Technical Report

Population status of rhesus macaque (*Macaca mulatta*) in Himachal Pradesh 2019-2020

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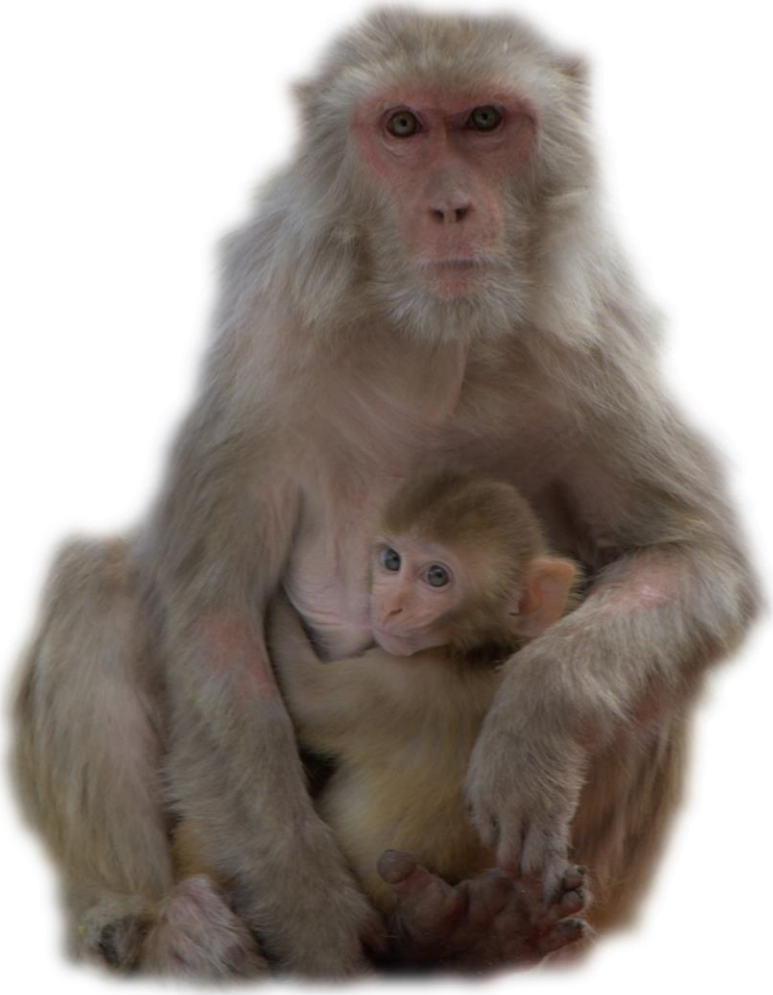
2020



Population status of rhesus macaque (*Macaca mulatta*) in Himachal Pradesh 2019-2020

Technical Report

Submitted to

Himachal Pradesh Forest Department

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Contents

List of Tables

List of Figures

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H. N. Kumara
Aakriti Singh

Summary

Rhesus macaque *Macaca mulatta* is one of the most common commensal species in Himachal Pradesh, and is known for heavy crop damage and conflicts with humans. The conflict with macaques in this landscape has become a serious sociopolitical issue and thus perhaps various steps are being taken by the Forest Department to control the macaque population. One of the major steps is the sterilization of macaques. A total of 155257 adult macaques were sterilized in the last 14 years wherein 74982 were females and 80275 were male. The population trend of a targeted species is the indicator of the measures taken to control its population. Himachal Pradesh Forest Department has undertaken a state-level survey in December 2019 to estimate the current population size of rhesus macaque in the state. A total of 2795 trails were walked consecutively for three days with a total effort of 23440 km. Using all the detections of rhesus macaque from the survey in maximum entropy algorithm using MaxEnt, we modelled the suitable area for macaques, which was calculated to be **27276.83** km^2. Using the estimate of macaques in the sampled area and the suitable habitat available in each forest division, the population size of rhesus macaque was computed. Population estimation was done using the strip width method, and the estimated population is **1,36,443** macaques in **3336** groups. The overall population appears to have declined when compared to the estimates of 2015. This decline can be accredited to measures taken like mass sterilization and translocation of macaques. Although there has been a decrease in the overall population of macaques, the conflict issue is still a big concern. This issue can only be managed by changing the perception of the people. Further, a synergy between the Forest Department and the local people might help in efficient management of the macaque conflict in the state.

Introduction

India is a megadiverse country which comprises of ten ecoregions four of which are considered a global biodiversity hotspot. Geographical and climatic variations in the region have been responsible for the creation of a variety of ecosystems and habitats. The increasing human population, these habitats have been encroached (Cincotta et al. 2000). This has increased the proximity to human-dominated landscape, and thus interactions between humans and wild animals. Even though many species are only confined to the forests; some species have adapted themselves to live among the human population either by occupying the same habitat or the marginal habitats near the forested areas. These species which are highly adapted to live with humans are called 'commensal species'. Commensalism is an association between two species in which one benefits without either harming or benefiting the latter (Southwick and Siddiqi 1994a, b), with primates being such prominent commensal species. They are usually habitat generalists and occupy various human habitations ranging from urban areas to agricultural fields, temples, tourist spots, and even roadsides. There are 22 species of primates known from India (Molur et al. 2003), of which the bonnet macaque *Macaca radiata*, rhesus macaque *Macaca mulatta*, and Hanuman langur *Semnopithecus* sp. (Southwick and Siddiqi 1994a) are the few common commensal species that have adapted themselves to the human-dominated landscape. Among these, rhesus macaque and Hanuman langurs are widely distributed. Rhesus macaque occurs throughout northern and central India (Southwick and Siddiqi 1994b), where the range of Hanuman langur (now classified as several species) extends from the Himalayas in the north to Sri Lanka in the south and from Bangladesh in the east to Pakistan in the west (Groves 2001). The rhesus macaques occur in high density in the hilly state of Himachal Pradesh, Jammu and Kashmir, Uttarakhand (Ross et al. 1993; Pirta et al. 1997).

Of these hilly states, Himachal Pradesh has been experiencing severe conflict with rhesus macaque. Crop raiding and snatching away of food from the people is severe in Himachal Pradesh (Chauhan and Pirta 2010 a). Many people have stopped cultivation due to the losses incurred by crop-raiding macaques (Singh and Thakur 2012). Heavy economic losses incurred by regional horticulture due to rhesus macaques amplified the human-macaque conflict in the state (Anand et al. 2018; Saraswat et al. 2015). This has become a socio-political issue and prompted the government to invest in mitigation measures, thus various steps have been initiated to control their population and one of that is sterilization of macaques.

Overpopulation of feral and free-roaming animals like macaques is a major problem across the world. Macaques have lost their natural fear of humans over the years due to frequent contact with them in the human-dominated landscapes (Shek and Cheng 2010). This sometimes led to excessive aggressive behaviour shown by animals towards humans usually when seeking food (Lee and Priston 2005). Similar observations have been made in macaques of Ubud Monkey Forest where the aggressive behaviour of the macaques is leading to an intensification of the conflict between primates and humans (Fuentes and Gamerl 2005). Further, close contact between humans and primates may also lead to the transmission of various pathogens due to bite or during contact with macaques' hands when feeding them (Wellem 2014). This issue is even severe in developing countries where religious beliefs and other cultural perspectives impede the implementation of the population control strategies (FAO 2014). Animal welfare, as well as the safety and public health, are affected by the lack of effective population control methods. There are various methods used for controlling the primate population in an anthropogenic habitat (Liu 2011). Chemical or surgical sterilization to control reproductive growth is the most commonly used methods serving as an ethical alternative to culling and translocation (Reddy and Chander 2016; Malaivijitnond et al. 2011; Rattan 2011). A number of methods have been implemented in controlled (captive) as well as wild populations of macaques (Wallace et al. 2016). However, not much is known about the short or long-term effects of these strategies on the wild populations (Wallace et al. 2016; Gray and Cameron 2010). Although, various such sterilization projects and studies have been carried out across the world, however, large scale sterilization is not reported and its impact on the natural population is not clear. The impact of such sterilization drives on the reproduction and survival of a species has remained understudied. Thus, the efficacy of such sterilization drives in controlling population cannot be ascertained. Therefore, it is critical to assess the changes if any in their demography or behaviour for their efficient management and conservation (Jones-Engel et al. 2011; Singh and Kaumanns 2005).

Himachal Forest Department started the sterilization program for rhesus macaque, following the surgical tubectomy and vasectomy as this is a wild population and non-surgical methods such as contraceptive pills or implants are not feasible options. A total of seven sterilization centres have been established in the entire state (Fig 1), wherein 190162 animals were captured between 2006 and 2019, of which 155257 macaques were sterilized (Fig 2). The difference in a number of capture and sterilization was due to some individuals who were either juveniles or pregnant females who cannot be sterilized. Also, already sterilized

individuals could also be recaptured but are released without re-sterilization. Out of these sterilized animals, 80275 were males and 74982 were females (Fig 3). The sterilized macaques were relocated to the natural habitat.

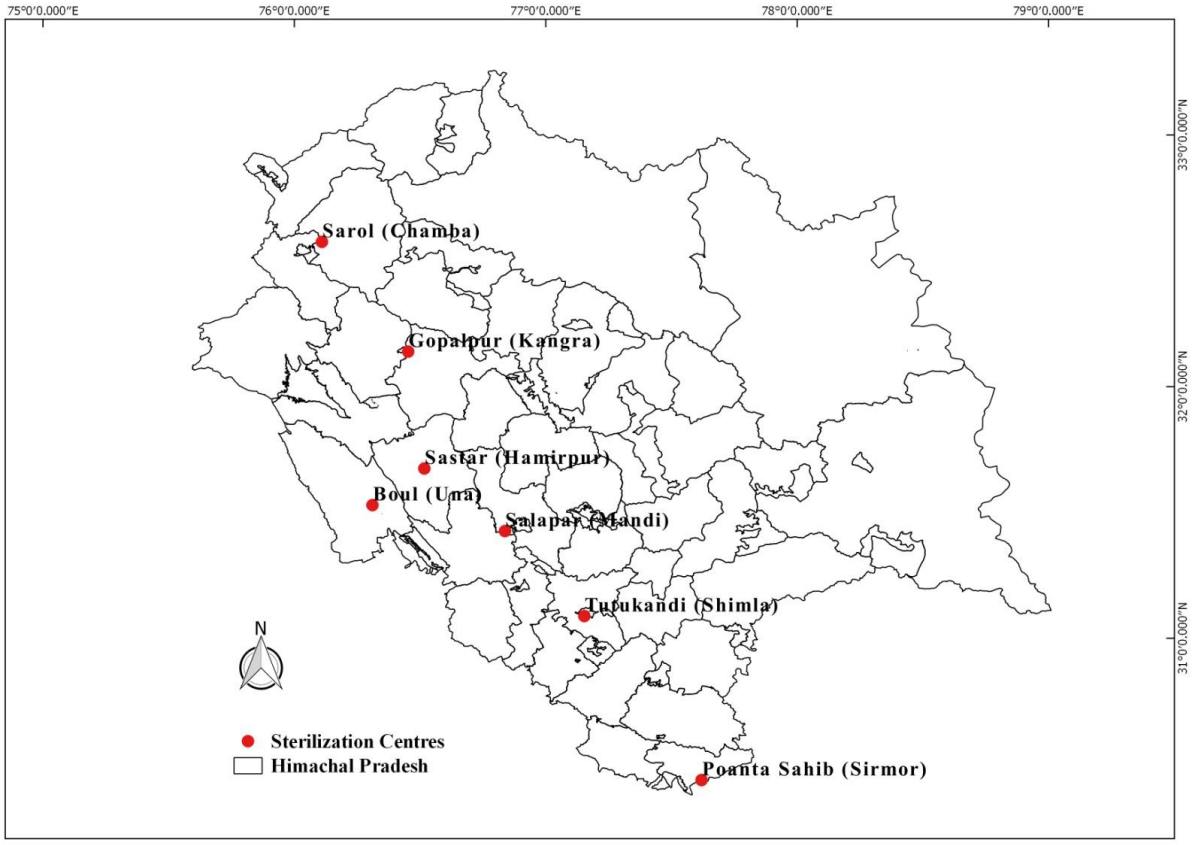


Figure 1. Location of the sterilization centres in Himachal Pradesh

Understanding of the consequences of such sterilisation on population comes from periodic monitoring. The Forest Department of Himachal Pradesh has initiated such monitoring program in the state as they also have been doing the sterilisation of macaque over period of 14 years. The current report is of the state level population assessment of rhesus macaque made in December 2019.

