DELINEATING ECO-SENSITIVE ZONES USING GEOSPATIAL METHODS – A TEST CASE OF JHILMIL JHEEL CONSERVATION RESERVE

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KEY WORDS: Eco-Sensitive Zones (ESZ), buffer areas, Swamp Deer (*Rucervus duvaucelli duvaucelli*), Jhilmil Jheel Conservation Reserve (JJCR), Maxent

ABSTRACT:

Most of the protected areas (PAs) in India have a hard boundary; very rarely having a transition zone to minimise the negative human wildlife interface. With increasing anthropogenic pressures, areas surrounding PAs are becoming integral for conservation. Government of India introduced a concept of Eco-sensitive Zones (ESZ) around PAs to minimise anthropogenic pressures and regulate rapid development in these areas. However, delineation of ESZs is a complex process and may take a long time. In this paper, a novel geospatial approach has been presented to delineate ESZ using a species centric approach. A case study using Swamp deer (*Rucervus duvaucelli duvaucelli*) as focal species was explored for its potential to delineate ESZ around protected area Jhilmil Jheel Conservation Reserve (JJCR) located in Uttarakhand India. Maximum entropy or Maxent model was used to identify habitat suitability. Normalised difference vegetation index (NDVI), altitude, land cover and distance to roads were used as co-variates. Seasonal variations for habitat suitability were also considered. In this study habitat suitability map of swamp deer was further rationalised based on habitat fragmentation and management limitations and proposed as ESZ of JJCR. This approach for delineation of ESZ can be very useful for PAs in India which have focal species and are yet to declare their ESZ.

1. INTRODUCTION

1.1 Protected Areas (PAs) and Eco-sensitive Zones (ESZs)

In India Protected Areas (PAs) are constituted and governed under the provisions of the Wildlife (Protection) Act, 1972. Other acts viz. Indian Forest Act, 1927, Forest (Conservation) Act, 1980, Environment (Protection) Act, 1986 and Biological Diversity Act, 2002 and the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 further complement the implementation of this act.
PAs are considered to be subsets of a larger surrounding ecosystem which are vulnerable to human impacts due to the absence of protection of these contiguous areas (Hansen et al., 2011). The National Wildlife Action Plan indicates that "Areas outside the protected area network are often vital ecological corridor links and must be protected to prevent isolation of fragments of biodiversity which will not survive in the long run. Land and water use policies will need to accept the imperative of strictly protecting ecologically fragile habitats and regulating use elsewhere".
Increased pollution, use of pesticides and insecticides, degradation of forest biodiversity, weed infestation, encroachment of forest land due to unplanned development in the areas peripheral to the forests, make ESZ delineation even more significant. Delineation of ESZ therefore becomes very important in this context. ESZ can create a zone of transition from areas of high protection to areas of less protection. ESZ are described as "Shock Absorber" for the PAs by the Ministry of Environment, Forest and Climate Change, Government of India (Annonymous, 2011). The delineation of the ESZ is provided legal backing under Section 3 (v) of the Environment (Protection) Act, 1986 and Rule 5 Sub-rule (viii) and (x) of the Environment (Protection) Rule, 1986. Further, Honourable Supreme Court of India ordered that in case of non- declaration of ESZ around a PA, a minimum of 10 km buffer around a PA would be declared as ESZ.

The activities which can be carried out within the ESZ can be regulated, prohibited or promoted. Many of the existing PAs are already seeing huge developments in close vicinity to their boundaries which are not harmonised with conservation objectives. Some of the PAs are almost nested within urban setup. Therefore, defining the extent of eco-sensitive zones has to be PA specific and done in a very judicious manner.

1.2 Delineation of ESZ

The delineation of ESZ is complex and protracted process. Delineation of transition zones around PA can be done in various ways scientifically, depending on the objective. Some approaches are – Land Use Land Cover (LULC) Approach, Landscape Approach, Ecosystem Approach, Species-centric Approach etc. We tested species-centric method of delineating ESZ around JJCR using Swamp deer as the focal species for conservation.

The next step after delineating ESZ is to prepare a Zonal Master Plan (ZMP) according to the guidelines, where activities are identified which have to be prohibited, regulated or permitted within the ESZ.

