<td>Degree</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Forest canopy height *</td>
<td>FCH</td>
<td>Dimensionless</td>
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<tr>
<td></td>
<td>Annual minimum NDVI *</td>
<td>NDVI_min</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td>Annual mean NDVI</td>
<td>NDVI_mean</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td>Annual maximum NDVI *</td>
<td>NDVI_max</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td>Amplitude NDVI *</td>
<td>NDVI_jmp</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td>Standard deviation NDVI *</td>
<td>NDVI_std</td>
<td>Dimensionless</td>
</tr>
</tbody>
</table>

and open scrubland. The species is common in evergreen and moist deciduous forest, especially secondary forest, and is sometimes dominant in the undergrowth (Gangwar et al., 2014).

Most presence data of Kamala trees were collected by the authors during field visits in February and March of 2014. Several sampling belts were randomly selected within the Shivalik landscape based on a north-south gradient. We actively searched for Kamala tree during passes through each belt, and recorded the locations of the target trees using a hand-held GPS receiver. The remaining presence data of Kamala trees were extracted from the database collected as part of various projects carried out by the Indian Institute of Remote Sensing during 2005–2013. In total, 200 records were obtained. To reduce the spatial auto-correlation effect, points within 2 km from each other were excluded for further model validation. Finally, 95 Kamala tree presence points were used for species distribution modeling.

2.3. Asian elephant presence data

Most of the elephant presence data were obtained from the Uttarakhand Forest Department. The data was collected using a transect method (Transect of 10 km from N-S direction; 15 transects in Rajaji National Park; 10 transects in Corbett National Park) during the dry seasons from 2010 to 2012. In order to cover the entire study area (i.e., the areas outside the two major national parks), we conducted an additional elephant survey in the Timli Forest Range, Chilla Forest Range and Saharanpur District in February 2014. We used the road-strip counting method (Joshi et al., 2009a) to gather geographical coordinates for Asian elephant presence data.

Evidence of elephant presence considered as fresh Asian elephant dung, footprints, indications of foraging on plants, signs of bark stripping using their tusks or by rubbing, trampled vegetation and destroyed building structures. In total, 339 Asian elephant presence points were collected.

2.4. Environmental variables

2.4.1. Topography data

Topography is recognized as an important factor in controlling plant distribution and diversity patterns. The distribution of Kamala trees is also affected by topographical variables. For example, Kamala tree mostly grows at an altitude of 300–1600 m (Bhatt et al., 2011). In this study, a 90 m spatial resolution Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) (http://srtm.usgs.gov/) was used to calculate the slope and aspect using ArcGIS 10.0 (ESRI, Inc., Redlands, CA, USA).

2.4.2. Bioclimatic data

The Kamala tree mainly grows in regions with mean annual temperature of 16–28 °C and with mean annual rainfall of 800–2000 mm. This tree species withstands considerable shade, and it is frost-hardy and resistant to drought (Sharma and Varma, 2011). To model the distribution with its bioclimatic ranges, climatic data with 1 km resolution were obtained from the WorldClim database (www.worldclim.org/), including 19 bioclimatic variables directly related to species’ distribution.

2.4.3. Satellite-derived vegetation indices

Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) are frequently used to monitor seasonal fluctuation in the green cover to capture seasonal difference in phenology (Jiang et al., 2014; Lambert et al., 2015). The temporal behavior of NDVI has been proven valuable for mapping different forest type (Vancutsem et al., 2009). In this study, atmospherically corrected SPOT 4 and SPOT 5 Vegetation (VGT) sensor 10-day composite NDVI images at 1 km resolution over the 9 year period from 2005 to 2013 were obtained from www.vgt.vito.be (324 images, three images per month). The upper-envelope method was used to smooth the time series (Jonsson and Eklundh, 2004). Then, a time series of 9 yearly averaged images was generated and used to calculate the following meaningful NDVI indices: annual maximum NDVI, annual mean NDVI, annual minimum NDVI, NDVI
amplitude (difference between maximum and minimum NDVI) and NDVI standard deviation. In addition, a forest canopy height map with 1 km resolution was also downloaded from the NASA website (http://lidarradar.jpl.nasa.gov/).