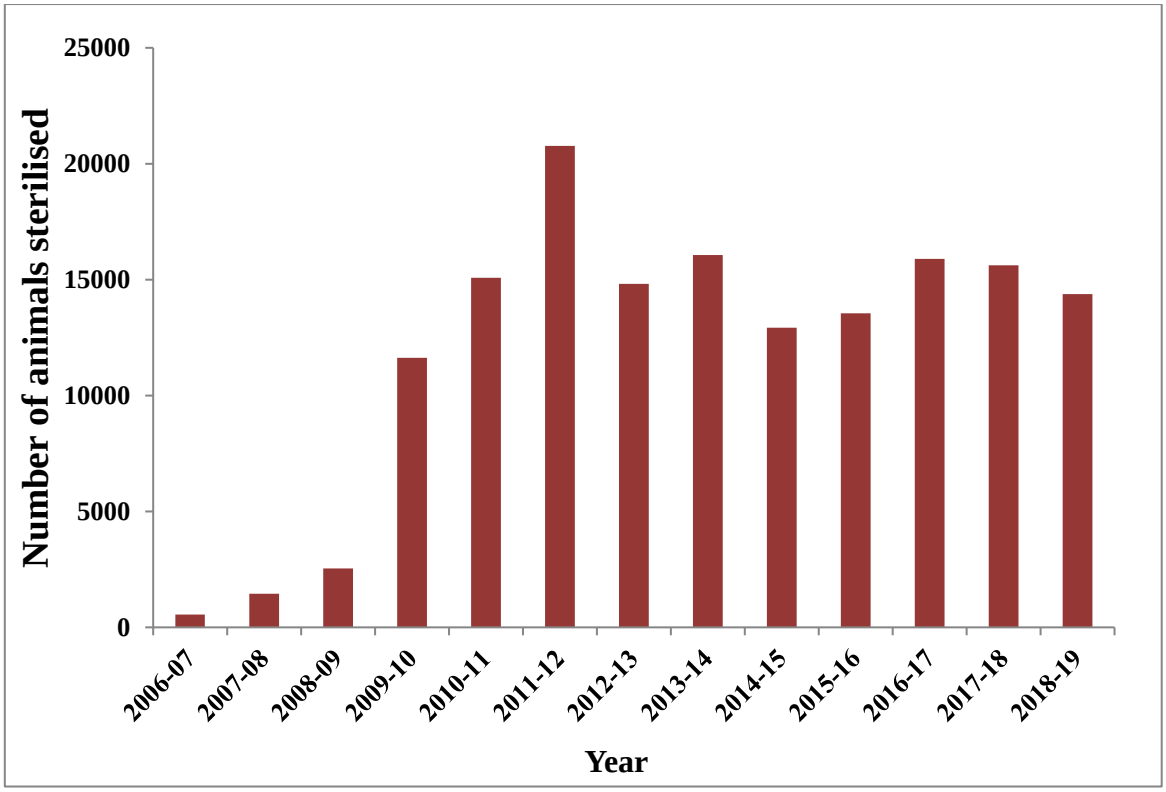


Figure 2 Sterilisation of rhesus macaques between 2006 and 2019 in Himachal Pradesh

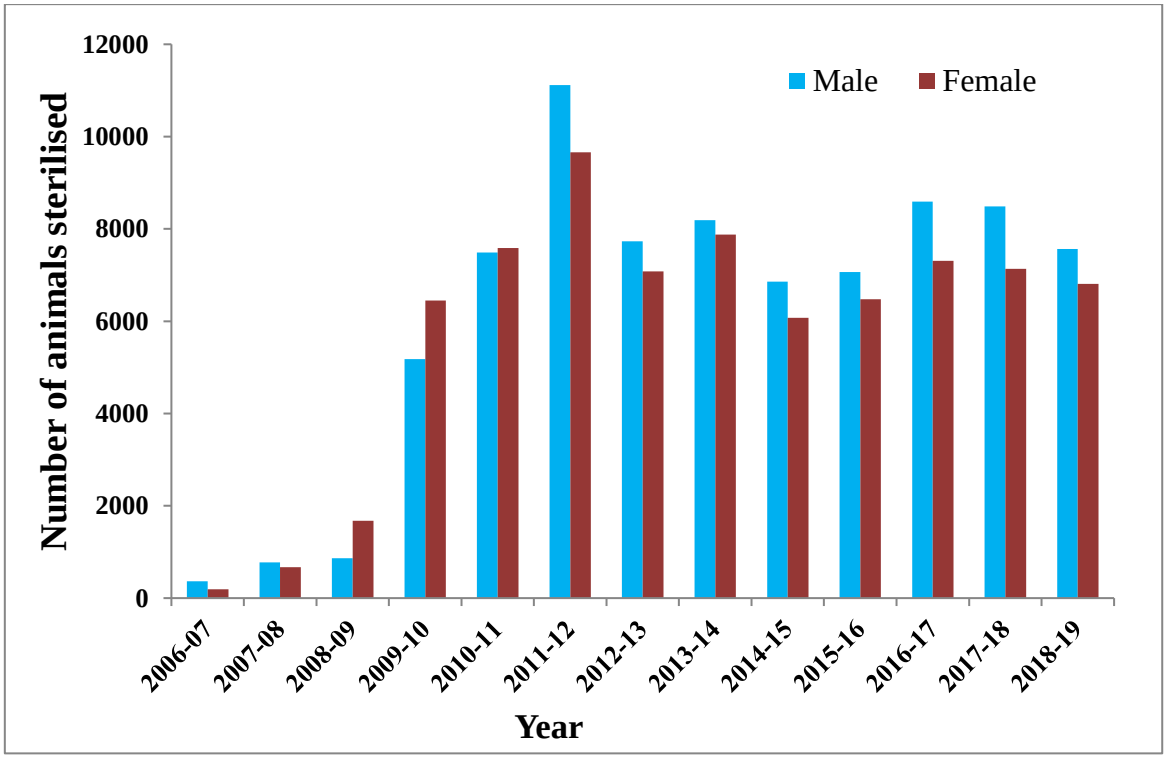


Figure 3 Sterilization of male and female rhesus macaques between 2006 and 2019 in Himachal Pradesh

2.1 Survey method

The terrain of Himachal Pradesh comprises of highly undulating mountain ranges of the Himalayas, hence straight line transects were not possible. Hence in each forest beat, two to three existing trails or animal pathways were selected for sampling the macaques (Fig 4). The trails were walked by the forest department personnel along with one local assistant. A total of 2795 trails were walked consecutively for three days between 06:00 hr and 11:30 hr. The total kilometre walked was amounted to 23440 km. Each trail was recorded from starting point to end point using the track record option in the handheld global position system.

The study involved visual counts of animals (Karanth and Nichols, 2002; Jathanna et al. 2003) which is an extensively used method for estimating abundance. For each sighting of macaques (detection of a 'cluster') recorded, the coordinates of the observer using hand held GPS, number of individuals sighted, age and sex of the individuals, observer–animal distance (r) and sighting angle were recorded. During the walk each sighting of the macaque was recorded in the data sheet with total count and age-sex of the visible individuals. The habitat type of the location of the sighted group was recorded.

2.2. Estimation of Suitable habitat for rhesus macaque: A total of 4699 occurrence records of rhesus macaque was obtained. These records were used to obtain model of the 'realized niche' (possible extent of the niche of species) using maximum entropy algorithm available in MaxEnt 3.3.3k (Phillips and Dudik 2008).

Environmental Coverage Variables: To achieve a suitable model for habitat, 22 environmental variables were used of which 18 were bioclimatic and 3 were altitude, slope and ruggedness index (Table 1). Bioclimatic and altitude layers were acquired from global climate data repository (www.worldclim.org). Slope and ruggedness index layers were generated from altitude layer by using digital terrain modelling module in QGIS Pisa (v 2.10). All layers were of 1 km spatial resolution. Maximum entropy algorithm using MaxEnt (Phillips and Dudik 2008) was utilised to achieve the probability distribution model of rhesus macaque across the environmental layers. Model was set with random test percentage of 25 % and output of 5 models run separately was averaged to obtain final model.

2.3. Population estimation: Keeping 5 km^2 as average home range size for the rhesus macaques, we created 1.26 radial distance from trail, hence the strip width was calculated to

be 2.52 km. As the surveyed trails were existing paths, they were found to be meandering and had no uniform shape. Assuming trails as straight paths and using area of rectangle would have overestimated sampled area. Hence, we created buffer of 1.26 km radial distance from each trail and clipped semicircles from start and end of trails to get actual surveyed area. Buffers were overlaid using QGIS v 3.10. The mean number of groups was calculated using three temporal replications. The macaque group density was calculated by proportionating the group density to the effective strip area calculated. The mean group size was multiplied with the density of groups to calculate the density of macaque individuals. The density of macaque from all trails was pooled division wise and we computed the mean density of macaques. The suitable area estimated by the MaxEnt for each circle or division which provided the suitable habitat available in each circle or division was multiplied with the mean density of macaques to obtain the total population size for each division.

Table 1. Environmental layers used to build the habitat suitability model using MaxEnt.

Layer	Discription
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter
ALT	Altitude
SLP	Slope
RI	Ruggedness Index

2.4 Population estimation using Distance Sampling

The distance data was analysed using 'DISTANCE' software v. 7.3 and the density was computed. The animal detection data from the replicated trails were pooled and treated as a single sample for different divisions. The measure of parsimony among competing models was examined using Akaike's information criterion (AIC) values (Focardi et al. 2002) that give an agreement between the quality of fit and the number of model parameters to achieve the model, generated by the program DISTANCE. The best possible model with lowest AIC values was then selected (Burnham et al. 1980; Buckland et al. 1993). We estimated encounter rate (n/l), average probability of detection (p), cluster density (D), using the selected model in 'Distance'. Depending on the outliers, the detection distances for each species were truncated to achieve the best fitted model as AIC cannot be used to choose between models that have different truncation distances (Buckland et al. 1993; Buckland et al. 2001). Outliers are truncated to fit the best fit line to achieve the best estimate (Buckland et al. 2001). Using this technique, the density estimation was done using distance software for few circles in order to check the viability of the procedure for the given area. It was found that the estimation was giving unreliable results due to various reasons. The selection of the trails should be random and not based on the previous knowledge of the animals. The trails should not be selected only in the areas where the presence of the animals is already known. Also due to the altitude of the area and the terrain which is highly undulating, the trails are not straight lines which give an additional bias to the estimation. The distance calculated by the observer also gets affected when the trails were placed on the undulating mountains, which in turn affects the perpendicular distance between the observer and the animal sighted affecting the total estimation. The estimation hence gave an over estimation of the macaques in the area and hence the methodology was discarded and the earlier (in 2015-16) used fixed strip methodology was used for the current estimation.

