

Ecological preferences of large carnivores in remote, high-altitude protected areas: insights from Buxa Tiger Reserve, India

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SUPPLEMENTARY MATERIAL 1 Detailed methodology for spatial data analysis

Land Use Land Cover (LULC) classification

We used a LANDSAT 8 satellite image (image ID: LC81380422013349LGN00) for Land Use Land Cover classification of Buxa Tiger Reserve (Fig. 1). A false colour composite map was initially classified by an unsupervised classification technique, and the classified output was then compared with high-resolution images from Google Earth (Google Inc., Mountain View, USA). Settlements, water bodies, rail lines, major roads and rivers were digitized separately from Google Earth images, incorporated in Land Use Land Cover classification with the AOI tool in *ERDAS Imagine v.9.3* (Leica Geosystems, Milton Keynes, UK) and subsequently recoded. Buxa was classified into seven major land cover classes, all easily identifiable in Google Earth images: Agriculture&human settlement, Dense forest, Road&railline, River, Hilly forest, Open forest and Riverbed/riverine forest. We generated 50 random global positioning system locations (reference points) of each land cover class from high-resolution Google Earth images, and our output image was assessed using these reference points. The Kappa Coefficient method was used to assess the accuracy of our final LULC map. The overall accuracy of the map was 89%.

Preparation of eco-geographical variables

Agriculture & human settlement

Agriculture & human settlement features were extracted from the LULC map and used to create a new binary layer (i.e. agriculture – human settlement and non-agriculture – human settlement area). We overlaid 90 x 90m grids on the Buxa Tiger Reserve boundary map and calculated the proportion of agriculture and human settlement area within each grid cell. The value of each grid cell is 0–1, where 0 represents a total absence of agriculture and human settlement area, and 1 indicates presence of agriculture and human settlement area throughout a grid cell. Here each grid cell was considered to be a resource unit.

Dense forest

We followed the above method to calculate the proportion of dense vegetation present in each resource unit.

Distance to roads and railines

The effect of linear infrastructure such as roads and railines on large carnivores is a more reliable variable than their mere presence. As the distance from linear infrastructures is a function of disturbance level, we created a Euclidean distance layer from road and railines present within Buxa Tiger Reserve, using the spatial analyst tool in *ArcGIS v. 9.3* (ESRI, Redlands, USA). Mean distance was recalculated for each resource unit, and ranged from 0 to 31,415m.

Distance from water

We followed the above method to calculate a Euclidean distance layer from water bodies (i.e. rivers, ponds) within the study area. Mean distance was recalculated for each resource unit, and ranged from 0 to 4,385m.

Elevation

Altitudinal gradient influences the occurrence of large carnivores. An Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) image of 30m resolution was used as a digital elevation model layer. Mean elevation was recalculated for each resource unit.

Hilly forest

The hilly forest layer was extracted from the LULC map to estimate the proportion of hilly forest area in each resource unit, using a method similar to the one described for creating the Agriculture & human settlement layer. The layer has a value of 0–1.

Open forest

The open forest layer was extracted from the LULC map to estimate the proportion of open forest area in each resource unit, using a method similar to the one described for creating the Agriculture & human settlement layer. The layer has a value of 0–1.

Rivers & water bodies

The river and pond area layer was extracted from the LULC map to estimate the proportion of water bodies in each resource unit, using a method similar to the one described for creating the Agriculture & human settlement layer. The layer has a value of 0–1.

Riverbed & riverine forest

The riverbed & riverine forest area layer was extracted from the LULC map to estimate the proportion of river bed and riverine forest area in each resource unit, using a method similar to the one described for creating the Agriculture & human settlement layer. The layer has a value of 0–1.

Slope

Slope (°) influences the occurrence of large carnivores. It was calculated from a digital elevation model using DEM Surface Tools (Jenness, 2010) in *ArcGIS v. 9.3*. The mean slope was recalculated for each resource unit.

Sunshine

The intensity of sunlight is a function of dryness and humidity in various aspects of hill regions. Sunshine intensity was calculated from a digital elevation model using DEM Surface Tools in *ArcGIS v. 9.3*. The mean value of sunshine intensity was recalculated for each resource unit.