All environmental variables (Table 1) were resampled to 1 km cell size because the Asian elephant requires a large habitat range to meet its daily requirement (Williams et al., 2008). Variables were projected as GIS raster layers with the GCS WGS 1984 system, and then converted into ASCII format for MaxEnt modeling. In addition, a multi-collinearity test was conducted using Pearson correlation coefficient to remove collinearity among the environmental variables. The variables with high correlations ($r \geq 0.8$) were left only one for further modeling (Hosseini et al., 2013; Yang et al., 2013; Ardestani et al., 2014).

2.5. Maximum entropy ecological niche model

We used MaxEnt version 3.3.3.k which is available for free download at www.cs.princeton.edu/~schapire/maxent/. While building the model, we randomly selected 70% of the dataset for model training and the remaining 30% for testing. A maximum 5000 background points was accepted according to our study extent. There were 30 runs of the model and defaults were retained for other values. The jackknife procedure was used to assess the importance of each variable (Phillips et al., 2006), and the area under the receiver operating characteristic curve (AUC) (Phillips and Dudík, 2008) and true skill statistic (TSS) (Allouche et al., 2006) were used to evaluate model fitness and performance. AUC has a range of 0–1, with 0 and 1 representing systematically wrong prediction and a perfect model, respectively. Value $>0.8$ represent a good model and 0.5 a random model (Phillips and Dudík, 2008). TSS ranges from $-1$ to $+1$, with $-1$ and $+1$ indicating systematically wrong and right predictions, respectively, and 0 a random model (Gallien et al., 2012).

Finally, a potential occurrence probability map of Kamala trees with value range from 0 to 1 was predicted.

2.6. Predicted distribution of Kamala trees in relation to protected areas

To calculate the distribution proportion of Kamala trees within and outside the protected areas, the occurrence probability of Kamala trees was grouped into three categories, low (0.6–0.7) and high (>0.7). Afterward, maps of predicted areas were used to mask the occurrence probability map of Kamala trees, from which the proportion of each class of Kamala trees within and outside protected areas were estimated.

2.7. Logistic regression model

The relationship between the presence of Asian elephants and the predicted occurrence of Kamala trees was evaluated using a logistic regression model, which was performed using “lrm” function of “rms” package under R environment (version 3.2.2). To develop the logistic regression model, 339 pseudo absence points – equal to the number of elephant presence points – were generated outside the elephant presence points. We combined the pseudo absence and presence points of Asian elephants as response variables. The pseudo absence points were generated at distances of 2 km, 3 km and 4 km outside the buffer zone. The three buffer zone distances were chosen based on the size of the home range of Asian elephants, which ranges from 13 km² to 63 km² in this region during the dry season (Joshi and Singh, 2009). A 70% subset of the data was used to develop the model and the remaining 30% was used for model evaluation. The introduction of the pseudo absence points and the selection of buffer zone distances may incur uncertainty and bias to the model development and thus model evaluation. To realize and minimize this bias and uncertainty, we applied a
repeated randomization process, in which we randomly generated 10 sets of pseudo absence points for each buffer zone distance and split each data set 10 times randomly for model fitting and evaluation (Fig. 2). Thus, with each buffer zone distance, 100 models were fitted and evaluated. The models were evaluated using Likelihood Ratio Test for overall model performance, Wald Test for predictor, Nagelkerke $R^2$ for goodness-of-fit, and Overall Accuracy, Sensitivity and Specificity for validations of predicted probabilities (Peng et al., 2002). The average values and their standard deviations of above mentioned evaluation statistics for each buffer zone distance were used as the final consensus results, amongst which the Wald Test was used as the direct indicator to determine whether Kamala tree occurrence is an effective indicator for the elephant distribution.