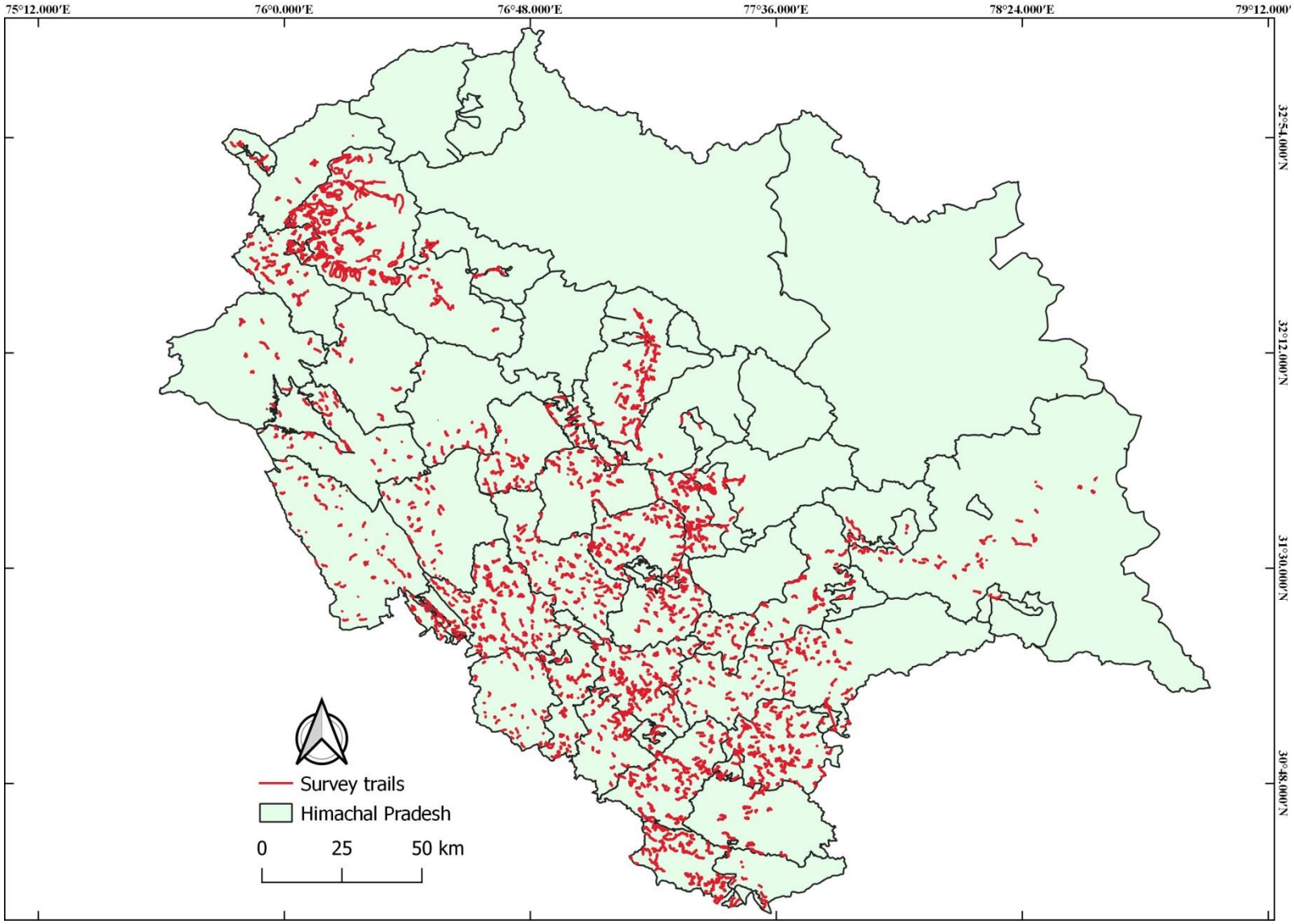


Figure 4 Trails used to survey the rhesus macaque during the 2019 state level macaque census

Population Estimation of Rhesus Macaques in Himachal Pradesh

The estimated realized niche model using MaxEnt provided an area of 27276.83 km^2 (Fig 5) suitable for rhesus macaque habitation in Himachal Pradesh. MaxEnt model revealed that temperature seasonality (Bio4, percent contribution = 25.8) and annual precipitation (Bio12, percent contribution = 23.2) were most important determinants for predicting habitat suitability. The northern parts of Himachal Pradesh were unsuitable for the macaques due to the extreme temperature seasonality. Central, western and eastern divisions of Himachal Pradesh were predicted to be highly suitable for rhesus macaques, while northern divisions of Pangi, Lahaul and Spiti, Kinnaur, GHNP wildlife and Kullu wildlife have low suitability. Habitat suitability maps for each division are given in appendices.

A total of 4746 groups were observed along 23440 km of walk across the state except the Pangi division. The mean overall group density was estimated to be 0.17 groups km^{-2} with minimum group density in Dehra and Rohru divisions (0.01 groups km^{-2} each) and maximum group density in Kunihar division (1.04 groups km^{-2}). Extrapolating group density with predicted suitable area and average group size observed, the total population of rhesus macaque was estimated to be 1,36,443 individuals (Table 2) in 3336 groups with lowest population in Hamirpur wildlife division (37 individuals) and highest in Una division (10123 individuals). The wild population of animals in the state was estimated to be 1,05,627 individuals. Division-wise estimates of rhesus macaque population are provided in Table 2.

When compared to the estimates of 2015 census, the overall population in Himachal Pradesh appears to have declined in the last four years (Table 3). The overall intrinsic rate of change of -0.08 was observed in the population. Intrinsic rate showed maximum decline of the population in GHNP (-0.51) followed by Rohru division (-0.44), Chopal division (-0.42) and Hamirpur wildlife division (-0.36), however is not that significant in Mandi division (-0.01) and Nachan division (-0.05). However, in some divisions *viz*. Solan, Nalagarh, Sarhan wildlife sanctuary, Theog, Rampur, Kotgarh, Kinnaur, Parvati, Poanta Sahib, Churah and Shimla urban an increase in the overall population has been observed.. Intrinsic rate showed maximum increase in Kotgarh division (0.29) followed by Parvati division (0.24) and Poanta Sahib (0.21), however in Bharmaur and Chamba wildlife division (0.01 each) the increase was not that steep. Figure 6 shows the rate of change of macaque population in all the

divisions. As population estimation exercise was not conducted in Pangi division during 2019 survey, it has been omitted from current results.

A Comparative Inverse Distance Weighted Interpolation of density estimates of rhesus macaques in Himachal Pradesh in the year 2015 and 2019 is given in figure 7 wherein hotspot areas of high density are depicted in dark color. When compared to hotspot analysis from 2015, it can be seen that most of the hotspots are the same with Shimla Urban division showing highest probability. Due to geo-referencing error in group locations, hotspots in Una and Nurpur division could not be predicted due to which they are not depicted on the map.

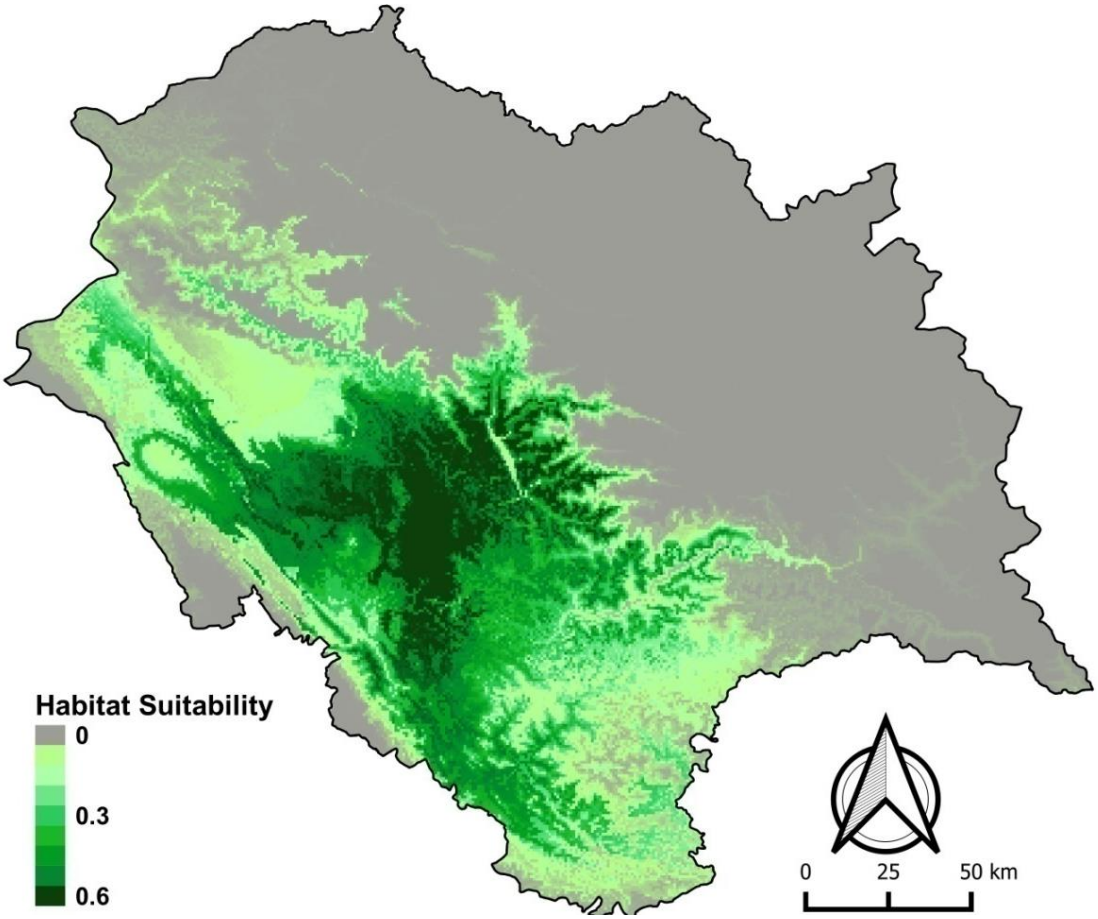


Figure 5. The modelled suitable habitat of rhesus macaque in different Forest Divisions of Himachal Pradesh

Table 2. Population estimation of rhesus macaque in Himachal Pradesh

DIVISION	Density (Macaque groups per km^2)	Number of groups observed	Standard deviation	Average group size	Population in the estimated area	Urban Population	Total Population
Bilaspur circle							
BILASPUR	0.14	274	0.19	33	4807	3185	7992
KUNIHAR	1.04	55	0.08	38	2011	2321	4332
Chamba circle							
BHARMAUR	0.06	29	0.07	35	1191	730	1921
CHAMBA	0.10	163	0.13	38	4387	0	4387
CHURAH	0.16	108	0.08	31	2685	658	3343
DALHOUSIE	0.25	167	0.13	40	6458	871	7329
Dharamshala circle							
DHARAMSHALA	0.09	213	0.09	36	3084	2013	5097
NURPUR	0.15	243	0.14	30	6240	1478	7718
PALAMPUR	0.13	137	0.16	31	4577	1158	5735
Dharamshala Wildlife North Circle							
CHAMBA WL	0.06	26	0.14	32	292	131	423
HAMIRPUR WL	0.03	11	0.11	10	37	0	37
GHNP Circle							
GHNP	0.02	15	0.05	14	60	102	162
KULLU WL	0.06	57	0.07	26	969	0	969
Hamirpur Circle							
DEHRA	0.01	6	0.02	35	238	2743	2981
HAMIRPUR	0.09	99	0.09	25	2394	970	3364
UNA	0.21	149	0.30	31	10123	0	10123
Kullu Circle							
KULLU	0.20	236	0.19	16	2165	157	2322
PARVATI	0.19	97	0.17	10	1103	25	1128
SERAJ	0.10	103	0.09	22	750	259	1009
LAHAUL	-	-	-	-	-	-	-
Mandi circle							
JOGINDERNAGAR	0.09	128	0.08	38	2046	862	2908
KARSOG	0.08	89	0.07	38	1705	0	1705
MANDI	0.13	185	0.14	38	3921	0	3921
NACHAN	0.12	81	0.12	34	2459	70	2529
SUKET	0.09	131	0.13	42	3254	1618	4872
Nahan Circle							
NAHAN	0.13	185	0.09	39	2534	1736	4270
PAONTA SAHIB	0.31	233	0.31	35	5135	835	5970
RAJGARH	0.06	80	0.21	38	1724	1417	3141
RENUKA JI	0.06	60	0.08	27	1496	3314	4810
Rampur circle							
ANNI	0.07	55	0.16	23	972	242	1214
KINNAUR	0.05	26	0.07	32	824	0	824
KOTGARH	0.51	136	0.25	16	2098	194	2292
RAMPUR	0.18	135	0.25	27	3172	975	4147

