Technical Report -PR 242

# Population status and post-sterilisation behaviour of rhesus macaque *Macaca mulatta* in Himachal Pradesh

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**Submitted to**

**Forest Department, Himachal Pradesh**

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# Content

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## EXECUTIVE SUMMARY

A high population of free-roaming animals is a major problem across the world like macaques in India. Macaques have lost their natural fear of humans over the years due to frequent contact with people in human-dominated landscapes. This sometimes led to excessive aggressive behavior shown by animals towards humans usually when seeking food. The close contact between humans and primates may have led to the transmission of pathogens due to biting or during contact with macaques' hands when feeding them. This issue is even more severe in developing countries where religious beliefs and other cultural perspectives impede the implementation of population control strategies. Chemical or surgical sterilization to control reproductive growth is the most used method serving as an ethical alternative to culling and translocation. Although, various sterilization projects and studies have been carried out across the world, however, large-scale sterilization is less common and its impact on the natural population is not clear. Forest Department, Himachal Pradesh 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 centers were established in the entire state since 2006, wherein 170169 macaques were sterilized between 2006 and 2021. Although the number of captured macaques was high in the number, some individuals were either juveniles or pregnant females, and some already sterilized individuals were recaptured, thus they were released back without re-sterilization. Out of these sterilized animals, 88187 were males and 81982 were females. The sterilized macaques were relocated to their natural habitat. The Forest Department of Himachal Pradesh initiated a monitoring program in the state as they also have been doing the sterilization of macaques since 2006. Our study provides the consequences of sterilization on population status, social organization, and behaviour of rhesus macaques in Himachal Pradesh.

Population status: The estimated realized niche of rhesus macaque in Himachal Pradesh was 27276.83 $km^2$. The temperature seasonality and annual precipitation were the most important determinants for predicting habitat suitability. A total of 4746 groups were observed along 23440 km of a walk across the state except for 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 the predicted suitable area and average group size observed, the total population of rhesus macaque was estimated to be 1,36,443

individuals in 3336 groups with the lowest population in Hamirpur Wildlife Division (37 individuals) and highest in Una division (10123 individuals). The wild population of macaques in the state was estimated to be 1,05,627 individuals excluding urban macaques. 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. The rest of the forest divisions have shown a decline in the macaque population from the 2015 census. We also came across a report of the culling of macaques by local people, however, the same is not reported or recorded in any documents. Thus, the number of culling incidents and the 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.

Social organisation: A total of 6394 macaques were counted (1065 adult males, 2267 adult females, 830 sub-adults, 1279 juveniles, and 881 infants) in 391 groups in 9945.2 km of effort around sterilisation centres (Chamba, Gopalpur, Hamirpur, Mandi, Paonta Sahib, Shimla, and Una) in Himachal Pradesh. This provided the encounter rate of 0.04 groups/km and 0.64 macaques/km. The mean group size of the macaque was $16.35 \pm 12.62_{SD}$. The rhesus macaque groups had $8.56 \pm 6.46_{SD}$ adults and $7.68 \pm 6.64_{SD}$ immature; composed of $2.73 \pm 1.82_{SD}$ adult males, $5.82 \pm 4.96_{SD}$ adult females, $2.13 \pm 2.23_{SD}$ sub-adults, $3.28 \pm 3.40_{SD}$ juveniles and $2.27 \pm 2.21_{SD}$ infants. A significant variation in the mean number of individuals of sub-adults, juveniles, and infants, was observed between the seven sites. The number of groups observed tends to decrease in relation to the increasing group size. Rhesus macaque groups with ≤10 individuals were 138, which is followed by 132 groups under 11-20 individuals, 80 groups under 21-30 individuals, 27 groups under 31-40 individuals, nine groups under 41-50 individuals, and five groups under ≥51 individuals. The mean number of adult females/adult male was $2.14 \pm 1.39_{SD}$, infants/adult female were $0.38 \pm 0.28_{SD}$, immature/adult female was $1.36 \pm 0.83_{SD}$, and adults/immature was $1.39 \pm 1.03_{SD.}$ The study reveal, one of the consequences of such measures on macaques was more number of smaller groups and very few larger groups. The mean group size of macaques in Himachal Pradesh (16.40) was lower than in Hoshiarpur (29.10). Even the mean group size of macaques in Himachal Pradesh was much lower than the earlier records e.g., 33.10 in 1980. The mean group size of macaques in Himachal Pradesh is much lesser than in many other locations in its distribution range. This clearly indicates that the drop in the mean group size of macaques within Himachal Pradesh over a period, and also lesser than the many other locations is the consequence of the sterilization program and also the randomization of the macaques while capturing and releasing of the macaques as indicated by genetic study of relatedness of individuals from different sterilisation centres.

Behaviour: We studied two groups of macaques located at Una, Himachal Pradesh. The T1 and T2 groups were followed from June 2021 to August 2022. Initially, the T1 group had 19 individuals with 2 adult males, 15 adult females, and 2 immatures. At the end of May 2022, a new infant was born for an adult female named MTR in the T1 group which is the only one birth recorded in T1 group during the study period. The T2 group consisted of 7 females, 3 males, and 3 immatures. During the study period, 2 adult females (BM and SM) from T2 had given birth once. No deaths were recorded in both groups during the entire study period. A total of 2141 activity records from T1 group and 2305 activity records from T2 group were used for analysis. A total of 157:30 hr and 122:00 hr of observation was made for T1 and T2 groups respectively.  Both the groups spent more time on Resting (T1- 37.46%, T2-33.80%) and Moving (T1- 34.80%, T2- 28.46%).

A combined total (T1 and T2) of 203:30 hrs of observation was made between October to December 2021. During this period, reproductive behaviour was observed in both T1 and T2 groups. 22 matings were recorded in T1 group during the study period by two males (BAB and NH) and four females (MTR, SF, GRY, and ES i.e., females: 26.67%), in which the NH immigrated to the T1 group during the starting phase mating season. 190 matings were recorded by four males (HED, LC, 1E, and MP) in T2 group, in which 1E joined the group during the mating season and six females (BM, SM, PRT, HMP, LMP and SHD). The percentage of males recorded mating is 100% whereas the percentage of females recorded mating was 85% in T2 group. The limited opportunity of mating probably has resulted in less cohesion, high dispersal of individuals, more emigration and immigration, also highly skewed group composition, and male band in macaques.