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1.3 Swamp Deer

The swamp deer (*Rucervus duvaucelli*) or ‘Barasingha’ is a 5-6 tined swampy grassland dwelling large cervid currently endemic to India and Nepal (Qureshi et al, 2004). Scientific classification of the Swamp deer is shown in Figure 1. Historically swamp deer was widely distributed throughout Indo-Gangetic plain and the lowlands flanking the southern Himalayas from Pakistan to Bangladesh through India (Schaller, 1967). Three subspecies of swamp deer (based on morphological characteristics) are described across their range. The northern subspecies *Rucervus duvaucelli duvaucelli* is found in the north Indian states of Uttar Pradesh (UP) and Uttarakhand (UK) along with Nepal. The hard ground barasingha *Rucervus duvaucelli branderi* is found as a single population in Central India and the eastern subspecies *Rucervus duvaucelli ranjitsinhii* is found in the state of Assam (Qureshi et al, 2004). Figure 2 depicts this historical and current distribution of swamp deer. All swamp deer populations in India have declined in recent time due to increased human pressure and changing land use practices (Qureshi et al, 2004). Swamp deer is now considered as ‘Vulnerable’ by the IUCN Red List (Duckworth et al, 2015). The species are listed in Appendix I in CITES and Schedule I of Wildlife Protection Act of India, 1972, i.e. highest level of protection. Currently, these animals are found in small, fragmented populations across the states of Uttar Pradesh (Hastinapur Wildlife Sanctuary, Bijnore forest division, Pilibhit forest division, Kishanpur Wildlife Sanctuary, Dudhwa National Park and Katerniaghat Wildlife Sanctuary) and Uttarakhand (Jhilmil Jheel Conservation Reserve)(Qureshi et al, 2004). Swamp deer is a highly specialised species that prefers wetlands (also called ‘Swamps’ or ‘Tals’ locally) and flooded grasslands (Tewari & Rawat, 2013a). Swamp deer are the largest mammals occupying these areas. Swampy areas or grasslands are home to variety of endangered and unique fauna and hence need to be protected.

Kingdom – Animalia
Phylum – Chordata
Class – Mammalia
Order – Cetartiodactyla
Family – Cervidae
Genus – *Rucervus*
Species – *duvaucelli*
(G. Cuvier, 1823)

Figure 1 – Scientific classification of swamp deer (Duckworth et al, 2015)

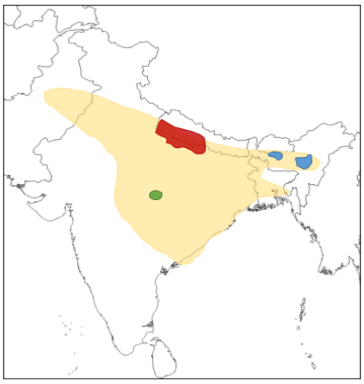

Figure 2 – Historic distribution (yellow) and current distribution of the three subspecies:
Rucervus duvaucelli duvaucelii (red)
Rucervus duvaucelli branderi (green)
Rucervus duvaucelli ranjitsinhi (blue)
(Qureshi et al, 2004)

2. OBJECTIVES

The objective of the study was to delineate the ESZ for JJCR.

3. STUDY AREA

3.1 Jhilmil Jheel Conservation Reserve (JJCR)

Jhilmil Jheel Conservation Reserve (JJCR) is a PA located in the North Indian state of Uttarakhand. It extends between N 29^0 32' to 29^0 50' and E 78^0 to 78^0 15' covering an area of 37.84 km² of Reserve Forest of Haridwar Division as shown in Figure 3. In 2005, the area was declared as a conservation reserve by the Government of Uttarakhand. The Haridwar–Najimabad national highway (NH-74) passes through the north-eastern part of the conservation reserve, which is located in Chidiyapur Range of Haridwar Forest Division. Jhilmil Jheel being a wetland can be considered as a cradle of biodiversity and provide multiple ecosystem services. The area is rich in faunal and floral diversity, including swamp deer, spotted deer, elephant, blue bull, wild boar, monkey, langur, mongoose, hare, common leopard and occasionally tiger, jungle cat, otter, porcupine, sambar, barking deer and hog deer are also seen in the area. Avifauna includes a large number of resident and winter migratory birds. (Annonymous, 2005).Anthropogenic pressures faced by JJCR include –agriculture and grazing by the locals. Sand and boulder mining are also prevalent in the riverbed areas.

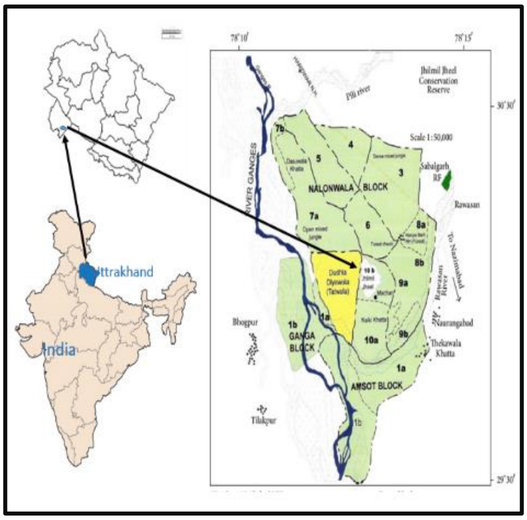

Figure 3 – Location of JhilmilJheel Conservation Reserve, Uttarakhand, India (Annonymous, 2005).