Shimla Circle							
CHOPAL	0.03	48	0.06	27	624	0	624
ROHRU	0.01	8	0.02	49	772	73	845
SHIMLA	0.16	196	0.22	38	3374	770	4144
SHIMLA URBAN	0.59	250	0.48	26	1638	0	1638
THEOG	0.20	77	0.14	21	2618	80	2698
Shimla Wildlife South							
SARHAN WL	0.18	64	0.20	29	1115	0	1115
SHIMLA WL	0.17	51	0.40	22	670	0	670
SPITI	-	-	-	-	-	-	-
Solan Circle							
SOLAN	0.32	256	0.29	33	5522	1356	6878
NALAGARH	0.16	84	0.13	38	4383	473	4856
Total estimated population					**105627**		**136443**

Table 3. Change in the population of rhesus macaque between 2015 and 2019

DIVISION	Average Group Size	2015	2019	Intrinsic rate (r)
Bilaspur circle				
BILASPUR	33	13810	7992	-0.14
KUNIHAR	38	6035	4332	-0.08
Chamba circle				
BHARMAUR	35	1839	1921	0.01
CHAMBA	38	7888	4387	-0.15
CHURAH	31	2756	3343	0.05
DALHOUSIE	40	10869	7329	-0.10
PANGI	-	2764		
Dharamshala circle				
DHARAMSHALA	36	8884	5097	-0.14
NURPUR	30	14931	7718	-0.16
PALAMPUR	31	8676	5735	-0.10
Dharamshala Wildlife North Circle				
CHAMBA WL	32	419	423	0.01
HAMIRPUR WL	4	154	37	-0.36
GHNP Circle				
GHNP	14	1231	162	-0.51
KULLU WL	26	1611	969	-0.13
Hamirpur Circle				
DEHRA	35	6246	2981	-0.18
HAMIRPUR	25	5541	3364	-0.12
UNA	31	18174	10123	-0.15

Kullu Circle				
KULLU	16	3052	2322	-0.07
LAHAUL	-	-	-	-
PARVATI	10	424	1128	0.24
SERAJ	22	2088	1009	-0.18
Mandi circle				
JOGINDERNAGAR	38	4609	2908	-0.12
KARSOG	38	3611	1705	-0.19
MANDI	38	4128	3921	-0.01
NACHAN	34	3129	2529	-0.05
SUKET	42	7797	4872	-0.12
Nahan Circle				
NAHAN	39	5743	4270	-0.07
PAONTA SAHIB	35	2546	5970	0.21
RAJGARH	38	9905	3141	-0.29
RENUKA JI	27	12466	4810	-0.24
Rampur circle				
ANNI	23	3015	1214	-0.23
KINNAUR	32	575	824	0.09
KOTGARH	16	730	2292	0.29
RAMPUR	27	2465	4147	0.13
Shimla Circle				
CHOPAL	27	3293	624	-0.42
ROHRU	49	4855	845	-0.44
SHIMLA	38	5580	4144	-0.07
SHIMLA URBAN	26	1166	1638	0.08
THEOG	21	2092	2698	0.06
Shimla WL South Circle				
SARHAN WL	29	673	1115	0.13
SHIMLA WL	22	964	670	-0.09
SPITI	-	-	-	-
Solan Circle				
NALAGARH	33	3114	4856	0.11
SOLAN	38	5319	6878	0.06
Total		**205167**	**136443**	**-0.08**

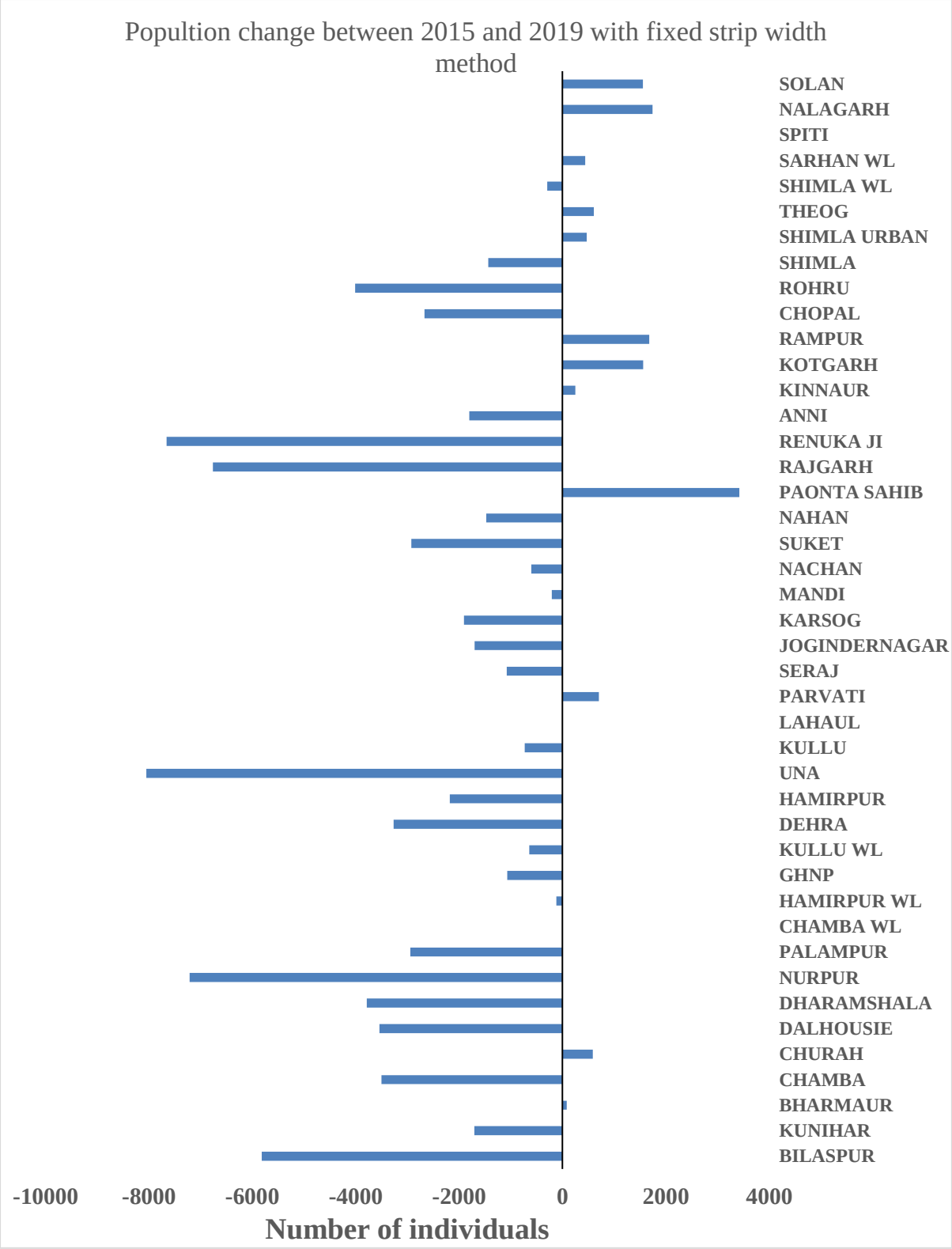


Figure 6. The change in the rhesus macaque population between 2015 and 2019

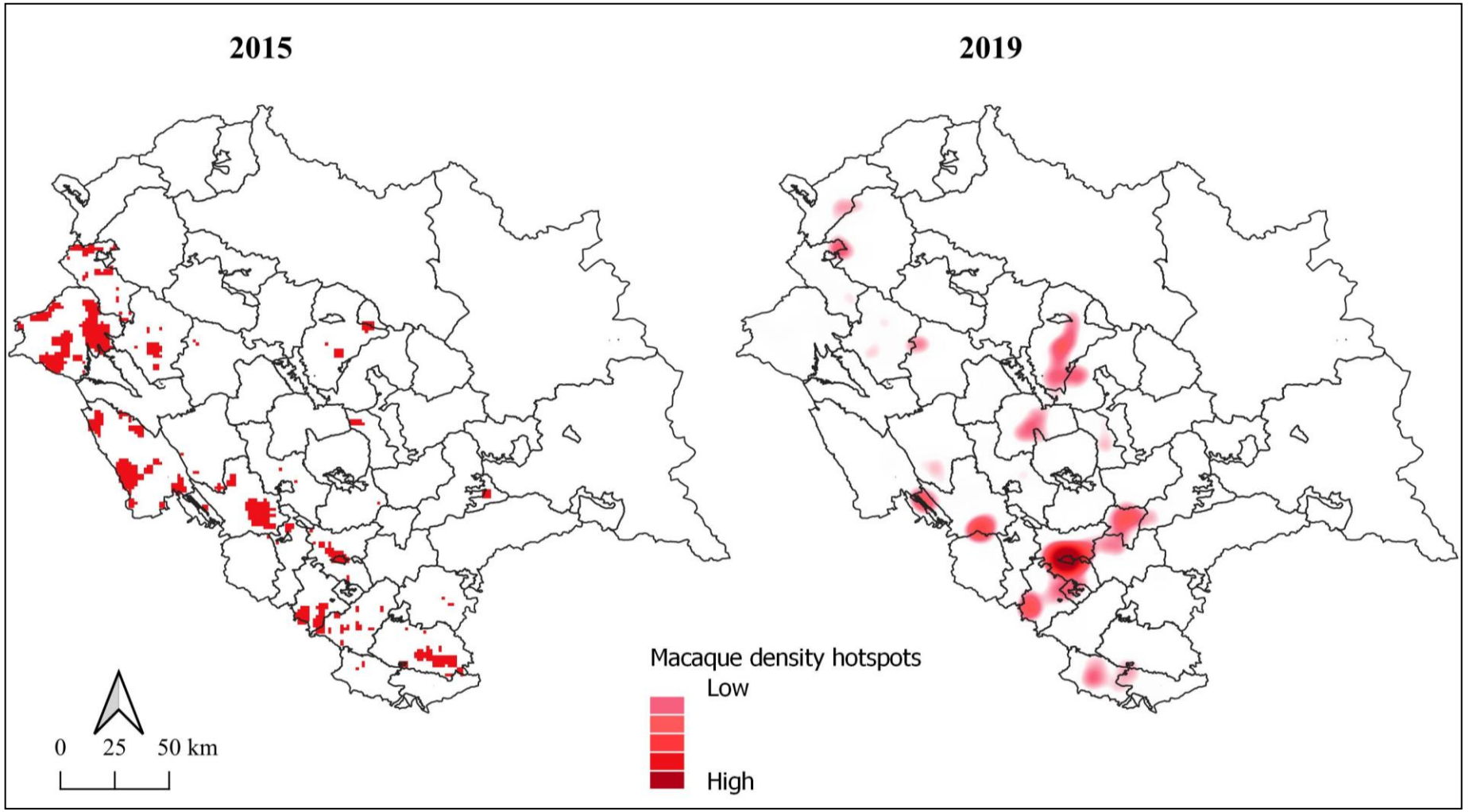


Figure 7. Comparative Inverse Distance Weighted Interpolation of density estimates of rhesus macaques in Himachal Pradesh in the year 2015 and 2019.