Normalized difference vegetation index

We used the red (R) and near infrared (IR) bands of the LANDSAT 8 satellite image (Image ID: LC81380422013349LGN00) to estimate the normalized difference vegetation index using the following formula in *NDVI calculator 9.1*, a plug-in extension tool in *ArcGIS v. 9.3*:

$$\text{NDVI} = (\text{IR} - \text{R}) / (\text{IR} + \text{R})$$

This layer shows the greenness across Buxa Tiger Reserve, which is a function of canopy density, which influences carnivore occurrence. The mean value of NDVI was recalculated for each resource unit and ranges from -0.04 to 0.06.

All eco-geographical variable layers were projected in the Universal Transverse Mercator coordinate system. Grains of each raster map were considered as resource units (Manly et al., 2002).

Code used for statistical analysis in R

```
#####Pearson correlation coefficient#####  
library ("adehabitat")  
# keep all eco – geographical variables in ASCII format of a folder within a respective r directory  
setwd("C:/R_Directory/Buxa/ASCII-Final")  
# load all eco-geographicvariables in R platform  
Agri_and_Hu_Settle <- import.asc ("Agri_and_Hu_Settle.asc")  
Dense_forest<- import.asc ("Dense_forest.asc")  
Distance_to_road_rail<- import.asc ("Distance_to_road_rail.asc")  
Distance_to_water<- import.asc ("Distance_to_water.asc")  
Elevation<- import.asc ("Elevation.asc")  
Hilly_forest<- import.asc ("Hilly_forest.asc")  
Open_forest <- import.asc ("Open_forest.asc")  
River_and_Water<- import.asc ("River_and_Water.asc")  
River_bed_riverine_forest <- import.asc ("River_bed_riverine_forest.asc")  
Slope <- import.asc ("Slope.asc")  
Sunshine<- import.asc ("Sunshine.asc")  
NDVI <- import.asc ("NDVI.asc")  
#Layer stack  
kasc<-as.kasc(list(Agri_and_Hu_Settle=Agri&Hu, Dense_forest =DenseF, Distance_to_road_rail  
=DistR, Distance_to_water =DistW, Elevation =Elev, Hilly_forest =HillF, Open_forest =OpenF,  
River_and_Water=Riv, River_bed_riverine_forest =RivB, Slope =Slop, Sunshine =SunS, NDVI  
= NDVI))  
df<- kasc2df(kasc)  
names(df)  
head(df$tab)  
cor(df$tab)  
write.table (cor(df$tab), file="correlation")  
  
#####Principal Component analysis#####  
pca<-dudi.pca(kasc2df(kasc)$tab,center=T,scale=T)  
#To get the results of PCA eigenvalues  
pca$eig
```

```
#To get the see loading plots of PCA
```

```
x11()
```

```
s.arrow(pca$co)
```

```
x11()
```

```
s.arrow(pca$co,xax=3,yax=4)
```

```
#to see variation explained by each pc
```

```
sum(pca$eig)
```

```
#####Ecological Niche Factor Analysis (ENFA) #####
```

```
# See principle of Ecological Niche Factor Analysis (ENFA) in SUPPLEMENTARY MATERIAL 2
```

```
#Load location data of tiger in R platform
```

```
loc<-read.table("Buxa_tiger_location.txt",h=T)
```

```
dataenfa1 <- data2enfa(kasc,loc)
```

```
pc<- dudi.pca(dataenfa1$tab, scannf = FALSE)
```

```
enfa<- enfa(pc, dataenfa1$pr)
```

```
# Plot eigenvalue histogram
```

```
hist(enfa)
```

```
#Plot biplot of the ENFA result
```

```
scatter(enfa)
```

```
#####Habitat Suitability map using Mahalanobis distance statistics (D2) #####
```

```
#Add libraries
```

```
library("adehabitat")
```

```
library("adehabitatHS")
```

```
# load all eco-geographic variables layers in R platform  
Agri_and_Hu_Settle<- import.asc  
("Agri_and_Hu_Settle.asc")
```

```
Dense_forest <- import.asc ("Dense_forest.asc")
```

```
Distance_to_road_rail <- import.asc ("Distance_to_road_rail.asc")
```

```
Distance_to_water <- import.asc ("Distance_to_water.asc")
```

```
Elevation <- import.asc ("Elevation.asc")
```

```
Hilly_forest <- import.asc ("Hilly_forest.asc")
```

```
Open_forest <- import.asc ("Open_forest.asc")
```

```
River_and_Water <- import.asc ("River_and_Water.asc")
```

```

River_bed_riverine_forest <- import.asc ("River_bed_riverine_forest.asc")
Slope <- import.asc ("Slope.asc")
Sunshine <- import.asc ("Sunshine.asc")
NDVI <- import.asc ("NDVI.asc")
#Layer stack
kasc<- as.kasc(list(Agri_and_Hu_Settle = Agri&Hu, Dense_forest = DenseF,
Distance_to_road_rail = DistR, Distance_to_water = DistW, Elevation = Elev, Hilly_forest =
HillF, Open_forest = OpenF, River_and_Water= Riv, River_bed_riverine_forest = RivB, Slope
= Slop, Sunshine = SunS, NDVI = NDVI))
raster<- kasc2spixdf(kasc)
# Load locations of tiger scat samples
loc<-read.csv("Buxa_tiger_location.csv",h=TRUE)
X <- loc$X
Y <- loc$Y
xy<- cbind(X,Y)
head(xy)
xy.sp<-SpatialPoints(xy)
head(xy.sp)
# Mahalanobish Suitability modeling
hsm<- mahasuhab(raster, xy.sp, type = "probability")
x11()
# Plot suitability map in R platform
plot(hsm)
#Preparing suitability map in raster layer.
Suitability <-raster(hsm)
writeRaster(Suitability, "Suitability.asc")
# The suitability map can be exported to ArcGIS 9.3 platform

