USING ENVIRONMENTAL NICHE MODELING TO FIND SUITABLE HABITATS FOR THE HARD-GROUND BARASINGHA IN MADHYA PRADESH, INDIA

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Abstract: The subspecies of Swamp Deer, the Hard-ground Barasingha (Rucervus duvaucelli branderi Pocock), is presently found only in Kanha Tiger Reserve (KTR) in Madhya Pradesh, India. This subspecies is highly vulnerable to extinction, and reintroduction in suitable sites is the need of the hour. Environmental niche models (GARP, SVM, ED, CSM) aimed at providing a detailed prediction of species distribution by relating presence of species to 19 bioclimatic indices were developed, using swamp deer occurrence records in KTR. The predictions were appropriately weighted with the prevailing LU/LC classes to identify suitable habitats in Madhya Pradesh, India. The result shows that the southern region of Madhya Pradesh is suitable for the sustenance of Barasingha with varying degrees of habitability. Vicarious validation shows that most of these forest areas were the same as that of historical records dating back to 50 years. However, land use maps can help identify areas where this subspecies can be reintroduced.

Keywords: Bioclimatic index, environmental niche, Kanha Tiger Reserve, Swamp Deer.

Abbreviations: CSM - Climate Space Model; ED - Environmental Distance; GARP - Genetic Algorithm for Rule set Production; GIS - Geographic Information System; HIS - Habitat Suitability Index; HVA - Habitat Viability Analysis; IRS - Indian Remote Sensing Satellite; ISRO - Indian Space Research Organisation; IUCN - International Union of Conservation of Nature; KTR - Kanha Tiger Reserve; LISS-III - Linear Imaging and Self Scanning Sensors-III; LU/LC - Land use / Land cover; NRDB - Natural Resource Database; SFRI - State Forest Research Institute; STR - Satpura Tiger Reserve; SVM - Support Vector Machines

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INTRODUCTION

The Swamp Deer or Barasingha *Rucervus duvauceli*, which inhabits marshy areas, was once distributed widely in the Indian subcontinent but is now restricted to isolated localities in northern and central India, and southwestern Nepal. It is extinct in Pakistan and Bangladesh. The Swamp Deer is classified as Vulnerable (C1 ver 3.1) by the IUCN Red List (Duckworth et al. 2013). There are three subspecies of the Indian Swamp Deer (*Rucervus duvauceli duvauceli* Cuvier), the northern Indian subspecies, occurring mainly in Dudhwa National Park in Uttar Pradesh, the Hard-ground Barasingha (*Rucervus duvauceli branderi* Pocock) also known as the central Indian Barasingha (Image 1) is classified as a threatened species and is found only in Kanha Tiger Reserve (KTR) of Madhya Pradesh. The northeastern Indian subspecies (*Rucervus duvauceli ranjitsinho* Groves) occurs only in Kaziranga National Park.

In the last century the Hard-ground Barasingha was distributed along the foothills of the Himalaya from upper Assam (Kaziranga) to the Indus and part of the area between Ganga and Godavari rivers, as east as Mandla, Madhya Pradesh and as far east as the Sunderbans (Forsyth 1889). The species could be found in marshy areas all over the Brahmaputra–Ganges–Indus Basin. The southern most limit of the Barasingha was Bastar District in Chhattisgarh about 18°N. Essentially, the Barasingha inhabited moist deciduous, semi-evergreen and wet-evergreen forests and the swampland plains of northern and highlands of central India. It did not inhabit drier areas (Fig. 1). In Madhya Pradesh it was reported in good numbers in several places, including the Satpura Tiger Reserve (STR) in the Pachmarhi area (Forsyth 1889; Brander 1923). There is, however, no record suggesting its presence after the 1940s.

By the beginning of the 20th century, the Barasingha had completely disappeared from the western parts of its range, i.e., the plains of the Indus River. Yet, no precise information on its distribution until 1967. According to Schaller (1967) in 1964–65, the distribution range had reduced to a few places in Nepal, Uttar Pradesh, West Bengal, Assam and Madhya Pradesh. Schaller (1967) estimated that approximately 3000–4000 individuals of *Cervus* (now *Rucervus* *duvauceli duvauceli*) survived in 1965, plus 150 or more of *C.d. branderi* in central India. Its steady decline has been described by many workers, notably Sterndale (1884), Forsyth (1889), Inglis (1892), Low (1907), Brander (1923), Champion (1927), Finn (1929), Pocock (1939), Burton (1952), Burnett (1959) and Schaller (1967). Habitat loss and hunting were possibly the reasons why this species had disappeared. During 1970 only 66 individuals were left in KTR. Special conservation measures were undertaken by the park management to reverse the declining trend, and due to these efforts there are now around 475 animals in the park (Prakash et al. 2012).