# Chapter-I

# Population status of rhesus macaque in Himachal Pradesh

## Introduction

India is a megadiverse country that comprises 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. With the increasing human population, these habitats have been encroached (Cincotta et al. 2000). This has increased the proximity to human-dominated landscapes, and thus interactions between humans and wild animals. Even though many species are only confined to the forests; some species have adapted to live with the human population either by occupying the same habitat or the marginal habitats near the forested areas and those species 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), one such commensal animal is a primate. They are usually habitat generalists and occupy various human habitations ranging from urban areas to agricultural fields, temples, tourist spots, and along the roads.

There are 22 species of primates known from India (Singh et al. 2020), of which the bonnet macaque *Macaca radiata*, rhesus macaque *Macaca mulatta*, and Hanuman langur *Semnopithecus* sp. (Southwick and Siddiqi 1994a) are the few that have adapted to live in 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, and Uttarakhand (Ross et al. 1993; Pirta et al. 1997).

Of these hilly states, Himachal Pradesh has been experiencing severe conflict with the rhesus macaque (Anand et al. 2018; Saraswat et al. 2015). Crop raiding and snatching away the food from the people is severe in Himachal Pradesh (Chauhan and Pirta 2010a). 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 the sterilization of macaques.

Overpopulation of free-roaming animals is a major problem across the world like macaque in India. Macaques have lost their natural fear of humans over the years due to frequent contact with people in human-dominated landscapes (Shek and Cheng 2010). This sometimes led to excessive aggressive behavior 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 behavior of the macaques leads to an intensification of the conflict between primates and humans (Fuentes and Gamerl 2005). The close contact between humans and primates may have led to the transmission of pathogens due to biting or during contact with macaques' hands when feeding them (Wellem 2014). This issue is even more severe in developing countries where religious beliefs and other cultural perspectives impede the implementation of population control strategies (FAO 2014). Animal welfare, as well as 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 method 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 sterilization projects and studies have been carried out across the world, however, large-scale sterilization is less common and its impact on the natural population is also not clear. The impact of such sterilization drives on the reproduction and survival of a species remained understudied. Thus, the efficacy of such sterilization drives in controlling the population cannot be ascertained. Therefore, it is critical to assess the changes if any in their social organisation or behavior for their efficient management and conservation (Jones-Engel et al. 2011; Singh and Kaumanns 2005).

Forest Department, Himachal Pradesh 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 centers were established in the entire state since 2006 (Fig 1.1), wherein 170169 macaques were sterilized between 2006 and 2021 (Fig 1.2). Although the number of captured macaques is high in the number, some individuals were either juveniles or pregnant females that were not sterilized. And, some already sterilized individuals were recaptured, thus they were released back without re-sterilization. Out of these sterilized animals, 88187 were males and 81982 were females (Fig 1.3). The sterilized macaques were relocated to their natural habitat.