```

SUPPLEMENTARY MATERIAL 2 Ecological niche factor analysis in *adehabitat*

The niche concept (Hutchinson, 1957) considers the ecological niche of a species as a hyper volume in the multidimensional space defined by environmental variables, within which populations of a species can persist. Ecological niche factor analysis was developed by Hirzel et al. (2002) to analyse the position of a niche in the ecological space. Perrin (1984) described the position of a niche in n-dimensional space using two measures: M-specialization (hereafter marginality) and S-specialization (hereafter specialization). Marginality represents the squared distance of the niche barycentre from the mean available habitat. A large specialization corresponds to a narrow niche relative to the habitat conditions available for the species.

Ecological niche factor analysis first extracts an axis of marginality (vector from the average of available habitat conditions to the average used habitat conditions). Then the analysis extracts successive orthogonal axes (i.e. uncorrelated), which maximizes the specialization of the species. Calculations used in the function are described in Hirzel et al. (2002). The function `enfa` can be used on both quantitative and qualitative variables (although interpretation of results for qualitative variables is still under research), provided the table of values of habitat variables (columns) for each resource unit (rows) is correctly transformed (e.g. column-centred and standardized for tables containing only quantitative variables), and that appropriate column weights are given (e.g. sum of weights for levels of a factor should be the same as the weight of one quantitative variable). Therefore, the function `enfa` requires that a preliminary multivariate analysis is performed on the table (using analysis of the family of duality diagram; e.g. principal component analysis or Hill and Smith analysis). The object returned by this preliminary analysis contains appropriate weights and transformation of the original data frame; for example, the function `dudi.mix` can be used first on the data frame containing values of both quantitative (e.g. slope, elevation) and qualitative habitat variables (e.g. vegetation) for each pixel of a raster map. The result of this analysis can then be passed as an argument to the function `enfa`.