The Hard-ground Barasingha requires open moist and marshy grasslands with or without groves of trees in KTR (Schaller 1967; Martin 1977; Panwar 1977; Kotwal & Parihar 1992; Gopal 1995; Nayak 2007). After relocation of the villages, the old abandoned village sites became grasslands. The current area of grasslands accounts for about 8.04% of the total area of the KTR (Negi & Shukla 2011). Martin (1977) and Gopal (1995), observed that tall grass areas and moist open grasslands reduce the competition pressure between the barasingha and cheetal. The competition is severe on dry open grasslands. Martin (1977) has described the occurrence of different biotope types and also different usages of short and tall grass cover by the Hard-ground Barasingha. Heavily pregnant hinds remain hidden in the tall grass therefore, tall grasses are essential for their breeding success (Schaller 1967; Gopal 1995). The female of the species is monoestrous and monotochus (Qureshi et al. 2004) with a gestation period of 240–250 days (Asdell 1964). This long gestation period and delivery of one fawn per year reduces the growth rate of this small population. The peak breeding period is reported to be from mid-December to mid-January. The male-female ratio in the KTR is 1:1.94, and female-fawn is 1:0.37 (Negi & Shukla 2011). The Hard-ground
Barasingha depends upon a few forage species, mostly grasses (Schaller 1967; Martin 1977; Panwar 1977; Gopal 1995; Nayak 2007; Schaaf 1978; Singh 1982; Gopal & Shukla 2001). Favoured grasses are *Saccharum spontaneum* – *Eragrostis uniloides* and *Heteropogon contortus* – *Saccharum spontaneum* communities (Schaller 1967). Artificially created water bodies in KTR also support plants favoured by barasingha (Nayak 2007). The marshes are at their optimum during the rains.

There is an urgent need to reintroduce this species to sites where it had occurred earlier. In this regard environmental niche modeling can help identify suitable sites. The environmental niche models are basically aimed at predicting the distribution by relating presence of species to environmental predictors. Such models have been used in the study of relationships between environmental parameters and species richness (Mac Nally & Fleishman 2004), characterization and spatial configuration of habitats (Scotts & Drielsma 2002), invasive potential of non-native species (Peterson 2003), species distribution in past (Peterson et al. 2004) or future climates (Skov & Svenning 2004) and ecological and geographic differentiation of closely-related species (Cicero 2004).

**MATERIALS AND METHODS**

**Study area**

The KTR is situated in Mandla and Balaghat districts of Madhya Pradesh (Fig. 2). It is part of the central Indian highlands characterized by undulating landscape, sandy clay loam to clay soil, dotted with dense groves of vegetation, hillocks and rolling meadows and consists of mixed deciduous forests of sal interspersed with grasslands (Champion & Seth 1968). This study was carried out in Madhya Pradesh using ground truth data from KTR to calibrate the models. Four different environmental envelop models were used and the results were combined to minimise uncertainty and bias in the predictions. The landuse / landcover (LU/LC) data was also incorporated in GIS based modeling to come out with the final possible areas where swamp deer can be placed in similar environmental and LU/LC preferences.
Model parameters

Bioclimatic indices as a surrogate terms derived from mean monthly climate estimates, to approximate energy and water balances at a given location were used. Mainly, four models were used for predicting the environmental niche of Swamp Deer using bioclimatic indices along with digital elevation model and presence records of the Swamp Deer found in KTR (Fig. 2): (1) Genetic Algorithm for Rule set Production (GARP) is a genetic algorithm that creates ecological niche models for a given species. The models describe environmental conditions under which the species should be able to maintain populations; (2) Support Vector Machines (SVM) which is a set of related supervised learning methods that belong to a family of generalized linear classifiers; (3) Environmental Distance (ED) which is also a genetic algorithm based on environmental dissimilarity metrics which uses distance metric like, Euclidean, Mahalanobis, Manhattan/Gower, and Chebyshev; (4) Climate Space Model (CSM) which is a principle component based algorithm. We used...
these models which are implemented in Open Modeler Desktop (Stockwell & Peters 1999). The methodology flowchart is given in Fig. 3. The results of all these four models were combined to get the optimum result. The most suitable locations were zeroed in on using weighted union method in GIS domain. The remote sensing based LU/LC map prepared using IRS (LISS-III) at 1:50000 scale (NRDB 2012) was suitably weighted with known preferences of the barasingha and combined with niche modeling outputs to come out with habitability grades for Barasingha.

**Bioclimatic indices**

Current climatic (Version 1.4, release 3) data from WorldClim (Hijmans et al. 2005) at 30 arc-second resolution grid (http://www.worldclim.org) based on observations from year 1950–2000 were used. The minimum and maximum temperatures and monthly total precipitation data were used for generating 19 bioclimatic indices, the more biologically meaningful variables, using BIOCLIM model implemented in DIVA-GIS (ver. 7.1.7.2). The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). These 19 bioclimatic indices (Fig. 4) were used in ecological niche modeling.