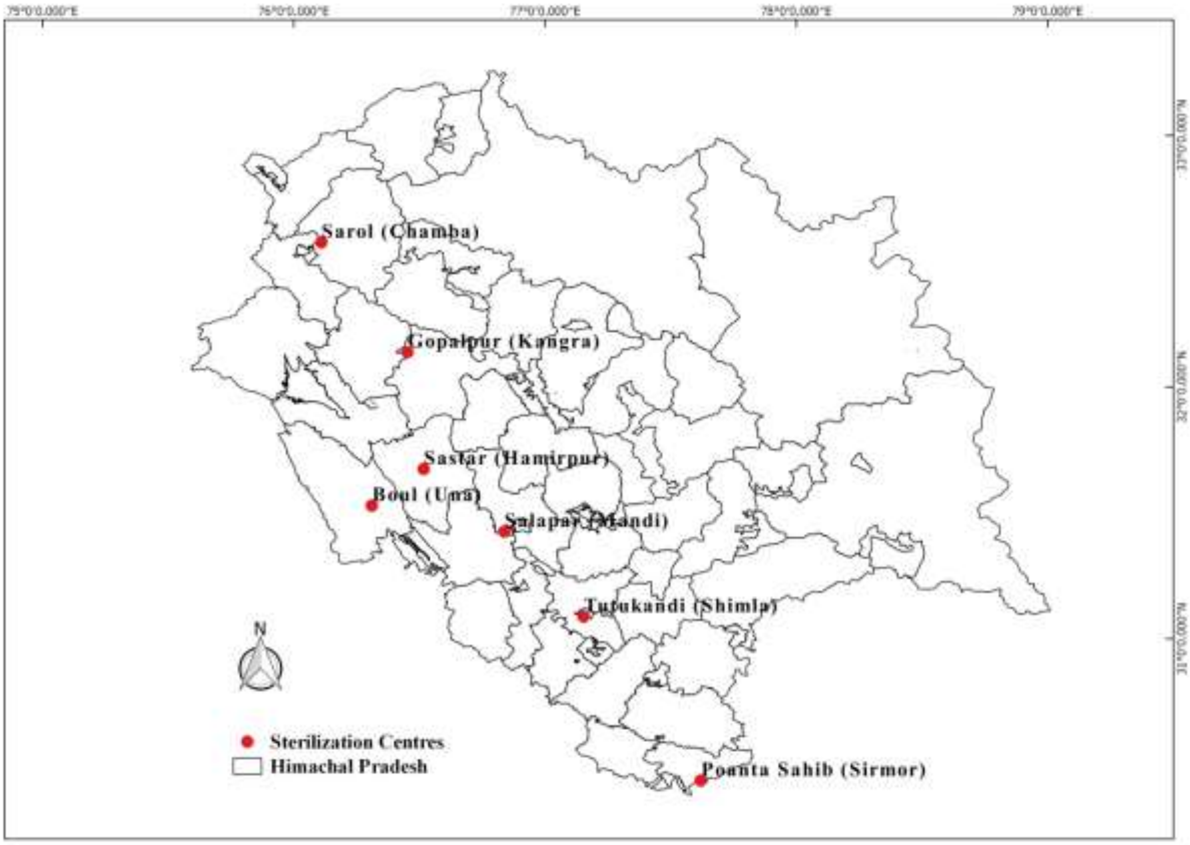


**Figure 1.1.** Location of the sterilization centres in Himachal Pradesh

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

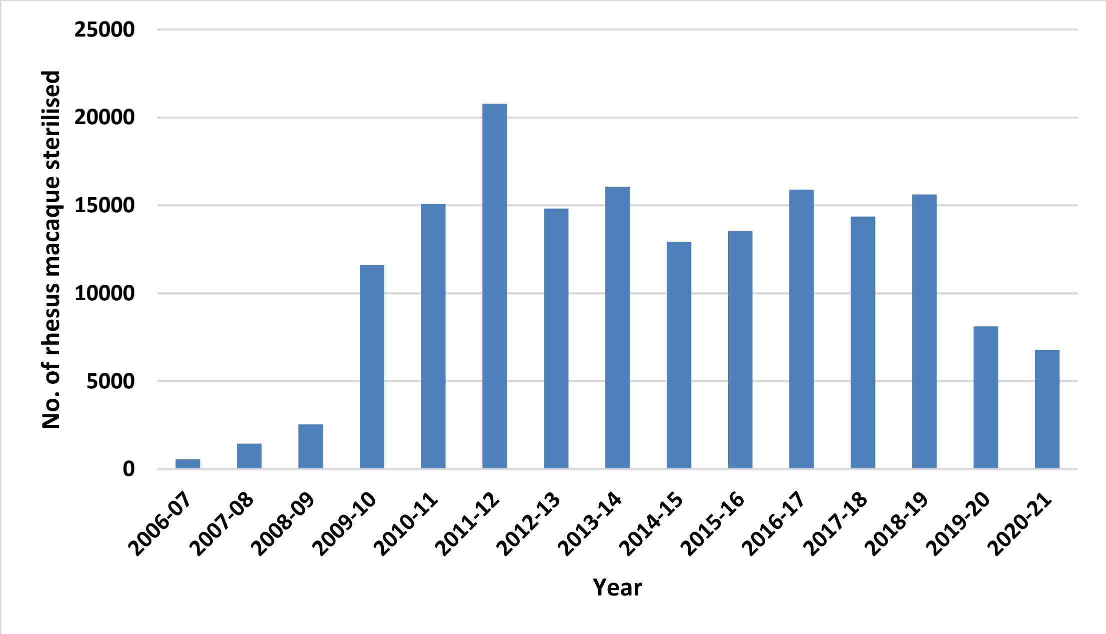


**Figure 1.2.** Sterilisation of rhesus macaques between 2006 and 2021 in Himachal Pradesh

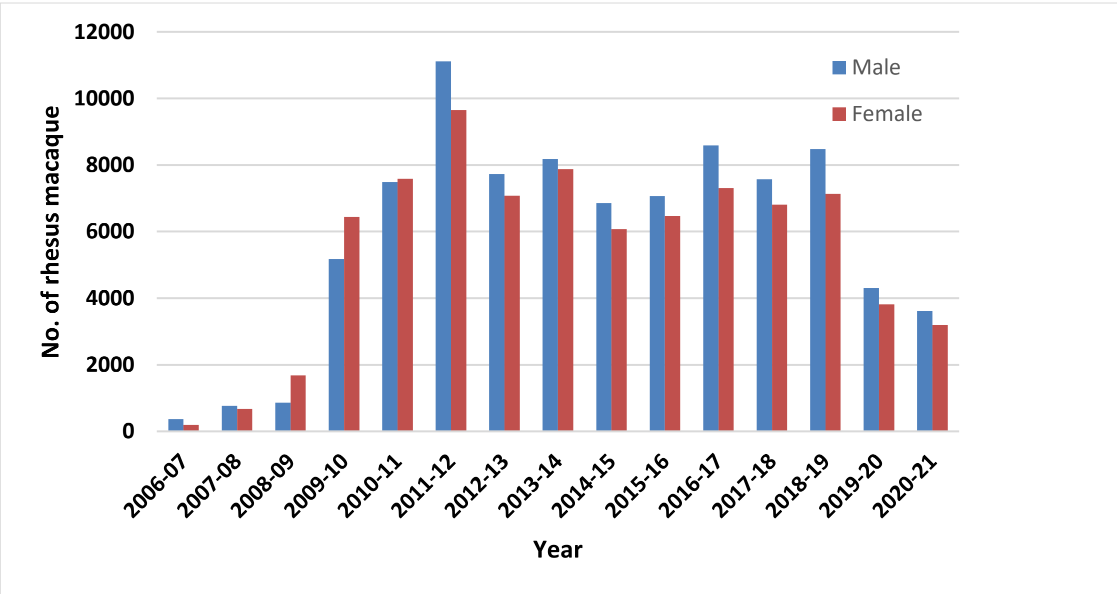


**Figure 1.3.** Number of adult male and female rhesus macaques sterilized between 2006 and 2021 in Himachal Pradesh

## Methodology

The terrain of Himachal Pradesh comprises 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 1.4). 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 distance walked was 23440 km. Each trail was recorded from starting point to the end point using the track record option in the handheld global position system (GPS).