### 3. Results

#### 3.1. Distribution of Kamala trees in Shivalik landscape

Our model showed good performance in predicting the occurrence probability of Kamala trees at Shivalik landscape scale, based on the selected environmental variables (AUC = 0.88, TSS = 0.51). Altitude, precipitation of the coldest quarter (Bio19), mean temperature of the driest quarter (Bio9), and precipitation seasonality (Bio15) had the largest contributions toward explaining the occurrence of Kamala trees (Fig. 3). A high occurrence probability of Kamala trees was predicted for the northwestern part of the Shivalik landscape, followed by the central portion, especially areas between the landscape and upper Gangetic plain (Fig. 4). We estimated the distribution proportion of Kamala trees within and outside the protected areas, and found that ~69% of high occurrence areas were within the protected areas, of which a maximum of 91% was within Rajaji National Park. Thirty-one percent of high occurrence areas were outside protected areas. Moderate occurrence areas had nearly the same proportion within and outside the protected areas (Table 2).

#### 3.2. Relationship between Kamala tree and Asian elephant

The location of Asian elephant presence points based on field surveys and the predicted occurrence probability of Kamala trees is shown in Fig. 5. The presence of Asian elephants can be predicted by the occurrence probability of Kamala trees using Eq. (1). The average values of the intercepts and coefficients of $x$ for each buffer zone distance are shown in Table 3.

$$y = \frac{\exp(b_0 + b_1x)}{1 + \exp(b_0 + b_1x)}$$  

(1)

### Table 2

<table>
<thead>
<tr>
<th>Occurrence probability</th>
<th>Sum (km²)</th>
<th>RNP (km²)</th>
<th>CNP (km²)</th>
<th>Outside PAs (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (&lt;0.6)</td>
<td>3678</td>
<td>268 (7%)</td>
<td>668 (18%)</td>
<td>2742 (75%)</td>
</tr>
<tr>
<td>Moderate (0.6–0.7)</td>
<td>1060</td>
<td>364 (34%)</td>
<td>106 (15%)</td>
<td>536 (51%)</td>
</tr>
<tr>
<td>High (&gt;0.7)</td>
<td>304</td>
<td>193 (63%)</td>
<td>18 (6%)</td>
<td>93 (31%)</td>
</tr>
</tbody>
</table>

RNP: Rajaji National Park; CNP: Jim Corbett National Park.
Table 3
Coefficients of the logistic regression models.

<table>
<thead>
<tr>
<th>Buffer Zone</th>
<th>$b_0$</th>
<th>$b_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 km</td>
<td>-3.85 ± 0.31*</td>
<td>7.71 ± 0.64*</td>
</tr>
<tr>
<td>3 km</td>
<td>-3.99 ± 0.25</td>
<td>8.12 ± 0.50</td>
</tr>
<tr>
<td>4 km</td>
<td>-4.14 ± 0.24</td>
<td>8.47 ± 0.50</td>
</tr>
</tbody>
</table>

Note: $b_0$ intercept, $b_1$ coefficient of x.
* Significance level at 0.0001.

Where $y$ is the presence of Asian elephants, $x$ is the occurrence probability of Kamala trees, $b_0$ is the intercept of logistic regression models, $b_1$ is the coefficient of $x$.

All the logistic regression models predicted the presence of Asian elephants with similar and adequate overall model performance, goodness-of-fit, and validation outputs of predicted probabilities under the three buffer zone distances we used to generate the pseudo absence points (Fig. 6, Table 4). The

![Fig. 4. Predicted occurrence probability of Kamala trees in Shivalik landscape.](image)

![Fig. 5. Map showing the location of Asian elephant presence points based on field surveys and the predicted occurrence probability of Kamala trees in Shivalik landscape.](image)
The 2 km, 3 km and 4 km indicate the three buffer zone distances, which were used to generate the pseudo absence points of elephants.

*Significance level at 0.0001.

4. Discussion

Many studies have documented that the Kamala tree is preferred fodder for Asian elephants during the dry season, based on localized surveys of the foraging behavior of elephants in northern India and the lowlands of Nepal (Pradhan and Wegge, 2007; Pradhan et al., 2007, 2008; Joshi and Singh, 2008a; Williams et al., 2008; Joshi et al., 2009a). In the present study, we demonstrated that the Kamala tree distribution is a good indicator of predicting the presence of Asian elephant during the dry season at broad spatial scale. These findings may be important implication for the conservation of Asian elephants, especially in designing wildlife corridors and mitigating human–elephant conflicts.