There has been a drastic decrease in the rhesus macaque population in the last four years however, the population in divisions of Solan, Nalagarh, Sarhan Wildlife Sanctuary, Theog, Rampur, Kotgarh, Kinnaur, Parvati, Poanta Sahib, Churah and Shimla urban has increased. Rest of the divisions have shown decline from the 2015 census. Although there is increase in population in some areas, the decrease is significant in the entire state. This overall decrease in the population size can be attributed to the gradual controlling of the population growth by sterilization program, emigration of the individuals and culling of the animals by locals after the declaration as vermin in the last one year. During the state level population assessment of macaques, we came across report of culling of macaque by local people, however, same is not reported or recorded. Thus, the number of culling incidents and also number of individuals culled could not be ascertained. Probably, culling in many areas in the state has also led to a decrease in the overall number of macaques.

Limitations of the current study

- The population assessment was carried out was based on principals of distance sampling. Distance sampling estimates effective strip width based on fitted detection function. For accurate fitting of detection function, it assumed that transects are of regular shape and distances are recorded with utmost accuracy. However, due to highly convoluted shapes of trails and non-accurate documentation of angular distance and bearings, fitting proper detection function was not possible and Distance (V7) estimate was highly biased. Hence traditional encounter rate method with fixed strip width was employed.
- Further, GIS data of beat boundaries and trails and observations recorded did not match. Many trails were found to be crossing beat, range and division boundaries. Further, recordings of trails and observations through improperly calibrated GPS units resulted in misrepresentation of the data as many points were falling out of the boundary of Himachal Pradesh. This prevented use of spatial modeling as it was difficult to geo-reference the trail data.
- Information about group size was highly unreliable. Recordings of same number of individuals in a group during the replication is not possible, it indicates the human bias added to the number estimation.

Mitigation measures

Although human macaque interface is age old, there has been a sharp increase in reporting of human primate conflict studies in past 20-30 years. Human primate conflict has been reported from Himachal Pradesh since 1977 (Roonwal and Monhot 1977). This has partly due to sharp increase in the human and rhesus macaque population in the region which has forced humans and macaques to compete for finite natural resources. Crop loss and attacks by rhesus macaque on humans have increased over the years and estimated economic loss to state. High behavioural plasticity and generalist nature of rhesus macaques enables them to adapt to environmental changes quickly. Due to this, many mitigation measures although effective initially tend to fail over long period.

To curb this Himachal Pradesh Forest department have already employed numerous solutions such as sterilization of macaques, large scale garbage management drive, public awareness campaign and strategic trapping and extirpation. Although these have helped in reduction of population of rhesus macaques, there is still major public outcry about conflict with rhesus macaques. Recent studies show that the prolonged conflict leads to people perception about rhesus macaques is negative (Chauhan and Pirta 2010 b; Saraswat et al. 2015). Priston and Mclennen (2013) reported people having paradoxical opinion towards rhesus macaques due to contrasting religious beliefs and psychological suffering due to economic loss.

Guiding principles for managing human wildlife conflict tell us that, sustainable management requires understanding perception of conflict as well as employing multiple and adaptive tools (Madden, 2004). To achieve this, we formulated following mitigation measures.

1. Improving existing population control: Himachal Pradesh Forest Department has established 9 sterilization centres where laser assisted tubectomy and vasectomy is performed on captured macaques. Since year 2006, total of 1,55,257 macaques have been sterilized. Monitory incentives are given to locals for capturing and re-releasing of the macaques. As macaques are captured from far away locations and brought to sterilization centres, reach of each centre is limited, and also further the random re-release of them probably has affected their social organisation and unexpected over crop raiding pattern. To avoid this, the proper release of them at their original locations has to be ensured.

However, the massive sterilisations drive has been effective in regulating population growth of macaques through prevention of subsequent births of progenies. A rough statistical model

shows prevention of about 5-6 lakh new births which has a cumulative effect in overall population growth of the species in the last 14 years.

2. Management of crop raiding: Behavioural plasticity of rhesus macaque enables it to learn and overcome any obstacles. Due to this adaptability, many preventive measures are rendered ineffective if used for prolonged period. Also, strategies or pattern of crop raiding varies between different groups and different sites. Hence, a turnkey based hard intervention such repellent devices, high frequency sound emitters etc might not work equally at different places. One of the most effective methods found is physically driving macaques away or regular patrolling.

3. Social programmes for livelihood diversification of affected community and Awareness generation: Communities which are dependent on crops which are frequently raided by macaques should be provided with alternative source of livelihood. Having multiple sources of livelihood will ensure that crop loss due to macaques will not drastically affect the livelihood of the communities. This can be done through developing eco-tourism, cultivation of non-food crops and value addition to existing produce to maximise economic returns. Backward and forward market linkages should be assessed for such interventions. Further, management of perception of conflict is equally important. Public should be made aware of existing interventions being carried out. Further synergy between forest department and citizens can be established through regular dialogues at village, district and state level representatives.

Currently, forest department has been conducting awareness drives with local residents and tourists. As tourism if one of the key sectors in the state, it was essential to educate the tourists to stop deliberate provisioning of the macaques by not throwing/ offering eatables to monkeys. Further, state wide development in transport infrastructure has resulted in reduction of stoppage of tourists along the highways thus preventing provisioning. Awareness about social organization or documented unique behaviours of the macaques can be used as tourist attraction.

4. Solid waste (kitchen waste management): In most of the Municipal corporation areas and other areas specifically having large number of human habitations, the door-to-door garbage collection and kitchen waste management has probably forced sizable macaque populations to migrate to the forests. More efforts are required in this direction so that the kitchen waste and the waste generated by various eateries is well managed.

6. Habitat enrichment: The effort of the department to increase the quality of the habitat of macaques through taking up plantation model comprising of plantation of mandatory 30% fruit trees (at least) has also probably lead to bringing down the rhesus macaque population. This effort has been further complemented by implementing plantation schemes such as 'Habitat Enrichment Plantations'

References

Anand, S., Binoy, V. V., and Radhakrishna, S. (2018). The monkey is not always a god: Attitudinal differences toward crop-raiding macaques and why it matters for conflict mitigation. *Ambio*, 47:711-720.

Buckland, S. T., Anderson, D. R., Burnham, K. P. and Laake, J. L. (1993). *Distance Sampling: Estimating Abundance of Biological Populations*, Chapman and Hall, London.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. and Thomas, L.(2001).*Introduction to Distance Sampling: Estimating Abundance of Biological Populations*, Oxford University Press, Oxford.

Burnham, K. P., Anderson, D. R. and Laake, J. L. (1980). Estimation of density from line transects sampling of biological populations. *Wildlife Monographs*, 72: 3-202.

Chauhan, A., and Pirta, R. S. (2010). Agonistic interactions between humans and two species of monkeys (rhesus monkey *Macaca mulatta* and Hanuman langur *Semnopithecus entellus*) in Shimla, Himachal Pradesh. *Journal of Psychology*, 1:9–14.

Chauhan, A., and Pirta, R. S. (2010). Socio-ecology of two species of non-human primates, rhesus monkey (Macaca mulatta) and Hanuman langur (Semnopithecus entellus), in Shimla, Himachal Pradesh. *Journal of Human Ecology*, 30: 171-177.

Cincotta, R. P., Wisnewski, J., and Engelman, R. (2000). Human population in the biodiversity hotspots. *Nature*, 404: 990-992.

FAO. 2014. Dog population management. Report of the FAO/WSPA/IZSAM expert meeting - Banna, Italy, 14-19 March 2011. Animal Production and Health Report. No. 6. Rome

Focardi S., Isotti, R. and Tinelli, A. (2002). Line transect estimates of ungulate populations in a mediterranean forest. Journal of Wildlife Management, 66: 48–58.

Fuentes, A., andGamerl, S. (2005). Disproportionate participation by age/sex classes in aggressive interactions between long-tailed macaques (*Macaca fascicularis*) and human tourists at Padangtegal monkey forest, Bali, Indonesia. *American Journal of Primatology: Official Journal of the American Society of Primatologists*, 66:197-204.

Gray, M. E., and Cameron, E. Z. (2010). Does contraceptive treatment in wildlife result in side effects? A review of quantitative and anecdotal evidence. *Reproduction*, 139: 45–55

Groves, C. P. (2001). *Primate taxonomy*. Smithsonian Institution Press, Washington DC.

Jathanna, D., Karanth, K. U., and Johnsingh, A. J. T. (2003). Estimation of large herbivore densities in the tropical forests of southern India using distance sampling. *Journal of Zoology*, 261: 285-290.

Jones-Engel, L., Engel, G., Gumert, M. D., and Fuentes A. (2011). Developing sustainable human- macaque communities. In: Gumery, M. D., Fuentes, A. and Jones-Engel, L. (eds). Monkeys on the edge: *Ecology and management of long-tailed macaques and their interface with humans* (295-326 pp.). Cambridge, England: Cambridge University Press

Karanth, K. U., and Nichols, J. D. (Eds.). (2002). *Monitoring tigers and their prey: a manual for researchers, managers, and conservationists in tropical Asia*. Centre for Wildlife Studies.

Lee, P. C., and Priston, N. E. (2005). Human attitudes to primates: perceptions of pests, conflict and consequences for primate conservation. *Commensalism and Conflict: The Human-primate Interface*, 4: 1-23.

Liu, I. K. M. (2011). A synopsis on contraception in wildlife and feral animal. *Revistabrasileira de reprodução animal*, 35: 77-79.

Madden, F. (2004). Creating coexistence between humans and wildlife: global perspectives on local efforts to address human–wildlife conflict. *Human dimensions of wildlife*, 9: 247-257.

Malaivijitnond, S., Vasquez, Y. and Hamada, Y. (2011). Human impact on long-tailed macaques in Thailand. In: Gumert, M. D., Fuentes, A. and Jones-Engel, J. (eds). *Monkeys on the edge Ecology and management of long-tailed macaques and their interface with humans* (pp.118-158). Cambridge, England: Cambridge University Press.

Molur, S., Brandon-Jones, D., Dittus, W., Eudey, A., Kumar, A., Singh, M., Feeroz, M. M., Chalise, M., Priya, P., and Walker. S. (2003). "*The status of South Asian primates*: conservation assessment and management plan (CAMP) workshop report."

Phillips, S. J. and Dudík, M. (2008). Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation.*Ecography,* 31: 161-175.

Pirta, R. S., Gadgil, M., and Kharshikar, A. V. (1997). Management of the rhesus monkey Macaca mulatta and Hanuman langur Presbytis entellus in Himachal Pradesh, India. *Biological Conservation*, 79:97-106.

Priston, N. E., and McLennan, M. R. (2013). Managing humans, managing macaques: Human–macaque conflict in Asia and Africa. In *The macaque connection* (pp. 225-250). Springer, New York, NY.

Rattan, S. (2011). Managing human-macaque conflict in Himachal, India. In: Gumert, M. D., Fuentes, A., Jones-Engel, J. (eds). *Monkeys on the edge: Ecology and management of long-tailed macaques and their interface with humans* (pp. 283-285). Cambridge, England: Cambridge University Press.

Reddy, A. R. M., andChander, J. (2016). Human-Monkey Conflict in India: Some Available Solutions for Conflict Mitigation with Special Reference to Himachal Pradesh. *The Indian Forester*, 142: 941- 949.

Roonwal, M. L., andMohnot, S. M. (1977). *Primates of South Asia: ecology, sociobiology, and behavior*. Cambridge, Mass.: Harvard University Press.

Ross, C., Srivastava, A., and Pirta, R. S.(1993). Human influences on the population density of Hanuman langurs Presbytis entellus and rhesus macaques *Macaca mulatta* in Shimla, India. *Biological Conservation*, 65: 159-163.

Saraswat, R., Sinha, A., and Radhakrishna, S. (2015). A god becomes a pest? Human-rhesus macaque interactions in Himachal Pradesh, northern India. *European Journal of Wildlife Research, 61*: 435-443.