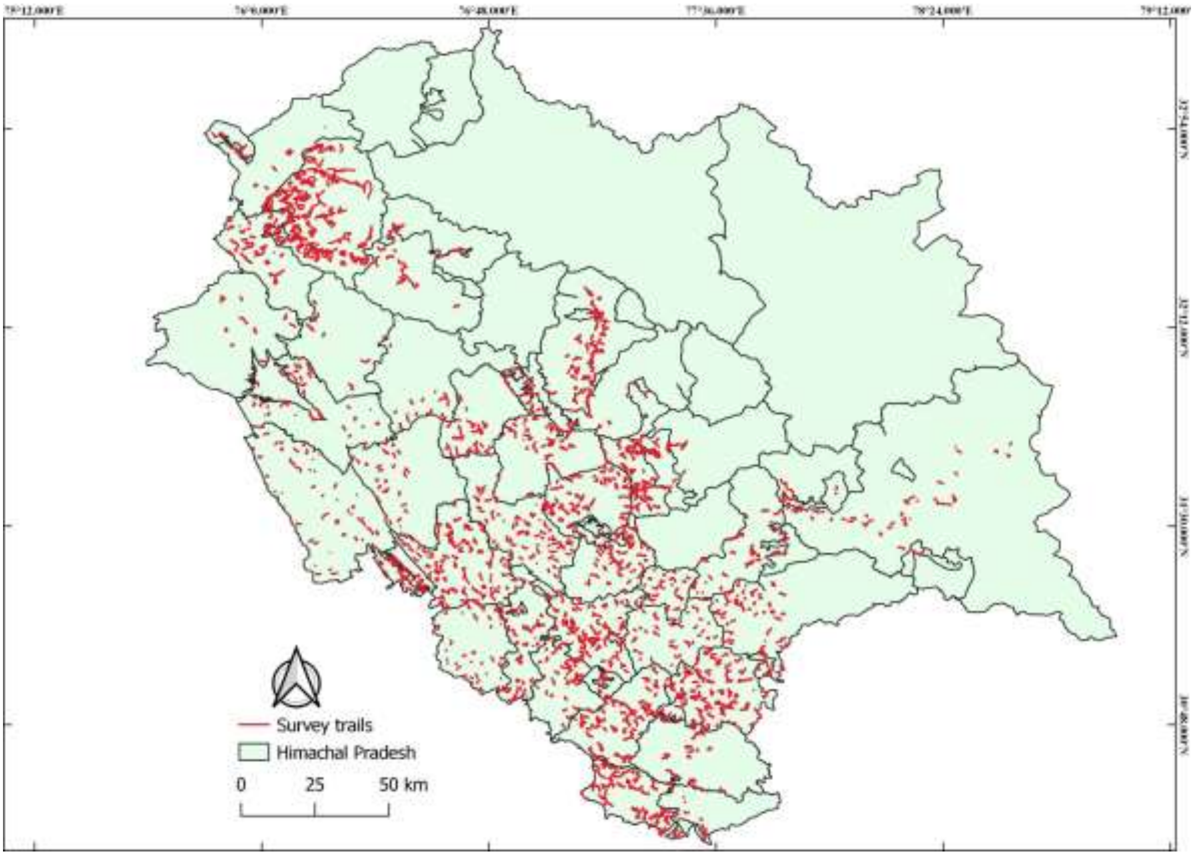


**Figure 1.4.** Trails used to survey the rhesus macaque in Himachal Pradesh in 2019

The study involved visual counts of animals (Karanth and Nichols, 2002; Jathanna et al. 2003) which is an extensively used method for estimating abundance. During the walk, for each sighting of macaques (detection of a ‘cluster’), the geocoordinates using hand-held GPS, the number of individuals sighted, age and sex of the individuals, observer–animal distance (r), sighting angle, and habitat type were recorded.

**Estimation of Suitable habitat for rhesus macaque:** A total of 4699 occurrence records of rhesus macaque were obtained. These records were used to obtain a model of the 'realized niche' (possible extent of the niche of species) using the 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 three were altitude, slope, and ruggedness index (Table 1.1). Bioclimatic and altitude layers were acquired from a global climate data repository (www.worldclim.org). Slope and ruggedness index layers were from the altitude layer by using a digital terrain modelling module in QGIS Pisa (v 2.10). All layers were of one-kilometer spatial resolution. A maximum entropy algorithm using MaxEnt (Phillips and Dudik 2008) was used to achieve the probability distribution model of rhesus macaque across the environmental layers. The model was set with a random test percentage of 25 % and the output of 5 models run separately was averaged to obtain the final model.

**Table 1.1.** Environmental layers used to build the habitat suitability model using MaxEnt.

| Layer | Description |
|---|---|
| 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 |

**Population estimation:** Keeping 5 $km^2$ as the average home range size for the rhesus macaques, we created a 1.26 radial distance from the 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 the area of the rectangle would have overestimated sampled area. Hence, we created a buffer of 1.26 km radial distance from each trail and clipped semicircles from the start and end of trails to obtain the 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. The mean group size was multiplied by the density of groups to calculate the density of macaque individuals. The forest division-wise, the density of macaques from all trails was pooled and 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 by the mean density of macaques to obtain the total population size for each division.

**Population estimation using Distance Sampling:** The distance data were 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 the lowest AIC values was then selected (Burnham et al. 1980; Buckland et al. 1993). We estimated the encounter rate (n/l), the average probability of detection (p), and 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 a 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. Perhaps that may be due to 1) The selection of the trails should be random and not based on the previous knowledge of the animals, 2) the trails should not be selected only in the areas where the presence of the animals is already known, 3) 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, and 4) 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 also affecting the total estimation. The estimation hence gave an overestimation 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.

**High-Density Hotspot:** To generate the high-density hotspots during the 2015 assessment Inverse Distance Weighted (IDW) interpolation was used using beat-wise density estimates. However, due to geo-referencing errors in data during the current assessment, density could only be estimated at the division level. Hence to generate a heat map, location data was considered and kernel density estimation (KDE) was performed with a triangular kernel shape and fixed kernel width. Areas with high density (>40 locations) were considered as hotspots.

## Results

*The realized niche of rhesus macaque*: The estimated realized niche of rhesus macaque in Himachal Pradesh was 27276.83 $km^2$ (Fig 1.5). MaxEnt model revealed that temperature seasonality (percent contribution = 25.8) and annual precipitation (percent contribution = 23.2) were the 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.

*The population size of rhesus macaque*: A total of 4746 groups were observed along 23440 km of a walk across the state except for 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 the predicted suitable area and average group size observed, the total population of rhesus macaque was estimated to be **1,36,443** individuals (Table 1.2) in 3336 groups with the 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 excluding urban macaques. Division-wise estimates of the rhesus macaque population are provided in Table 1.2.