4. METHODOLOGY

4.1 Maxent

Maxent is a tool used for presence only modelling of species distributions based on the maximum entropy approach (Phillips et al, 2006). Maximum entropy as defined by Jaynes is the least biased estimate possible on given information (Jaynes, 1957). The advantages of Maxent include the ability to work with small sample size (Phillips et al, 2006). Phillips et al have described Maxent as finding the distribution which has maximum entropy subject to constraints (Phillips et al, 2006). Constraints are feature types derived from environmental factors that constrain the geographical distribution of species. There are five feature types in Maxent – linear, quadratic, hinge, product and threshold (Phillips et al, 2006). Maxent works well with presence only data as compared to other model (Elith et al, 2011). Poor et al have concluded that Maxent outperformed analytic hierarchy process for modelling pronghorn habitat suitability (Poor et al, 2012). Hence Maxent was used for identifying suitable habitats for swamp deer.

4.2 Methodology

The swamp deer presence data (Paul et al, 2017) was used as an input in Maxent to predict the suitable habitats for the same in and around JJCR. The variables used while predicting the habitat were - Altitude, Normalised difference vegetation index (NDVI), Land Use Land Cover (LULC) and road network.

Default Maxent settings for ‘feature class’ selects Linear (L), Quadratic (Q) and Hinge(H) for sample size more than 15 and less than 80 (Phillips & Dudík, 2008). Regularization multiplier of 1 is the default settings. Lower regularization multiplier may result in restricted and over-fit prediction while broader and less specific prediction may result from large regularization multiplier (Philips et al, 2006). Lower omission rate and higher area under curve (AUC) respectively (Shcheglovitova & Anderson, 2013), were chosen to select the model. Feature type of L & Q with regularization multiplier of 1 was chosen for prediction of habitat suitability.

The outputs of Maxent indicated the potential distribution of swamp deer which was used as a surrogate for habitat suitability (summer, winter and monsoon months). Subsequently the output was reclassified into a binary map i.e. suitable and unsuitable areas using 10 percentile training presence as a logistic threshold.

The areas of high suitability, where disturbance due to roads is minimum, outside the boundary of PA were delineated using ArcGIS to identify the ESZ. The methodology used in this study is shown in Figure 4.

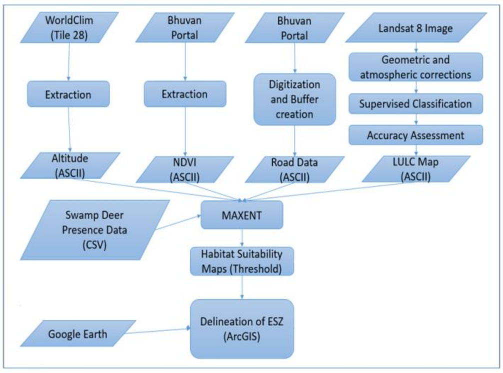

Figure 4– Flowchart depicting the methodology for study hgisdugndsngdngkddfgn

5. DATA LAYERS

5.1 Data Layers

The various data layers used are mentioned as below –

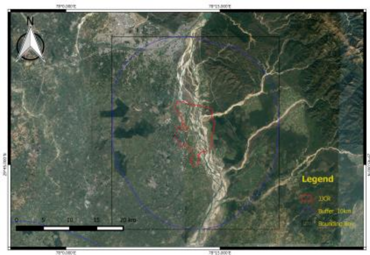

Figure 5 – Study area depicting the PA – JJCR in red colour. Blue colour depicts the 10km buffer while black depicts the bounding box created.

5.1.1 Boundary: PA boundary was provided by the forest department which was digitized at a scale of 1:50000. Bounding box at 10 km buffer around the PAs was generated in ArcGIS which was used as the study area depicted in Figure 5.

5.1.2 Swamp Deer Presence Data: The data for the swamp deer presence data was provided by Wildlife Institute of India, Dehradun, India (Paul et al, 2017). The data were collected during the field survey done in 2016. The presence data were collected based on direct evidence (sightings) and indirect evidence (pellets, antlers, carcases etc.). This data was digitized using Google Earth and the file was converted to a .csv file for input into the Maxent software.