Shek, C. T., and Cheng, W. W. (2010). Population survey and contraceptive/neutering programme of macaques in Hong Kong. *Honk Kong Biodiversity*, 19: 4-7.

Singh, V., and Thakur, M. L. (2012). Rhesus macaque and associated problems in Himachal Pradesh, India. *Tapro*, 4:112–116

Singh, M., and Kaumanns, W. (2005). Behavioural studies: A necessity for wildlife management. *Current Science*, 89: 1230-1236.

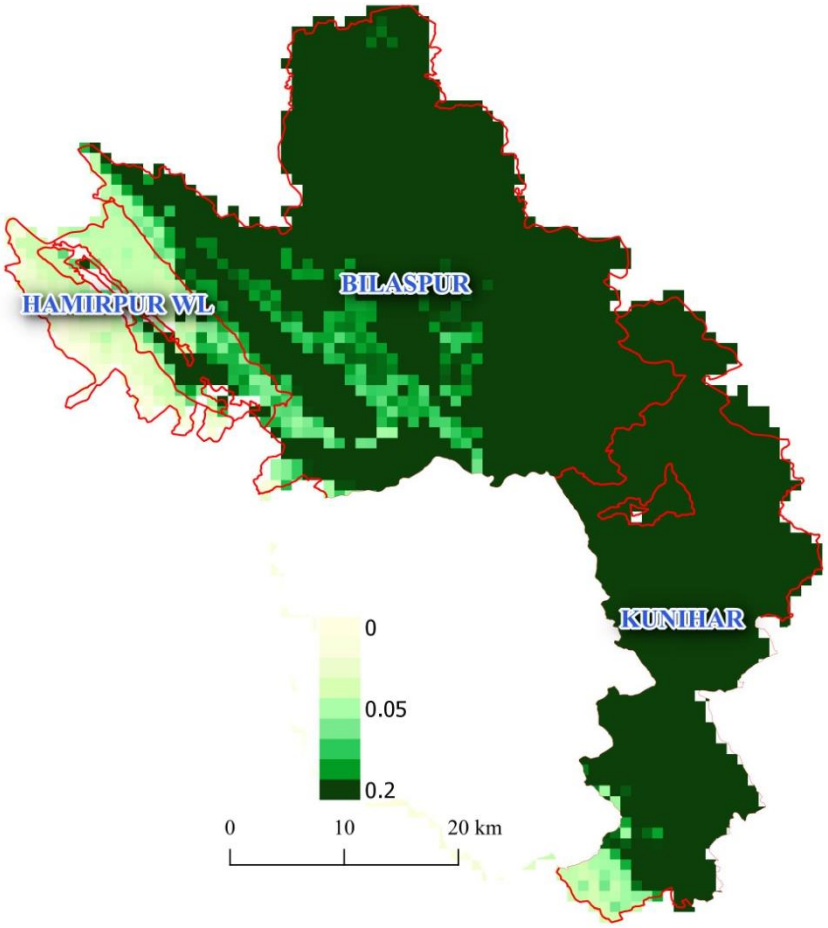
Southwick, C. H., and Siddiqi, M. F. (1994a). Population status of nonhuman primates in Asia, with emphasis on rhesus macaques in India. *American Journal of Primatology*, 34: 51-59.

Southwick, C. H., and Siddiqi, M. F. (1994b). Primate Commensalism: The Rhesus Monkey in India. *Revue d' Ecologie*, 49: 223-31.

Wallace, P.Y., Asa, C.S., Agnew, M., Cheyne, S.M. (2016). A review of population control methods in captive-housed primates. *Animal Welfare*, 25: 7-20.

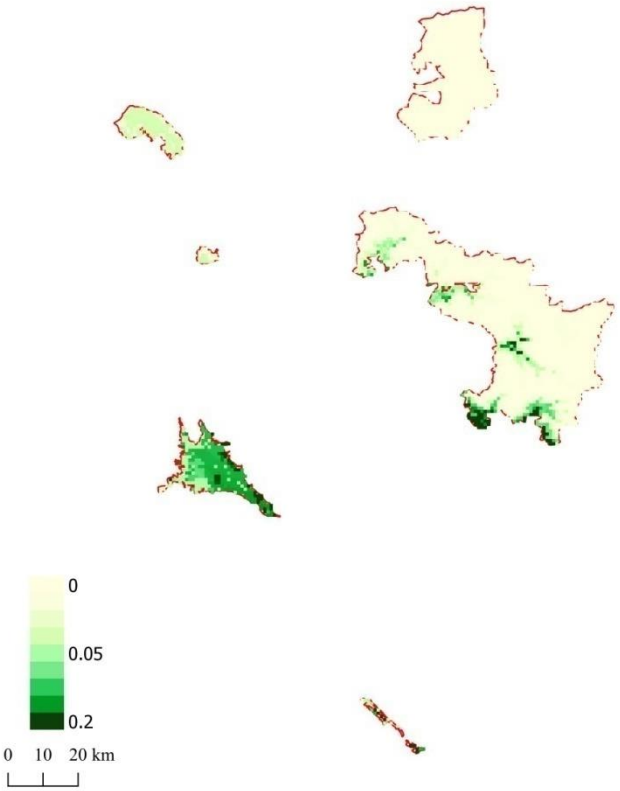
Wellem, C. W. W. (2014). *A review of the management measures of feral macaques in Hong Kong*. University of Hong-Kong.

Bilaspur Circle



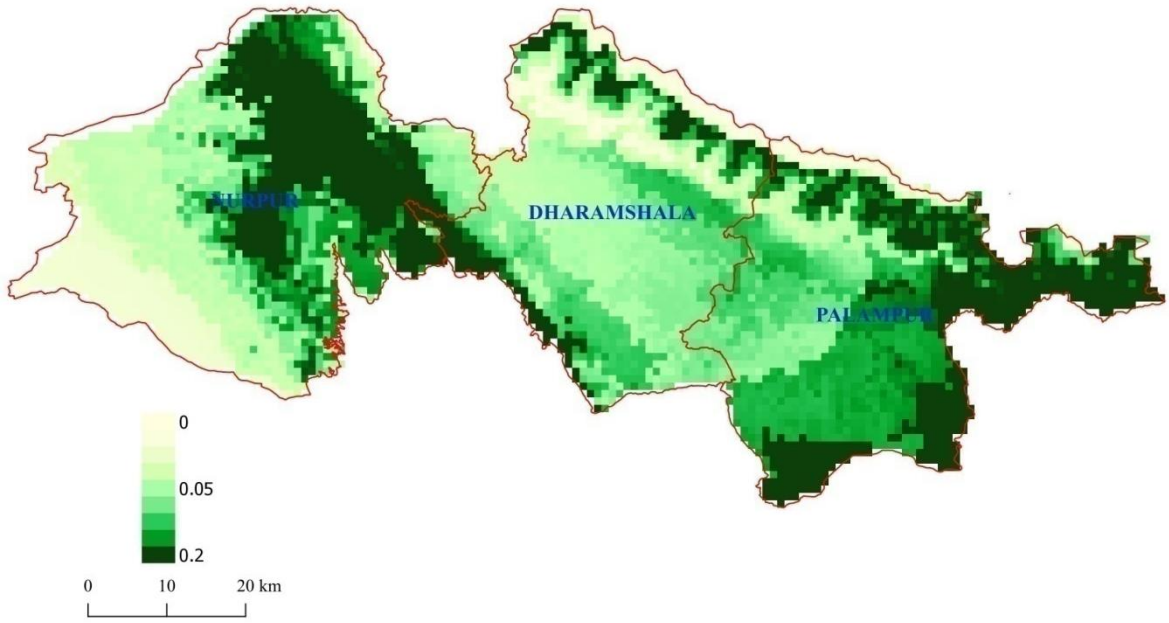
DIVISION	Density (strip area)	Average group size	2015	2019
BILASPUR	0.09	33	13810	7992
KUNIHAR	0.04	38	6035	4332
Total			**23923**	**12324**

Dharamshala Wildlife North Circle



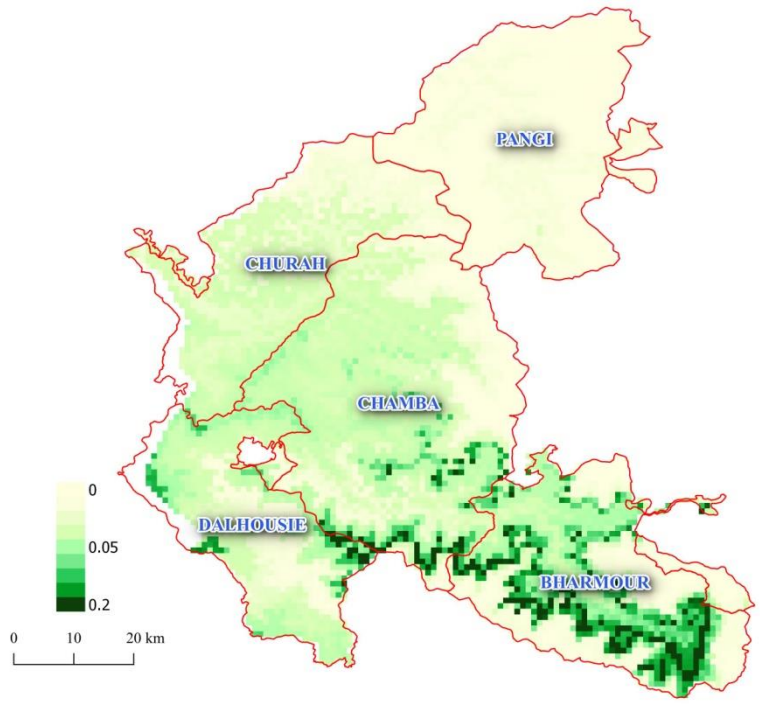
DIVISION	Density (strip area)	Average group size	2015	2019
CHAMBA WL	0.03	32	419	423
HAMIRPUR WL	0.05	10	154	37
Total			**573**	**460**

Dharamshala Circle



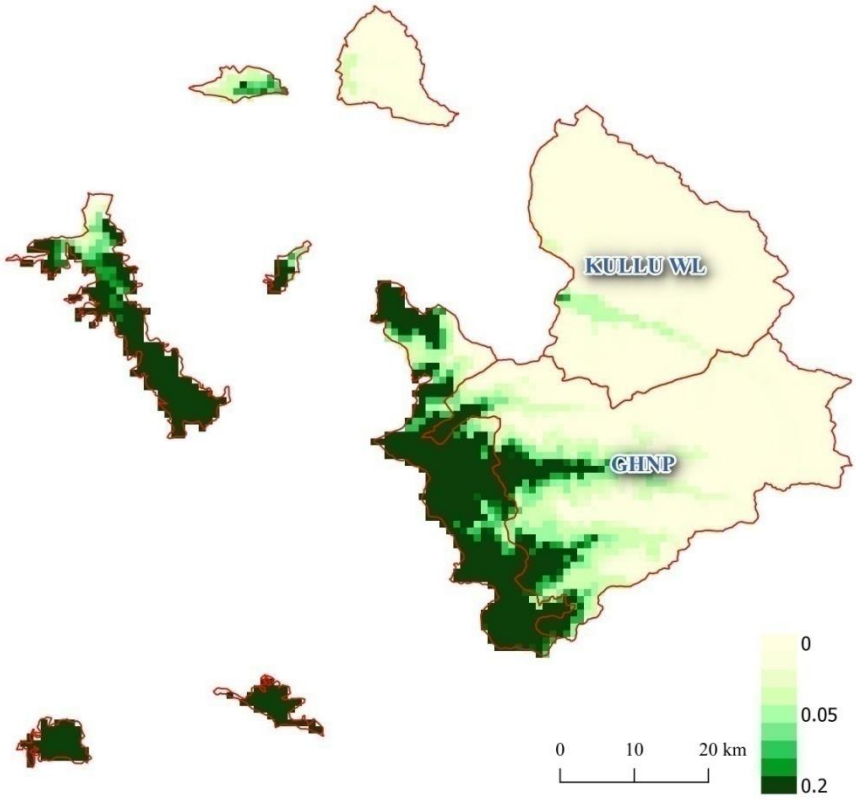
DIVISION	Density (strip area)	Average group size	2015	2019
DHARAMSHALA	0.09	36	8884	5097
NURPUR	0.15	30	14931	7718
PALAMPUR	0.12	31	8676	5735
Total			**32491**	**18550**