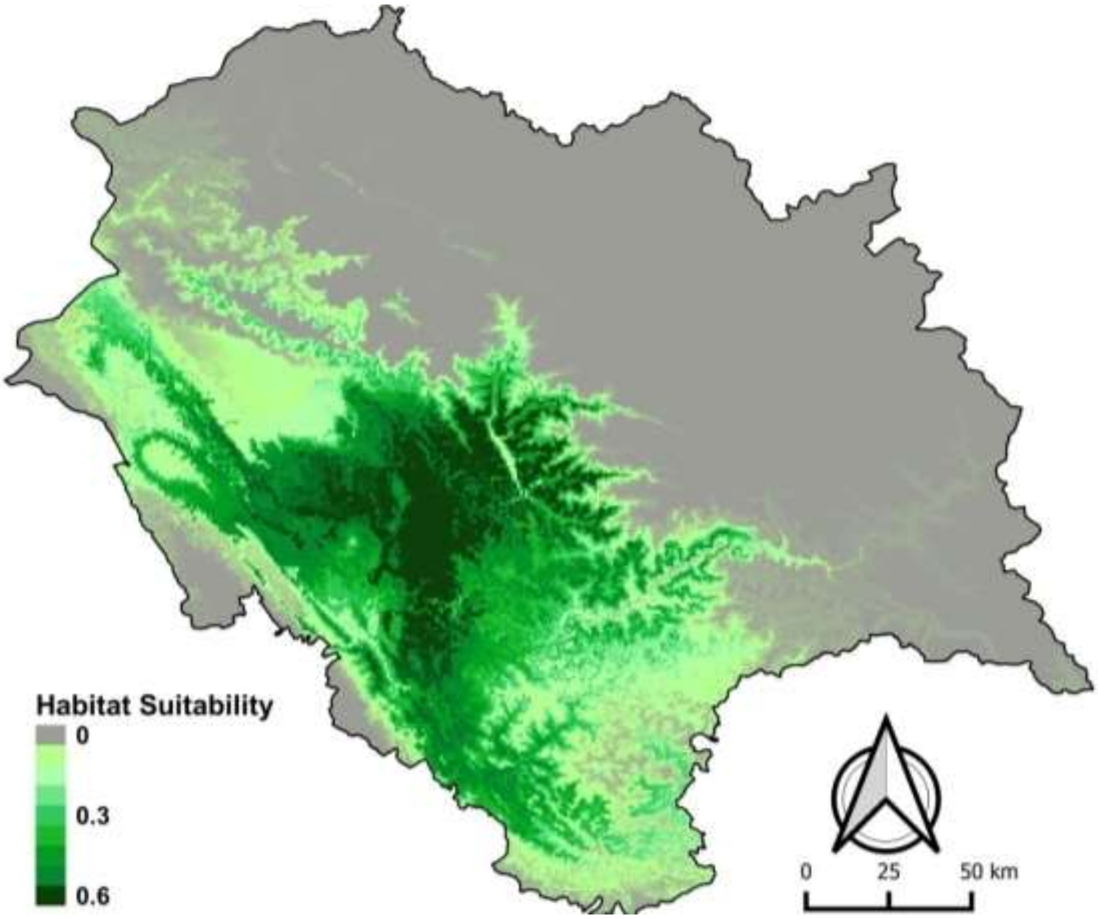


**Figure 1.5.** The modelled suitable habitat of rhesus macaque in different Forest Divisions of Himachal Pradesh

**Table 1.2.** Population estimation of rhesus macaque in Himachal Pradesh

| DIVISION | Density (Macaque groups/ $km^2$) | No. of groups detected | 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** | **30816** | **136443** |

*Changes in the population size of rhesus macaque*: When compared to the estimates of macaques in 2015, the overall population in Himachal Pradesh appears to have declined in the last four years (Table 1.3). The overall intrinsic rate of change of -0.08 was observed in the population. Intrinsic rate showed a 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, the change in the Mandi division (-0.01) and Nachan division (-0.05) is not too different. 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 was recorded. Intrinsic rate showed a 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. The rate of change of the macaque population in all the divisions is depicted in Figure 1.6. As the population estimation exercise was not conducted in Pangi division during the 2019 survey, it has been omitted from the 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 1.7 wherein hotspot areas of high density are depicted by dark green color. When compared to the hotspot analysis from 2015, most of the hotspots are the same with the Shimla Urban division showing the highest probability. Due to geo-referencing errors in group locations, hotspots in Una and Nurpur divisions could not be predicted due to which they are not depicted on the map.

**Table 1.3.** 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** |

The number of hotspots of macaque density in 2019 was 226 forest beats, which was 263 forest beats in 2015 (Table 1.4). Due to geo-referencing issues of the data collected on macaque locations with Una and Nurpur divisions and also survey trails, hotspots could not be predicted, thus comparison could not be made for these divisions. Overall the number of hotspots has decreased across the state, however, there has been an increase in the number of beats falling under the hotspot region that includes Chamba, Churah, Chamba WL, Kullu WL, Kullu, Mandi, Solan, Kotgarh and Shimla.