5.1.3 Variables Affecting Habitat of Swamp Deer: The Swamp deer's habitat is affected by- availability of food, water, cover and the land use pattern (Tewari & Rawat, 2013b; Bhattarai, 2011; Nandy et al, 2012). Swamp deer are generalist or opportunistic feeders during the winter and summer months due to the scarcity in food but they are selective feeder during the monsoon season due to the abundance of food (Tewari & Rawat, 2014). Six variables – temperature, precipitation, NDVI, altitude, LULC and road network were considered for prediction. But due to high correlation (more than 90%), the temperature and precipitation variables were dropped leading to a drop in correlation amongst the other variables less than 20%. Hence, four variables were used for predicting the habitat of Swamp deer viz. NDVI as a measure of food availability, Altitude as a measure of the terrain composition, LULC map of the study area as a measure of water availability and swampy areas. LULC and road network depict the disturbance in the habitat.

5.1.3.1 30-second arc resolution altitude data from WorldClim was downloaded for Zone28 in GeoTIFF format. The area of study was extracted and converted into ASCII format for input in Maxent using ArcGIS.

5.1.3.2 NDVI monthly product for the year 2016 was downloaded from the Bhuvan portal in GeoTIFF format. NDVI product was realised using Oceansat-2 Ocean Colour Monitor (OCM2) Global Area Coverage GAC) sensor. The area of study was extracted and converted into ASCII format for input in Maxent using ArcGIS. Seasonal data was derived by averaging of the data over 4-month period – monsoon (July – Oct), summer (Mar – June) & winter (Nov – Feb).

5.1.3.3 Road network data were digitized from IRS LISS-III satellite data available on Bhuvan portal. Only the major roads and highways were digitized. A buffer of 1 km was created around this network. It was a categorical input in Maxent. Figure 6 displays the road map used as an input for the habitat suitability assessment.

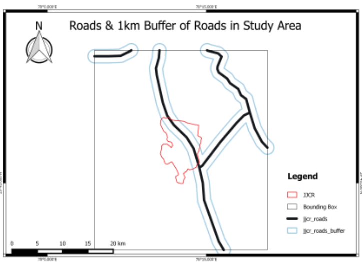

Figure 6 – Road network (black) in the study area and a 1 km buffer around the roads (blue).

5.1.3.4 LULC Map of the study area was created. LANDSAT8 Satellite image from USGS for the date 13th November 2016 was downloaded which was atmospherically corrected. Geometric corrections were performed. Supervised classification was done into 6 broad classes – Grasslands/Plantations, Swamps/Marshes, Agriculture, Settlements, Forests and Water. Accuracy assessment by visual method was done using the LULC Map generated by Bhuvan as a reference. Figure 7 displays the LULC map of the study area used.

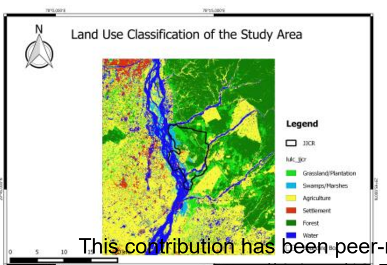

Figure 7– Land Use map of the study area depicting the various classes. JJCR is mostly insulated from human disturbance except 1 village inside. .

5.1.4 Villages: Census data of the year 2011 obtained from the National Census Handbook, 2011 was used for the village dataset.

5.1.5 Softwares: The software’s used for the study are as follows - Maxent - 3.3.3, Circuitscape - 4.0, ArcGIS 10.3, Google Earth.

5.1.6 Summary: A summary of the data inputs used are displayed in Figure 8.

S.No.	Layer Name	Source	Year	Modifications	Input Software	Input Format
1.	Altitude	WorldClim	2000	-	Maxent	ASCII
2.	NDVI	Bhuvan	2016	Monthly data was averaged	Maxent	ASCII
3.	LULC	USGS – Landsat8	2016	Supervised classification	Maxent	ASCII
4.	Road	Bhuvan	2017	Digitization and Buffering	Maxent	ASCII
5.	Presence Points	WII Report	2016	Digitization	Maxent	CSV

Figure 8 – Summary of inputs used

6. RESULTS

6.1 Potential Habitat of Swamp Deer

The output of Maxent predicting habitat suitability for the three seasons is shown in Figure 9. Figure 10 shows the variable contribution in assessment of suitable habitats. The two most important factors in identifying suitable areas were - LULC & NDVI. As the terrain in the study area is mostly even, altitude has not contributed for identification of suitable habitats. Habitat suitability maps were generated from the Maxent output. Based on the threshold, suitable and unsuitable areas were classified for 3 seasons, namely – monsoon, summer & winter of year 2016, which is depicted in the maps in Figure 11. Monsoon had the highest area prediction followed by winter and lastly summer.