Chamba Circle



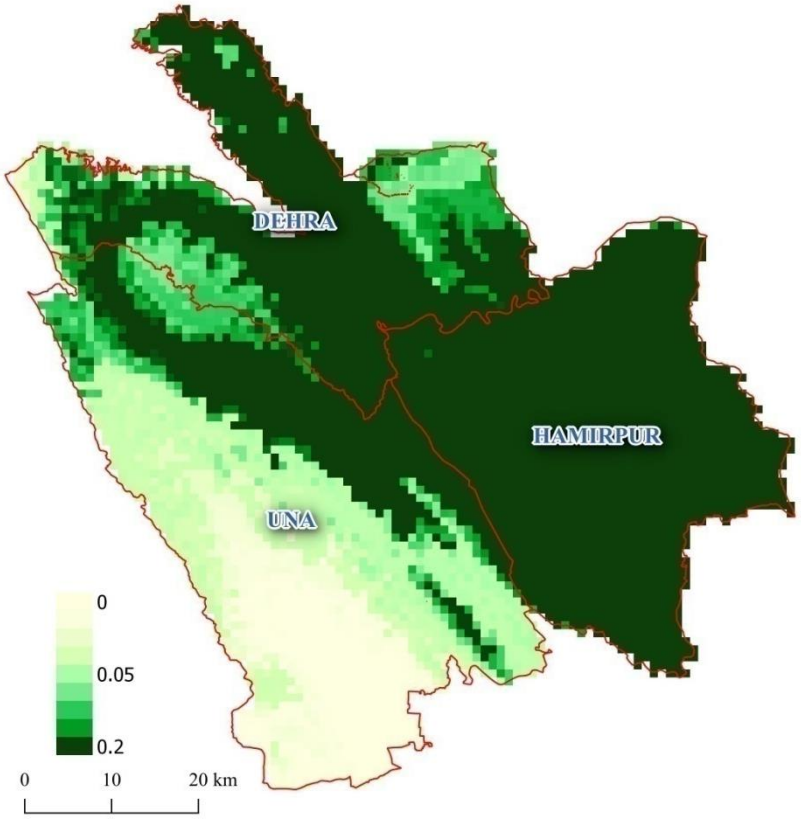
DIVISION	Density (strip area)	Average group size	2015	2019
BHARMAUR	0.05	35	1839	1921
CHAMBA	0.09	38	7888	4387
CHURAH	0.14	31	2756	3343
DALHOUSIE	0.12	40	10869	7329
PANGI			2764	-
Total			**26116**	**16980**

GHNP Circle



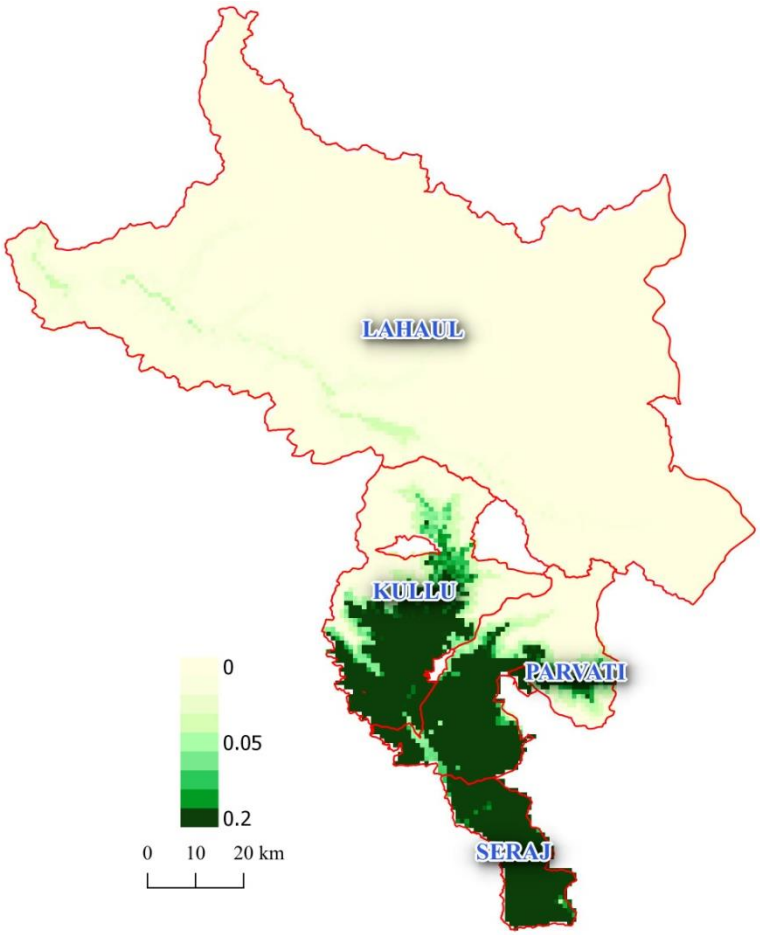
DIVISION	Density (strip area)	Average group size	2015	2019
GHNP	0.17	14	1231	162
KULLU WL	0.05	26	1611	969
Total			**2842**	**1131**

Hamirpur Circle



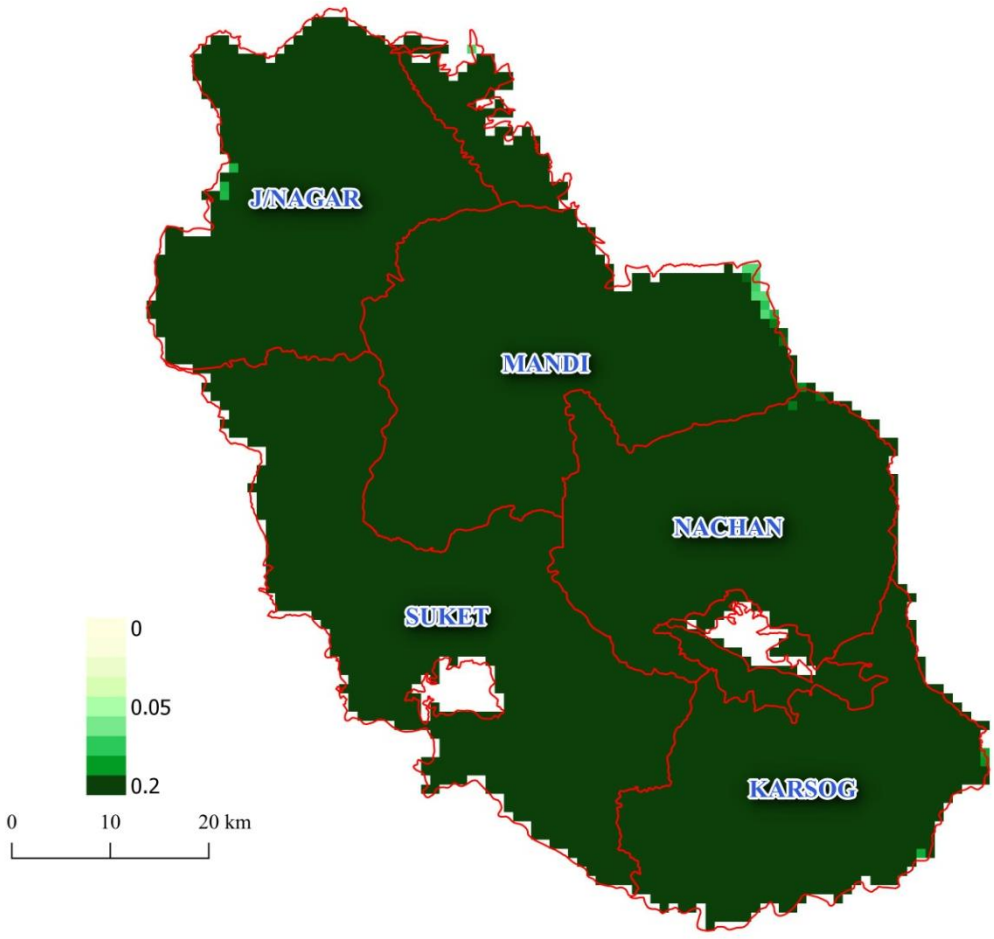
DIVISION	Density (strip area)	Average group size	2015	2019
DEHRA	0.01	35	6246	2981
HAMIRPUR	0.05	25	5541	3364
UNA	0.12	31	18174	10123
Total			**29961**	**16468**

Kullu Circle



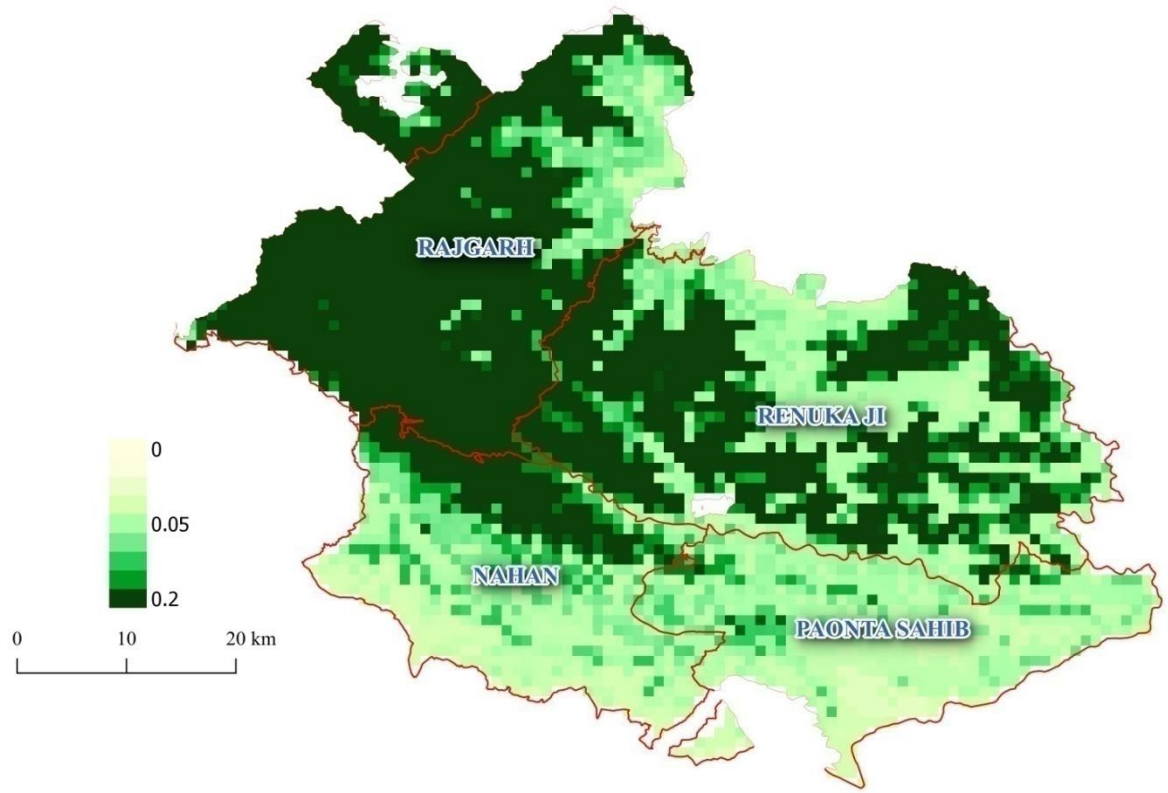
DIVISION	Density (strip area)	Average group size	2015	2019
KULLU	0.14	16	4075	2322
PARVATI	0.09	10	5964	1128
SERAJ	0.06	22	2451	1009
LAHAUL	-	-	-	-
Total			**5564**	**4459**