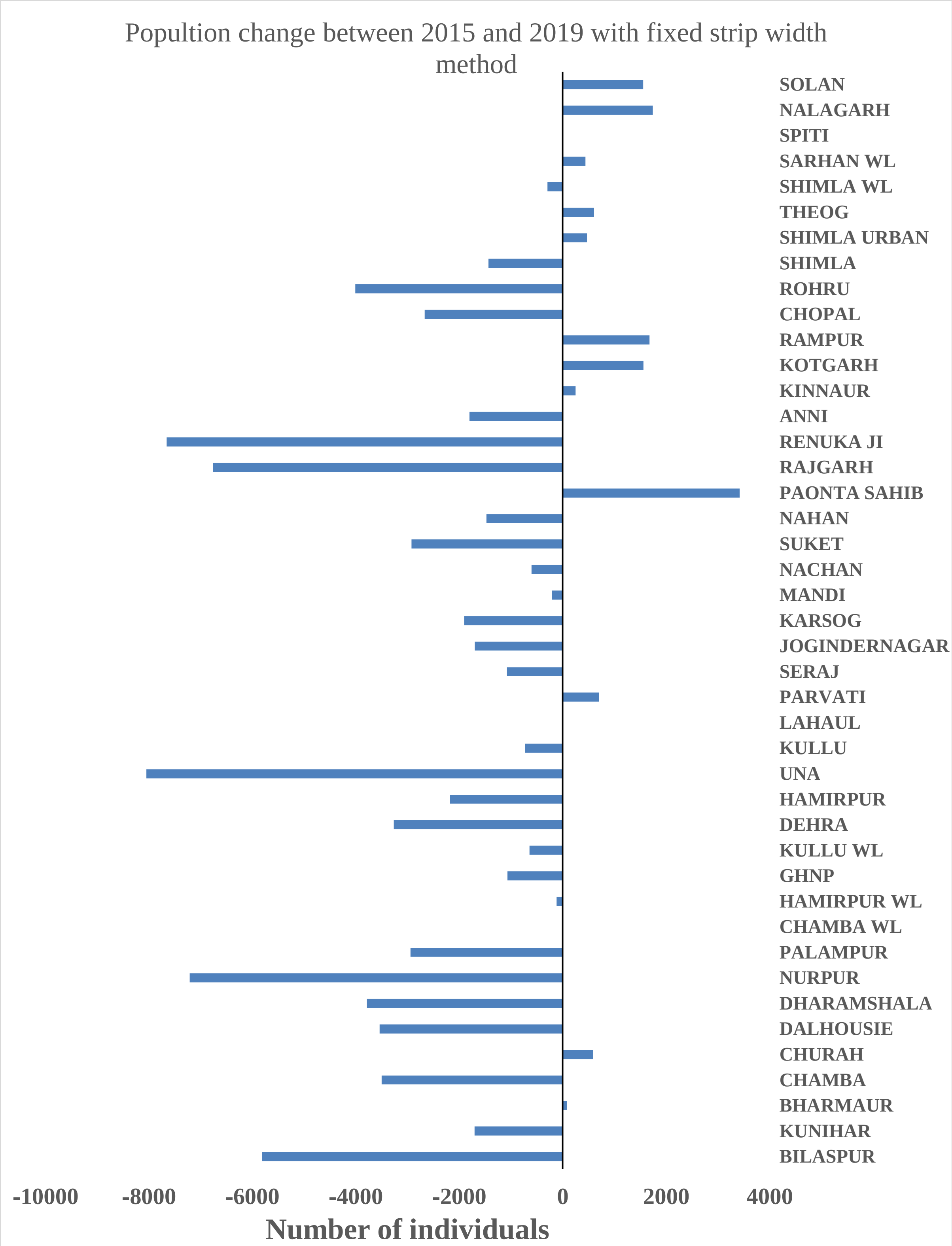


**Figure 1.6.** The change in the rhesus macaque population between 2015 and 2019

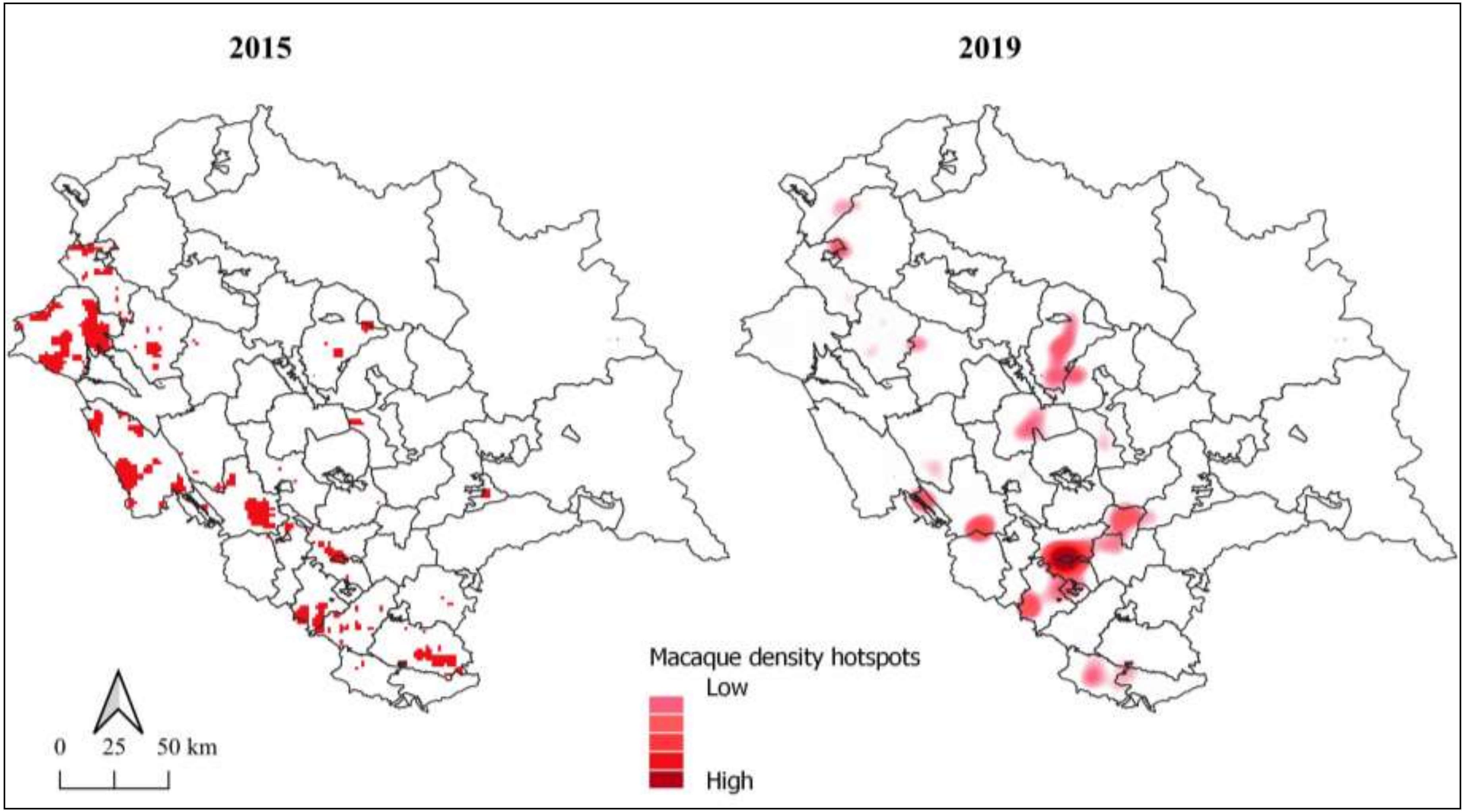


**Figure 1.7**. Comparative Inverse Distance Weighted Interpolation of density (hotspots) estimates of rhesus macaques in Himachal Pradesh in the year 2015 and 2019.