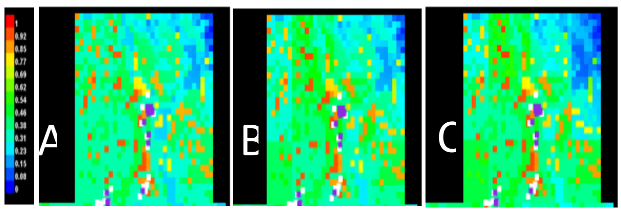

Figure 9 – Maxent output – A- Monsoon 2016, B- Summer 2016, and C- Winter 2016. Dark blue colour represents 0 i.e. least suitability while red colour represents 1 i.e. high suitability.

A

Variable	Percent contribution	Permutation importance
lulc	94.7	81.1
road1	4.2	6.6
alti	1.1	0
monsoonavgn	0.1	12.3

B

Variable	Percent contribution	Permutation importance
lulc	91.8	57.5
road1	4	9.2
summeravgn	3.5	33.3
alti	0.7	0

C

Variable	Percent contribution	Permutation importance
lulc	90	62.5
winteravgn	5.5	32.1
road1	3.9	5.4
alti	0.6	0

Figure 10 - Contributions of variables for various seasons A-Monsoon 2016, B - Summer 2016 & C-Winter 2016

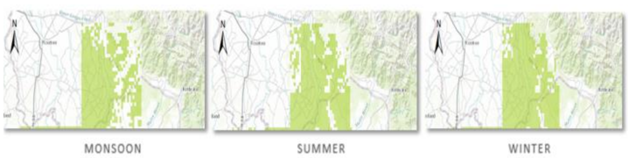

Figure 11 – Habitat Suitability Maps – 2016

6.2 ESZ Delineation

Figure 12 – Ideal ESZ which includes the suitable habitat

Figure 12 depicts the ideal ESZ that should be delineated for the PA. It includes the maximum area of suitable habitat. Considering the increasing population of Indian subcontinent and the subsequent anthropogenic pressures on land, delineating the ideal/suitable ESZ around a PA becomes difficult. The final ESZ delineation was done based on the following factors -
1. Guidelines of Honourable Supreme Court of India have restricted the delineation of ESZ as minimum 10 kms from the PA boundary. Considering the population pressures on land in a developing country like India, the feasibility of ESZ beyond 10 kms is a huge challenge.
2. JJCR is located in the state of Uttarakhand. Therefore, the problem of administration becomes cumbersome if the ESZ is delineated beyond the boundary of the state. Interstate coordination measures for administration and regulating ESZ on ground is a humongous task. This has restricted the southern boundary of ESZ of JJCR.
3. Presence of physical boundaries which fragment the ecosystem forms a barrier for ESZ delineation. The northern boundary formed by river Ganges and the eastern boundary of Rajaji National Park has restricted the ESZ.
4. Administration of ESZ becomes a challenge due to the differences in administrative and physical boundaries. Western boundary of ESZ of JJCR has been delineated keeping the administrative boundaries in mind.

Keeping the above mentioned factors in mind, ESZ which has been delineated is restricted in extent. This final delineated ESZ for JJCR is shown in Figure 13.

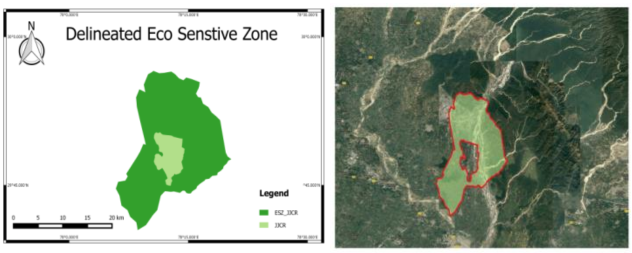

Figure 13 – Final ESZ for JJCR. The google earth image shows the final delineated ESZ.

6.3 Details of ESZ

The ESZ around JJCR to be constituted consists of minimum 1 km and a maximum of 10 km periphery. Townships have been excluded from the limits of ESZ, natural and artificial features such as rivers, ridges have been chosen to define the limits. Wherever possible, natural features have been chosen to define the limits of ESZ. But taking into account the problems faced by the managing committee on the ground, final delineated ESZ boundary coincides with the administrative and geographical boundaries. This kind of hard boundary delineation of ESZ

Figure 14 – Boundaries of villages in ESZ of JJCR

makes management and administration of ESZ relatively simpler to understand and implement at the ground level. The total area of the proposed ESZ would be approx. 307 sq. km.The total area would cover 4 community development blocks (C D Blocks) – Bhagwanpur, Bahadarabad, Laksar and Haridwar of the district Haridwar. Table 1 depicts the land use area in ESZ. Table 2 shows the block wise area of the ESZ.The list of 56 villages (Figure 14) identified in the ESZ are attached in Appendix 1.

The boundary of the ESZ:

North Side: River Ganga
Eastern Side: Rajaji National Park boundary
South Side: State boundary of Uttarakhand
Western Side: Villages – Shivpuri and Niranjanpur of Laksar block.