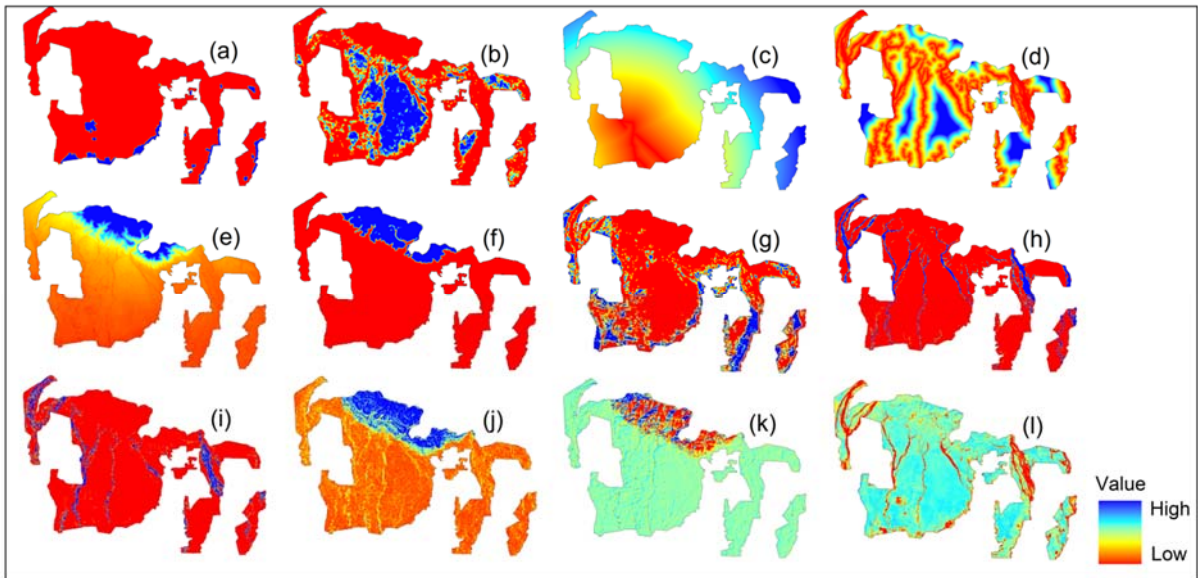


FIG.S1 Eco-geographical variables used for habitat analysis of the tiger *Panthera tigris* in Buxa Tiger Reserve: (a) agricultural land and human settlement, (b) dense forest, (c) Euclidian distance from roads and railines, (d) Euclidian distance from rivers and other water sources, (e) digital elevation model, (f) hilly forest area, (g) open forest area, (h) rivers and other water sources, (i) river bed and riverine forest area, (j) slope, (k) sunshine intensity, and (l) normalized difference vegetation index.

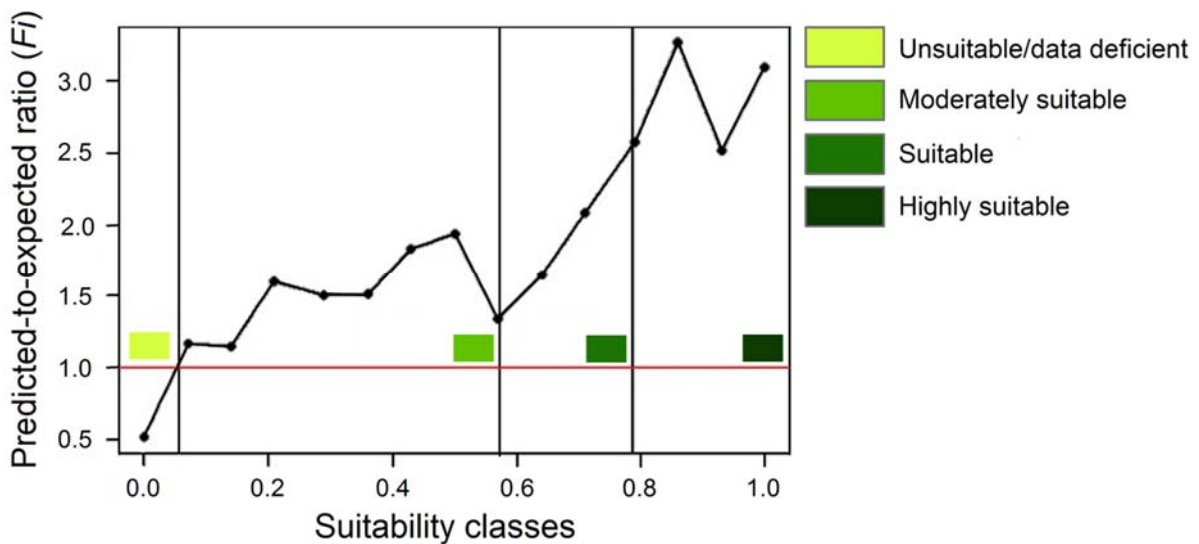


FIG. S2 Boyce index of habitat suitability for tigers in Buxa Tiger Reserve generated with Mahalanobis distance statistics.