Mandi Circle



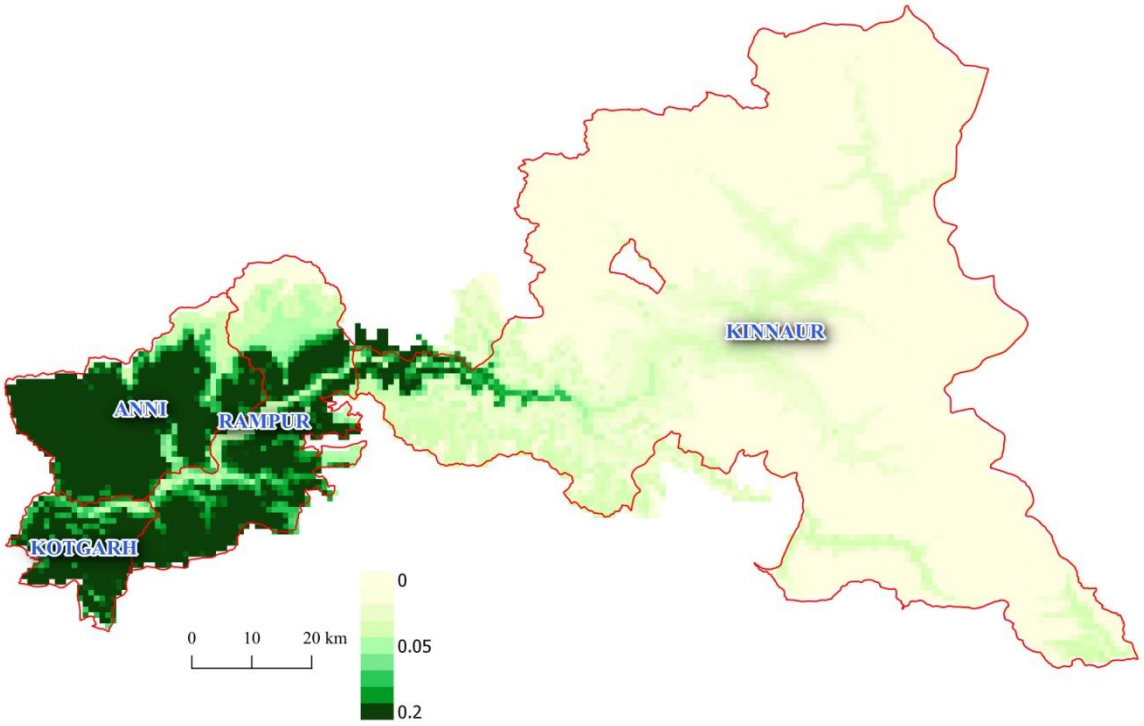
DIVISION	Density (strip area)	Average group size	2015	2019
JOGINDERNAGAR	0.06	38	4609	2908
KARSOG	0.05	38	3611	1705
MANDI	0.08	38	4128	3921
NACHAN	0.05	34	3129	2529
SUKET	0.09	42	7797	4872
Total			**23274**	**15935**

Nahan Circle



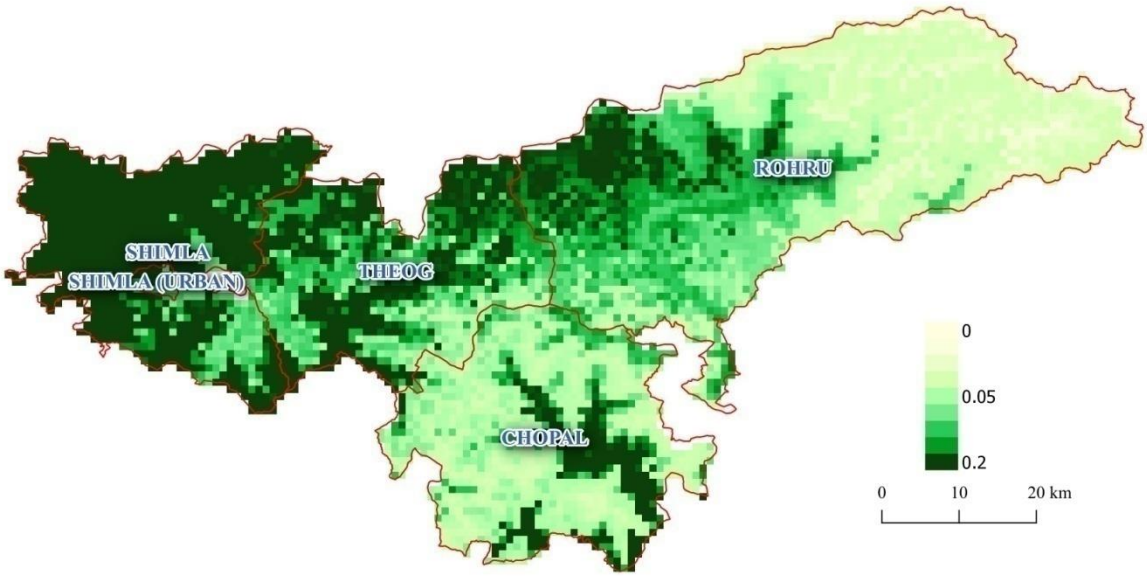
DIVISION	Density (strip area)	Average group size	2015	2019
NAHAN	0.08	39	5743	4270
PAONTA SAHIB	0.31	35	2546	5970
RAJGARH	0.05	38	9905	3141
RENUKA JI	0.06	27	12466	4810
Total			**35979**	**18191**

Rampur Circle



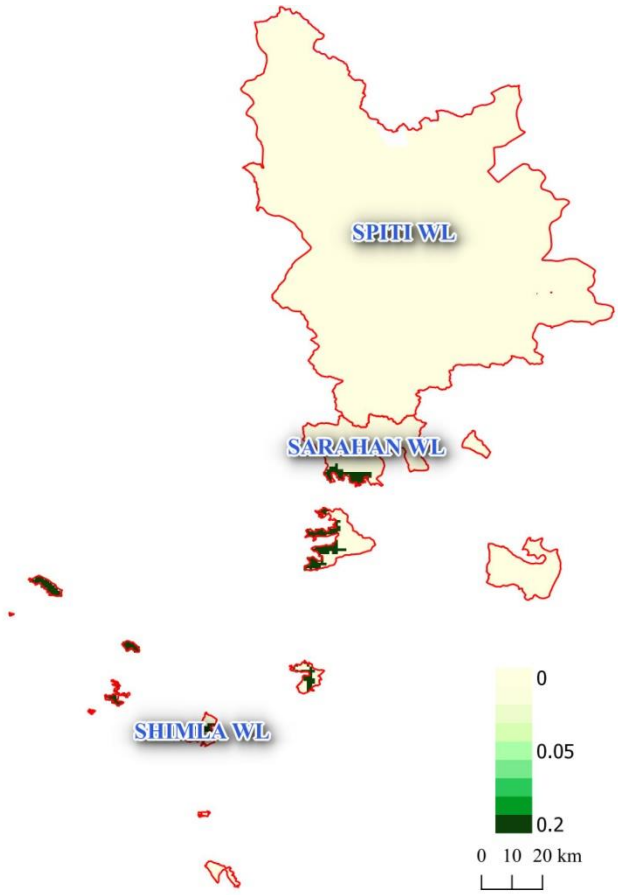
DIVISION	Density (strip area)	Average group size	2015	2019
ANNI	0.07	23	3015	1214
KINNAUR	0.03	32	575	824
KOTGARH	0.19	16	730	2292
RAMPUR	0.15	27	2465	4147
Total			**6785**	**8477**

Shimla Circle



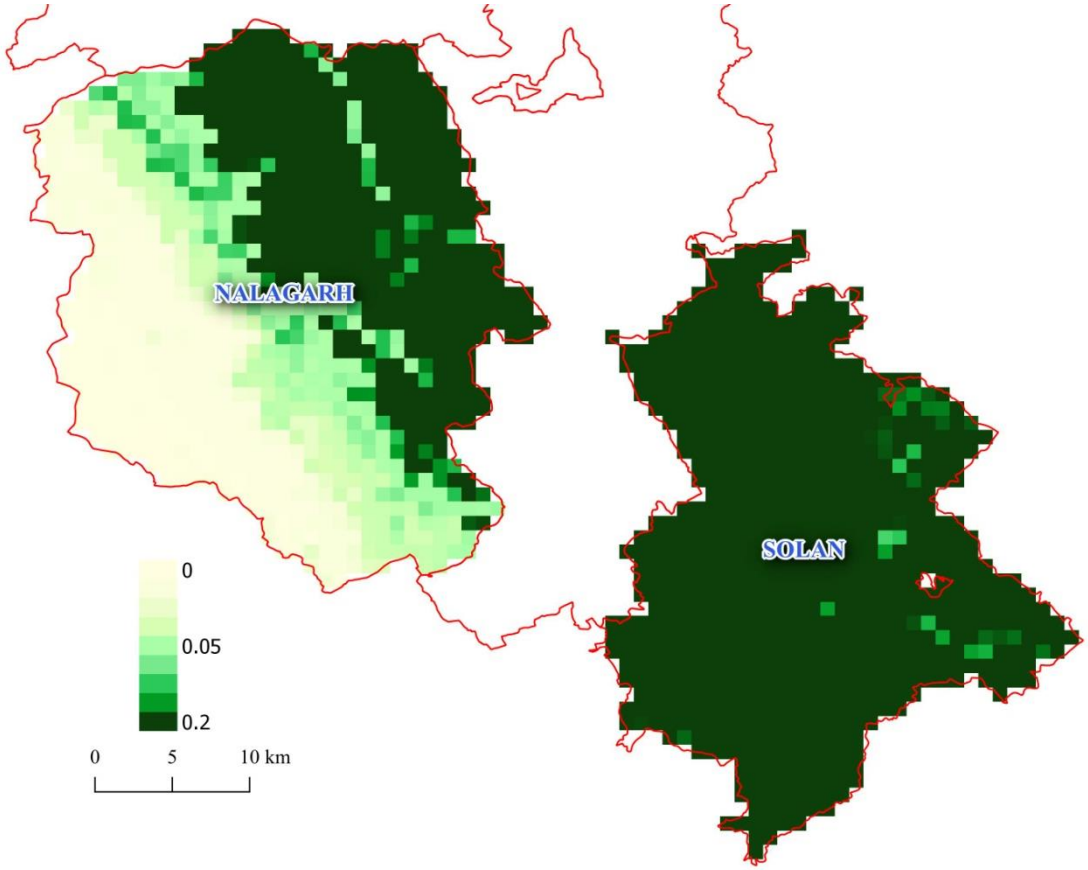
DIVISION	Density (strip area)	Average group size	2015	2019
CHOPAL	0.18	27	3293	624
ROHRU	0.01	49	4855	845
SHIMLA	0.09	38	5580	4144
SHIMLA URBAN	0.59	26	1166	1638
THEOG	0.11	21	2092	2698
Total			**16986**	**9949**

Shimla Wildlife South



DIVISION	Density (strip area)	Average group size	2015	2019
SARHAN WL	0.07	29	673	1115
SHIMLA WL	0.15	22	964	670
Spiti	-	-	-	-
Total			**1637**	**1785**

Solan Circle



DIVISION	Density (strip area)	Average group size	2015	2019
SOLAN	0.18	33	5319	6878
NALAGARH	0.07	38	3114	4856
Total			**8433**	**11734**