Table 1 : Land use area of JJCR ESZ

Settlements	**Agriculture**	**Forests/Grass lands**	**Water/Swampy areas**
3.5% (10.69 sq. km.)	40% (122.8 sq. km.)	40% (122.8 sq. km.)	16.5% (50.65 sq. km.)

Table 2 : Area of blocks included in JJCR ESZ

District	**C D Block**	**Area (Ha)**
Haridwar	Bhagwanpur	367.82
	Bahadarabad	13556.62
	Laksar	10401.97
	Haridwar	6368
	Total	30694.41 Ha = 306.94 sq.km.

7. DISCUSSION & CONCLUSION

7.1 Maxent modelling

Modelling is an abstraction of reality and hence is limited. Maximum entropy or Maxent method helps in predicting species geographic distribution and it works well with presence only data as compared to other approaches (Elith et al, 2006). Maxent model for predicting habitat suitability for swamp deer used L and Q feature type & regularization parameter of 1. Variables used for prediction included – LULC, NDVI, altitude and distance to roads. Minimum ten percentile training presence logistic threshold was used as it gives a better estimation of native habitat compared to minimum training presence threshold. Minimum training presence threshold tends to estimate the habitat range. LULC and NDVI parameters were found to be contributing highest for predicting suitable habitats. Average test omission rate was about 15% for all three seasons. Average training AUC was found to be 66%. Uncertainty of the model is apparent from the range of predictions observed on 10 repetitions. Test omission and test AUC have a wide range of prediction pointing to the limitation of the model. Maxent is sensitive to various parameters like feature type and regularization multiplier. As with any modelling approach, which requires a trade-off between accuracy and robustness, so does Maxent. Ensembling can help to improve the accuracy of the model but has a bearing on model interpretability.

7.2 Defining an ESZ

There is a lack of availability of universal definitions for buffer areas/transition areas/eco-fragile areas/eco-sensitive zones, etc. This has led to various countries adopting numerous measures which lead to ambiguity and uncertainty at international discourse. Usually in nature, as even identified by this study, ESZ extend for a large area. But the limitation of fragmented habitat both ecologically and administratively leads to identification of a much narrower ESZ. India being a developing country, with a huge populace, faces an immense pressure on land especially forests. Therefore, from the perspective of development and management, delineation of ESZ affects developmental activities and locks the changes in land use.

7.3 Limitations of buffer zones

Buffer zones are not always effective in conservation activities. The study of ineffectiveness of the Lore Lindu Biosphere Reserve, Indonesia identifies 3 factors for the same - 1. Boundary demarcation unawareness amongst the villagers 2.Political instability 3. Lack of clarity on buffer zone responsibility in local government agencies(Naughton, 2007).

Delineation of ESZ without proper physical boundaries leads to confusion. The most complex issue is the land tenure. Prohibition and regulation of activities and land use conversion are a source of fear for the local villagers. Encroachment and lack of political will further aggravate the problems of ESZ delineation. Another concern that arises after delineation of ESZ is the effective implementation.

7.4 Future recommendations

It can be safely concluded that the methodology of identifying the habitat suitability using Maxent has given satisfactory results. LULC and NDVI are the major parameters for identifying a suitable habitat. Future recommendations include collection and use of seasonally tagged temporal presence data with the absence of sampling bias (Radio collar data) to further improve the accuracy of the model. Factors like state boundaries, natural boundaries, forest boundary, has been taken into account while delineating ESZ resulting in varying widths of ESZ around PA.

Resource allocations become difficult and complex in areas of dense population with high dependency on natural resources. The way forward can only be by people's participation in the protection & conservation activities and alternate livelihood activities that improve the quality of life for the people. Delineation and management of ESZ can't be a panacea to all the problems of conservation but it can be a step towards that dream.

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DISCLAIMER

This document describes work undertaken as part of a programme of study at Indian Institute of Remote Sensing. All views and opinions expressed therein remain the sole responsibility of the author(s), and do not necessarily represent those of the Forest Department or the Government of India.

REFERENCES

Annonymous.(2005) Jhilmil Jheel Conservation Reserve. Forest Department, Government of Uttarakhand.

Annonymous. (2011). Guidelines for Eco-Sensitive Zones around Protected Areas. Ministry of Environment, Forest and Climate Change.

Bhattarai, B. (2011). Habitat Preference and Evaluation of Swamp Deer in Bardia National Park. *Kathmandu Forestry College*.

Duckworth, J.W.,Kumar, N.S., Pokharel, C.P., Sagar Baral, H. & Timmins, R.(2015) "*Rucervus duvaucelli.* The IUCN Red List of Threatened Species": e.T4257A22167675.

Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E., & Yates, C. J. (2011). A statistical explanation of MaxEnt for ecologists. Diversity and distributions, 17(1), 43-57.

Hansen, A. J., Davis, C. R., Piekielek, N., Gross, J., Theobald, D. M., & Goetz, S. (2011). Delineating the Ecosystems Containing Protected Areas for Monitoring and Management, *61*(5), 363–373. https://doi.org/10.1525/bio.2011.61.5.5

Jaynes, E. T. (1957). Information theory and statistical mechanics. *Physical review*, *106*(4), 620.

Nandy, S.,Kushwaha, S. P. S., & Gaur, P. (2012). Identification of Swamp Deer (Cervus duvauceli duvauceli Cuvier) Potential Habitat in Jhilmil Jheel Conservation Reserve , Uttarakhand , India Using Multi-Criteria Analysis, 902–914. https://doi.org/10.1007/s00267-012-9826-5

Naughton, L. (2007). Zoning for Conservation and Development in Proatected Areas, (Rowlands 1933), 1–16.

Paul, S., Pandav, B., Mohan, D., Habib, B., Nigam, P., & Mondol, S. (2017) Current distribution and status of swamp deer Rucervus duvaucelii duvaucelii in the upper Gangetic plains of north India. Oryx, 1–8. http://doi.org/10.1017/S0030605318000078

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. Ecological modelling, 190(3), 231-259.

Phillips, S. J., & Dudík, M. (2008). Modeling of Species Distributions with Maxent : New Extensions and a Comprehensive Evaluation. *Ecography*, *31*(2), 161–175. https://doi.org/10.1111/j.2007.0906-7590.05203.x

Poor, E. E., Loucks, C., Jakes, A., & Urban, D. L. (2012). Comparing habitat suitability and connectivity modeling methods for conserving pronghorn migrations. *PLoS One*, *7*(11), e49390.

Qureshi, Q. Sawarkar V.B., Rahmani, A.R. & Mathur, P.K.(2004). Swamp deer or barasingha (*Cervus duvauceli* Cuvier 1823). In: *Ungulates of India (Eds.: K.Sankar and S.P. Goyal) Envis Bulletin: Wildlife and Protected Areas, Vol.07, No. 1*, Wildlife Institute of India, Dehradun, India.181-192.

Schaller, G. B. (1967). *The Deer and the Tiger*.

Shcheglovitova, M., & Anderson, R. P. (2013). Estimating optimal complexity for ecological niche models: a jackknife approach for species with small sample sizes. Ecological Modelling, 269, 9-17.

Tewari, Rachna & Rawat, G. S. (2013a). Activity pattern and diunal time budget of swamp deer in Jhilmil Jheel Conservation Reserve, Haridwar, Uttarakhand, India. In *NeBIO* (Vol. 4, pp. 36–40). https://doi.org/10.1155/2013/278213

Tewari, Rachna & Rawat, G. S. (2013b). Assessment of swamp deer habitat in and around jhilmil jheel Conservation Reserve, Haridwar, India. *International Journal of Conservation Science*, *4*(2), 243–249.

Tewari, Rachna & Rawat, G. S. (2014). Studies on the Food and Feeding Habits of Swamp Deer (Rucervus duvaucelii duvaucelii) in Jhilmil Jheel Conservation Reserve. *International Journal of Conservation Science*.

APPENDIX 1

The list of 56 villages which have been delineated in the ESZ of JJCR are listed below with details-