The reason why Asian elephants prefer feeding on Kamala tree during the dry season can be attributed to several factors. The first may be associated with the elephants’ feeding habits. Asian elephants usually feed in dry forest (e.g., open canopy or disturbed and early-successional forests, and forest edges) because of greater accessibility of forage resources (Sukumar, 1993; Fernando and Leimgruber, 2011). The Kamala tree is an important component of dry forests in Shivalik landscape (Joshi and Singh, 2007; Bhatt et al., 2011), making it more accessible as feed for Asian elephants. The second factor is bark feeding, which can account for 73% of total feed intake for Asian elephant during dry seasons (Pradhan et al., 2008). The bark of Kamala trees contains substantial nutrients (e.g., dry matter and crude fiber) and minerals (e.g., calcium, phosphorus and sodium) that are necessary for skeleton and tusk development of the elephants (Joshi and Singh, 2008b). Therefore, it provides more nutrition for the elephants, especially during the dry season when grass has poor nutritive value (Field, 1971; Sukumar, 1990). The third factor is that, Kamala tree is a 2–18 m tall species, so it not only provides fodder for Asian elephants but also a cool shaded area during hot summer afternoons (Joshi et al., 2009b). Fourth, because the Kamala tree has high tolerance to human disturbance (Pathak and Shukla, 2004), in the strongly disturbed Shivalik landscape, it has become one of the most available foders for Asian elephants in recent years. This is because the elephant’ preferred forage species have continually decreased as a result of intense human activity in forest areas. For example, solid bamboo (Dendrocalamus strictus) and the Kamala tree are the most preferred forage species of Asian
elephants, but, the potential regeneration of solid bamboo has been decreasing continuously since 2002 (Joshi and Singh, 2008b).

We found high occurrence probability of Kamala trees mostly in the southern portion of the Shivalik landscape, and especially between that Shivalik landscape and the upper Gangetic plain, which suggesting that the Kamala tree is a heliophilous plant. This is consistent with previous research documented that the Kamala tree is a drought resistant (Sharma and Varma, 2011) and pioneer species. It usually occurs in mixed, riverine, thicket, secondary and dry deciduous forests at low elevation range (Joshi and Singh, 2007; Bhatt et al., 2011). Thus, it is a promising reforestation plant species and may survive well under the background of continuous climate change. We estimated the distribution proportion of Kamala trees within and outside protected areas, and discovered that ~69% of high occurrence areas of Kamala trees were within the protected areas, of which as much as 91% were in Rajaji National Park (Table 2). This is a key conservation indicator that can effectively protect Kamala tree inside the park, and support regional Asian elephant population. This is validated by the fact that the national park supports ~71% of the elephant population in Shivalik landscape according to elephant presence data analysis. Regions outside protected areas were also predicted to have substantial occurrence of Kamala trees (Table 2), suggesting that such regions constitute important potential forage areas for Asian elephants during the dry season. Consequently, with the purpose of effectively protect Asian elephants in the Shivalik landscape, it is urgent to monitor the elephant population and assess its habitat use outside protected areas. This would furnish fundamental information for elephant conservation planning. However, most completed and ongoing elephant surveys usually give priority to protected areas, neglecting areas outside them (Joshi and Singh, 2007; Pradhan and Wegge, 2007; Pradhan et al., 2007; Joshi and Singh, 2008b; Williams et al., 2008; Madhusudan et al., 2015). For instance, according to Asian elephant presence data obtained from Uttarakhand Forest Department in the Shivalik landscape, only 15% presence data of Asian elephants come from outside protected areas, 85% are from those protected areas. Therefore, we recommend that areas outside protected zones should be considered in subsequent state-wide wildlife census, even if, it is not possible to carry out elephant census across the entire Shivalik landscape. It is essential to consider areas with high occurrence probability of Kamala trees.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2016.07.011.

References