**Table 1.4.** Circle wise comparison of hotspots between 2015 and 2019 assessments showing number of beats falling under hotspots

| CIRCLE | DIVISION | RANGE | No of Beats in 2015 | No. of Beats in 2019 |
|---|---|---|---|---|
| BILASPUR | BILASPUR | BHARARI | 6 | - |
| | | GHUMRWAIN | 5 | - |
| | | JHANDUTTA | 5 | - |
| | | KALOL | - | 4 |
| | | SADAR | 13 | 2 |
| | | SWARGHAT | 5 | 9 |
| | KUNIHAR | ARKI | 2 | - |
| | | DARLA | 2 | - |
| | | KUTHAR | - | 2 |
| | NALAGARH | KOHU | 2 | 4 |
| | | NALAGARH | 2 | 1 |
| | | RAMSHEHAR | 1 | - |
| CHAMBA | CHAMBA | L/CHAMBA | 2 | 3 |
| | | MASRUND | - | 3 |
| | | TIKKARI | - | 1 |
| | CHURAH | BHALEI | 1 | - |
| | | CHAKOLI | - | 2 |
| | | HIMGIRI | - | 4 |
| | DALHOUSIE | ARMY AREA | 1 | - |
| | | BAKLOH | 7 | - |
| | | BHATTIYAT | 8 | - |
| | | CHOWARI | 8 | - |
| | | DALHOUSIE | 9 | 4 |
| | PANGI | KILLAR | 1 | - |
| DHARAMSHALA | DHARAMSHALA | DHARAMSHALA | 2 | - |
| | | KANGRA | 9 | - |
| | | LAPIANA | 2 | - |
| | | MALAN | 1 | 3 |
| | PALAMPUR | PALAMPUR | 2 | 6 |
| DHARAMSHALA WL NORTH | CHAMBA WL | KHAJJIAR | - | 1 |
| GHNP | KULLU WL | BAROT | - | 1 |
| | | INDERKILA NATIONAL PARK | 1 | - |
| | | KARSOG | 1 | - |
| | | MANALI | - | 4 |
| HAMIRPUR | DEHRA | DEHRA | 2 | - |

| | | | | |
|---|---|---|---|---|
| | | NAGRROTA SURIAN | 1 | - |
| | HAMIRPUR | BARSAR | 3 | - |
| | | BIJHARI | 3 | - |
| | UNA | AMB | 9 | - |
| | | BANGANA | 1 | - |
| | | BHARWAIN | 12 | - |
| | | RAMGARH | 7 | - |
| | | RAMGARH | 13 | 1 |
| KULLU | BANJAR | SAINJ | 3 | - |
| | KULLU | BHUTTI | - | 3 |
| | | KULLU | - | 8 |
| | | MANALI | - | 4 |
| | | NAGGAR | 5 | 6 |
| | | PATALIKUHAL | 3 | 4 |
| | PARVATI | BHUNTAR | - | 2 |
| | | JARI | - | 5 |
| MANDI | JOGINDER NAGAR | LADBHAROL | 1 | - |
| | KARSOG | SERI | 3 | - |
| | MANDI | KATAULA | - | 8 |
| | | MANDI | - | 8 |
| | | PANARSA | - | 2 |
| | NACHAN | PANDOH | - | 2 |
| | SUKET | JAIDEVI | 3 | - |
| | | KANGOO | 1 | - |
| | | SUKET | 1 | - |
| NAHAN | NAHAN | JAMTA | 2 | 3 |
| | | NAHAN | - | 9 |
| | | NAHAN MCA | - | 2 |
| | | TRILOKPUR | 1 | 1 |
| | PAONTA SAHIB | BHAGANI | 2 | - |
| | | GIRINAGAR | 1 | 2 |
| | | MAJRA | 1 | - |
| | RENUKA JI | KAFOTTA | 8 | - |
| | | NOHRA | 1 | - |
| | | RENUKA JI | 6 | 2 |
| | | SANGRAH | 1 | - |
| | | SHILLAI | 4 | - |
| | SOLAN | DHARAMPUR | 8 | 3 |
| | | KANDAGHAT | 1 | 9 |
| | | PARWANU | 11 | 9 |
| | | SOLAN | 1 | 4 |
| | | SUBATHU | 1 | 3 |
| RAMPUR | ANNI | ARSOO | 1 | - |

| | | | | |
|---|---|---|---|---|
| | | NITHER | - | 1 |
| | KOTGARH | KOTGARH | - | 7 |
| | | KUMARSAIN | - | 9 |
| | RAMPUR | NANKHARI | - | 1 |
| | | RAMPUR | 1 | - |
| SHIMLA | CHOPAL | CHOPAL | 2 | - |
| | | DEYA | 1 | - |
| | | NERWA | 2 | - |
| | SHIMLA | BHAJJI | 2 | 6 |
| | | DHAMI | 6 | 4 |
| | | KOTI | 2 | 4 |
| | | MASHOBRA | 8 | 11 |
| | | TARADEVI | 6 | 10 |
| | SHIMLA (URBAN) | CHAURA MAIDAN | 8 | 8 |
| | THEOG | THEOG | 1 | 9 |
| | SARAHAN WL | DHARANGHATI | 1 | - |
| SHIMLA WL SOUTH | SHIMLA WL | CHAIL | - | 1 |
| | | RENUKA JI | 2 | - |
| | | SIMBALBARA | 2 | - |
| | | SHIMLA WATER CATCHMENT | - | 1 |
| Total | | | 263 | 226 |

## Discussion

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. The rest of the forest divisions have shown a decline in the macaque population from the 2015 census. Although there is an increase in population in some areas, the decrease is significant in the entire state (Figure 1.8). This overall decrease in the population size can be attributed to the gradual controlling of population growth through sterilization program, emigration of individuals, and culling of the macaques by local people after the declaration as vermin in the last one year (from 2018). During the state-level population assessment of macaques, we came across a report of the culling of macaques by local people, however, the same is not reported or recorded in any documents. Thus, the number of culling incidents and the 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.