**Model training and validation**

Historical records (Martin 1977) were used to reconstruct the distribution of the Hard-ground Barasingha in the 19th century (Fig. 1) primarily using the association of sal forests with the presence of Barasingha. Since, the niche model used in this study works essentially on the bioclimatic indices, the presence record points depicted on the historical map (Fig. 1) were used to check the equivalence of the niche model prediction (Fig. 5) vis-à-vis the historical map of Martin (1977). The habitat locations of the Barasingha which are currently located in KTR were further used as training sets in the model for predicting the environmental niche of the species.

**RESULTS**

**Congruence of model with historical data**

The model output in Fig. 5 very closely matched the distribution in Fig. 1. The model suggests that the Barasingha ranged across the terai regions of northern India. However, the model output also gives potential ranges in the western and eastern parts compared with Fig. 1. In recent times, the relatively small areas which contained suitable Barasingha habitat have been converted to plantations, agriculture or other land uses.

**Validation of results**

This study has demonstrated the differential suitability of different sites for the reintroduction of the Barasingha. The Bori Wildlife Sanctuary of Satpura Tiger Reserve (STR) is among the most suitable areas. In terms of food component, the STR is better than KTR. Water availability was excellent in both sites, and Bori had an excellent refuge for the species. However, thermal/resting cover is rated under the category ‘good’
in the STR in comparison to KTR which have achieved the ‘excellent’ category (Prakash et al. 2012). Overall habitat suitability index (HIS) suggests that the sites were classified as ‘excellent’ for their potential to support Barasingha as far as habitat viability analysis is concerned. More such validations based on HVA can be carried out in other areas by environmental niche models.

Habitat suitability

The southern portion of Madhya Pradesh is most suitable for the Barasingha with varying degrees of habitability (Fig. 6). On the basis of forest division boundaries, parts of Kanha National Park and environs, north and south Balaghat, Mohgaon area, east & west Mandla, Dindori, north & south Seoni, west, east & south Chhindwara, Pench Tiger Reserve, Anuppur, west Betul, and STR forest divisions are found conducive for Swamp Deer conservation. The forest ranges which are recommended as habitat for conservation measures are Mukki, Kisli, Kanha, Bhaisan Ghat, Baiher, east & west Baihar, Ukwa, Motinala, Laugur, Supkhar, Phen Sanctuary, Chiradongri, Kanha buffer zone, north Ukwa, Harratola, Seoni, Chaurai, Jagmandal, Mawai, Balaghat, Ghansore, Bagra, Hatta and south Ukwa. It is interesting to note that most of these forest areas were the same as where the species occurred around 40–50 years ago. However, with the current scenario and updated land
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Figure 5. Niche modeling based probable distribution of Barasingha at the end of the 19th century.

DISCUSSION AND CONCLUSIONS

A study carried out by SFRI-Jabalpur (Prakash et al. 2012) on the HVA for the proposed reintroduction site for the Hard-ground Barasingha Cervus duvauceli branderi in the Bori Wildlife Sanctuary, STR has validated this study. The results have indicated that the southern portion of Madhya Pradesh, is most suitable for the reintroduction of Barasingha, with varying degrees of habitability. The current result may slightly differ from existing empirical/supervised knowledge of the park management and the present ground reality (biotic pressure from forest villages) as far as the conservation of Swamp Deer in the protected area is concerned. However, it would be interesting to see if this study is expanded to examine correlations between environmental niches, edaphic characteristics and the resultant plant communities forming optimal habitats of the Hard-ground Barasingha. This shows that niche modeling can be used as a management tool for species reintroductions into their former range.

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Figure 6. Environmental niche of Barasingha in Madhya Pradesh based on bioclimatic indices envelop models and remote sensing based land use and land cover.

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Hindi Abstract (तत्व): अध्ययन में उपयोगी दिशा में एक उप-उष्णकटिबंधीय मौसमीय कृतित्व (Cervus duvauceli branderi जैसे) मौसमीय उष्णकटिबंधीय क्षेत्रों में स्थित एक ऐसी शक्ति का उपयोग किया गया। गणराय समीप में स्थित कुछ रेगिस्ट्री का वर्तमान रूप में अध्ययन किया गया। यह जानकारी विशेषता प्रदान करने के लिए उपयोगिता की शक्ति को आदर्श रूप से नियंत्रित किया।

Author Contribution: CPS was involved in designing the study, field survey, gathering, and analyzing the data, niche modeling and writing the MS. JSC was involved in formulating the study, and conducting the field survey. JSP was involved in critical design review of the study, and field survey. RPS was involved in analysing modeling results. RS was involved in field research.

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