S.no.	Name of Village	Block	District	Area(Ha)	Household (Number)	Total Population	GPS Coordinates (degree decimal)
1	Alawalpur	Bhagwanpur	Haridwar	190.9	704	3,846	78.15 29.74
2	Khanpur	Bhagwanpur	Haridwar	176.92	288	1,544	78.14 29.71
3	Banganga No.2	Bahadarabad	Haridwar	394.85	673	3,768	78.13 29.78
4	Bhuwapur Chamrawal	Bahadarabad	Haridwar	261.15	258	1,361	78.12 29.76
5	Kangari	Bahadarabad	Haridwar	491.58	386	1,950	78.17 29.89
6	Gajiwali	Bahadarabad	Haridwar	172	375	2,107	78.178 29.88
7	Shyampur Nauabad	Bahadarabad	Haridwar	358	432	2,472	78.17 29.87
8	Sajanpur Peeli	Bahadarabad	Haridwar	340	340	1,999	78.18 29.86
9	Peeli Padav	Bahadarabad	Haridwar	529.13	267	1,805	78.25 29.85
10	Rasool Pur Mithi Beri	Bahadarabad	Haridwar	1,233.11	1,041	5,953	78.30 29.86
11	Laldhang	Bahadarabad	Haridwar	762	1,214	6,896	78.30 29.84
12	Samaspur Katabarh	Bahadarabad	Haridwar	581.78	116	647	78.3 29.82
13	Pamdowali	Bahadarabad	Haridwar	592.69	0	0	78.28 29.81
14	Tapadowali	Bahadarabad	Haridwar	391.7	15	115	78.29 29.82
15	NaloWala	Bahadarabad	Haridwar	304.65	59	403	78.24 29.82
16	DudhalaDayalwala	Bahadarabad	Haridwar	668.86	228	1,138	78.2 28.79
17	Gaindikhata	Bahadarabad	Haridwar	1,124.16	549	2,817	78.25 29.79
18	Naurangabad	Bahadarabad	Haridwar	210.84	87	410	78.23 29.78
19	Bulakganj	Bahadarabad	Haridwar	459.46	0	0	78.26 28.75
20	Baso Chandpur	Bahadarabad	Haridwar	550.73	2	2	78.20 29.74
21	Ahamadpur Chiriya	Bahadarabad	Haridwar	183.46	33	164	78.27 29.75
22	Boxowali	Bahadarabad	Haridwar	285.73	31	189	78.26 29.74
23	Shyampur Gairabad	Bahadarabad	Haridwar	140.35	13	73	78.28 29.76
24	Bhudhiwala	Bahadarabad	Haridwar	550.54	0	0	78.29 29.77
25	Lahadpur	Bahadarabad	Haridwar	603.28	103	541	78.31 29.82
26	Jaspur Chamaria	Bahadarabad	Haridwar	474.33	34	154	78.32 29.8
27	Hardaspur	Bahadarabad	Haridwar	476.08	0	0	78.31 29.79
28	Prem Nagar	Bahadarabad	Haridwar	325.57	6	40	78.33 29.79
29	Vandev Urf Khushahalpur	Bahadarabad	Haridwar	1,090.59	0	0	78.34 29.81
30	Bhogpur	Laksar	Haridwar	3,362.16	1,466	8,213	78.16 29.77
31	Baditeep	Laksar	Haridwar	395.11	184	1,074	78.15 29.76
32	Pathari Forest Range	Haridwar	Haridwar	6,368.00	1,300	8,430	78.24 29.85
33	Mubarikpur Alipur	Laksar	Haridwar	166.08	568	3,680	78.10 29.74
34	Pratappur	Laksar	Haridwar	146.98	240	1,292	78.11 29.72
35	Bhagatanpur Majra	Laksar	Haridwar	156.02	98	547	78.11 29.72

	Niranjanpur						
36	Barampur	Laksar	Harid war	126.6 6	50	255	78.12 29.72
37	Khanpur	Laksar	Harid war	337.1 6	500	2,810	78.14 29.7
38	Rasoolpur Urf Kankarkhata	Laksar	Harid war	582.2 6	462	2,591	78.13 29.70
39	Niranjanpur	Laksar	Harid war	827.5 8	803	4,600	78.13 29.68
40	Mahrajpur Khurd	Laksar	Harid war	533.1 1	439	2,482	78.12 29.67
41	Shivpuri (Must)	Laksar	Harid war	173.8	0	0	78.14 29.67
42	Shivpuri(Aht)	Laksar	Harid war	98	0	0	78.15 29.8
43	Mubarkpur	Laksar	Harid war	104.0 7	0	0	78.12 29.74
44	Sultanpur Adampur	Laksar	Harid war	242.6 3	2,564	16,042	78.11 29.75
45	Jawaharkhan Urf Jhiwerhedi	Laksar	Harid war	196.2 2	170	994	78.11 29.73
46	Suthari	Laksar	Harid war	191.6 6	442	2,690	78.12 29.74
47	Nehandpur	Laksar	Harid war	226.7 5	13	90	78.13 29.73
48	Mahtauli	Laksar	Harid war	278.9 1	521	2,911	78.12 29.75
49	Muzafferpur Gujra	Laksar	Harid war	52	0	0	78.16 29.74
50	Muzafferpur Gujra Jadeed	Laksar	Harid war	71.95	0	0	78.17 29.75
51	Musahibpur Majri	Laksar	Harid war	227	94	507	78.14 29.74
52	Fatwa Must	Laksar	Harid war	277.6 1	438	2,411	78.17 29.74
53	Fatwa Aht	Laksar	Harid war	108.1 8	6	53	78.19 29.72
54	Bakarpur	Laksar	Harid war	454.1 9	680	4,095	78.15 29.71
55	Jaspur Ranjeetpur Aht	Laksar	Harid war	330	0	0	78.16 29.69
56	Rampur Raighati Aht	Laksar	Harid war	735.8 8	0	0	78.16 29.72