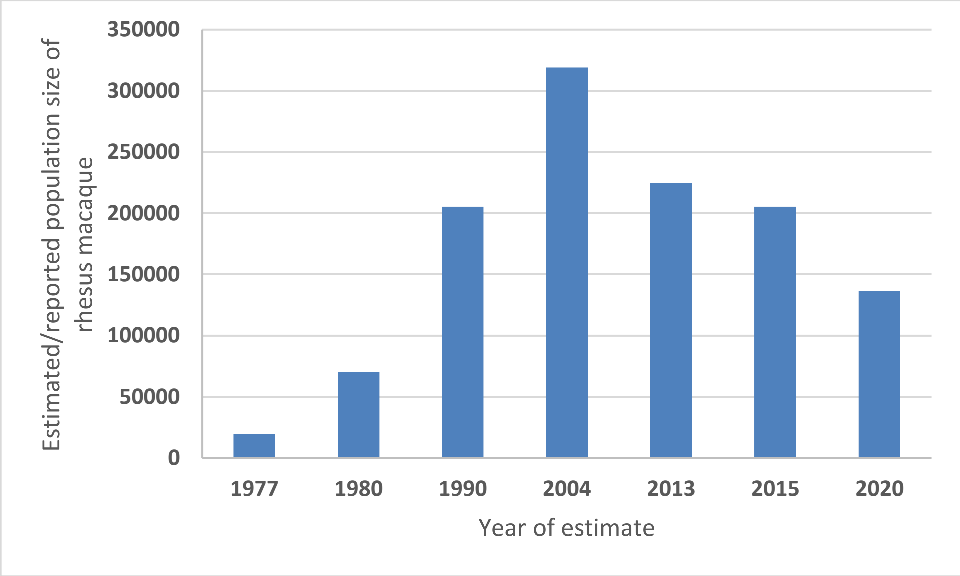


**Figure 1.8**. Population size from 1977 to 2020 in Himachal Pradesh

**Limitations in the current study:**

- The population assessment was carried out based on the principles of distance sampling. Distance sampling estimates the effective strip width based on the fitted detection function. For accurate fitting of the detection function, it is assumed that transects are of regular shape and distances are recorded with utmost accuracy. However, due to the highly convoluted shapes of trails and non-accurate documentation of angular distance and bearings, fitting proper detection function was not possible and the Distance 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 the misrepresentation of the data as many points were falling out of the boundary of Himachal Pradesh. This prevented the use of spatial modeling as it was difficult to geo-reference the trail data.
- Information on group size was highly unreliable. Recordings of the same number of individuals in a group during the replication are not possible, it indicates the human bias added to the number estimation.

**Mitigation measures**

Although the human-macaque interface is age-old, there has been a sharp increase in reporting of human-primate conflict studies in the past 20-30 years. The human-primate conflict has been reported in Himachal Pradesh since 1977 (Roonwal and Monhot 1977). This has partly been due to a 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 the state. The high behavioral plasticity and generalist nature of rhesus macaques enable them to adapt to environmental changes quickly. Due to this, many mitigation measures although effective initially tend to fail over a long period.

To curb this, the Forest Department of Himachal Pradesh has 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 the reduction of the population of rhesus macaques, there is still a major public outcry about conflict with rhesus macaques. Recent studies show a prolonged conflict leads to people's perception on rhesus macaques being negative (Chauhan and Pirta 2010 b; Saraswat et al. 2015). Priston and Mclennen (2013) reported people having paradoxical opinions 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 an understanding perception of conflict as well as employing multiple and adaptive tools (Madden, 2004). To achieve this, we formulated the following mitigation measures.

**1. Improving existing population control**: Himachal Pradesh Forest Department has established nine sterilization centers where laser-assisted tubectomy and vasectomy are performed on captured macaques. Since 2006, a 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 faraway locations and brought to sterilization centers, the reach of each centre is limited, and further, the random re-release of them probably has affected their social organisation and unexpected over crop raiding. To avoid this, the proper release of them at their original locations has to be ensured.

However, the massive sterilisation drive has been effective in regulating the population growth of macaques through the prevention of subsequent births of progenies. A rough statistical model shows the prevention of about 5-6 lakh new births which had a cumulative effect on the 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 a prolonged period. Also, strategies or pattern of crop raiding varies between different groups and different sites. Hence, a turnkey-based hard intervention such as repellent devices, or high-frequency sound emitters might not work equally at different places. One of the most effective methods found is physically driving macaques away or regular patrolling.

**3. Social programs for livelihood diversification of affected communities and Awareness generation:** Crops that are dependent by the communities are frequently raided by macaques required to be provided with an 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 crops to maximise their economic returns. Backward and forward market linkages should be assessed for such interventions. Further, the management of the perception of conflict is equally important. The public should be made aware of existing interventions being carried out. Further synergy between the forest department and citizens can be established through regular dialogues at the village, district, and state-level representatives.

Currently, the forest department has been conducting awareness drives with local residents and tourists. As tourism is 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 the reduction of stoppage of tourists along the highways thus preventing provisioning. Awareness about the social organization or documented unique behaviors of the macaques can be used as tourist attractions.

**4. Solid waste (kitchen waste management):** In most of the Municipal Corporation areas and other areas specifically having a large number of human habitations, the door-to-door garbage collection and kitchen waste management have 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 are well managed.

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

# Chapter II

# Social organisation of rhesus macaque population around sterilisation centers in Himachal Pradesh

## Introduction

In 2008, the Forest Department of Himachal Pradesh requested the government to lift the ban as an effort to control the monkey conflict in the state. Meanwhile, the department had ongoing management practices such as sterilization, and translocations. The human-macaque conflict was reported primarily in the agricultural fields, and this has emerged as a socio-political issue in the state. Many farmers had left cultivation due to heavy loss due to crop raiding rhesus macaques (Singh et al. 2016). Macaques in urban areas of the state are known to snatch food from the people and behave aggressively (Chauhan and Pirta 2010). The human-rhesus macaque conflicts have amplified over time (Anand et al. 2018; Saraswat et al. 2015) which led the people to appeal to the government for conflict resolution.

Conflicts can only be resolved by complex and multifaceted social and technical approaches (Hockings 2017). Various techniques are known to be used in controlling primate populations (Liu 2011). Considering the ethical alternative to culling and translocations, chemical or surgical sterilization is the most used method (Reddy and Chander 2016; Malaivijitnond et al. 2011; Rattan 2011) that has been adapted and practiced in Himachal Pradesh. Macaques have been trapped and bought to the sterilization centers and later released back after the sterilization process. Also, macaques have been translocated from highly problematic areas by releasing the sterilized individuals in different locations. Due to the capture and release process, there is a high chance of randomization of individuals. The government also declared the species as vermin in select Tehsils and permitted for culling. The effects of these management practices are understudied. Social organization study is important to understand the order and creates predictability in society (Parsons 1951). Social structures influence the behavior of the population. Thus, it is essential to document the influence of these management practices on the social organization of the species (Jones-Engel et al. 2011; Singh and Kaumanns 2005).

**Study site**:

We considered the surrounding areas of the sterilisation center to study the social organisation of the rhesus macaques (Figure 2.1). We selected the rhesus macaque population in Hoshiarpur, Punjab as the control site as there is no sterilisation of macaques (Figure 2.1). We mapped an area of 30 kilometers (aerial distance) using Google maps around the seven sterilization centers in Himachal Pradesh (Sarol, Gopalpur, Sastar, Salapper, Tutikandi, Boul, and Paonta Sahib) and around Hoshiarpur in Punjab.

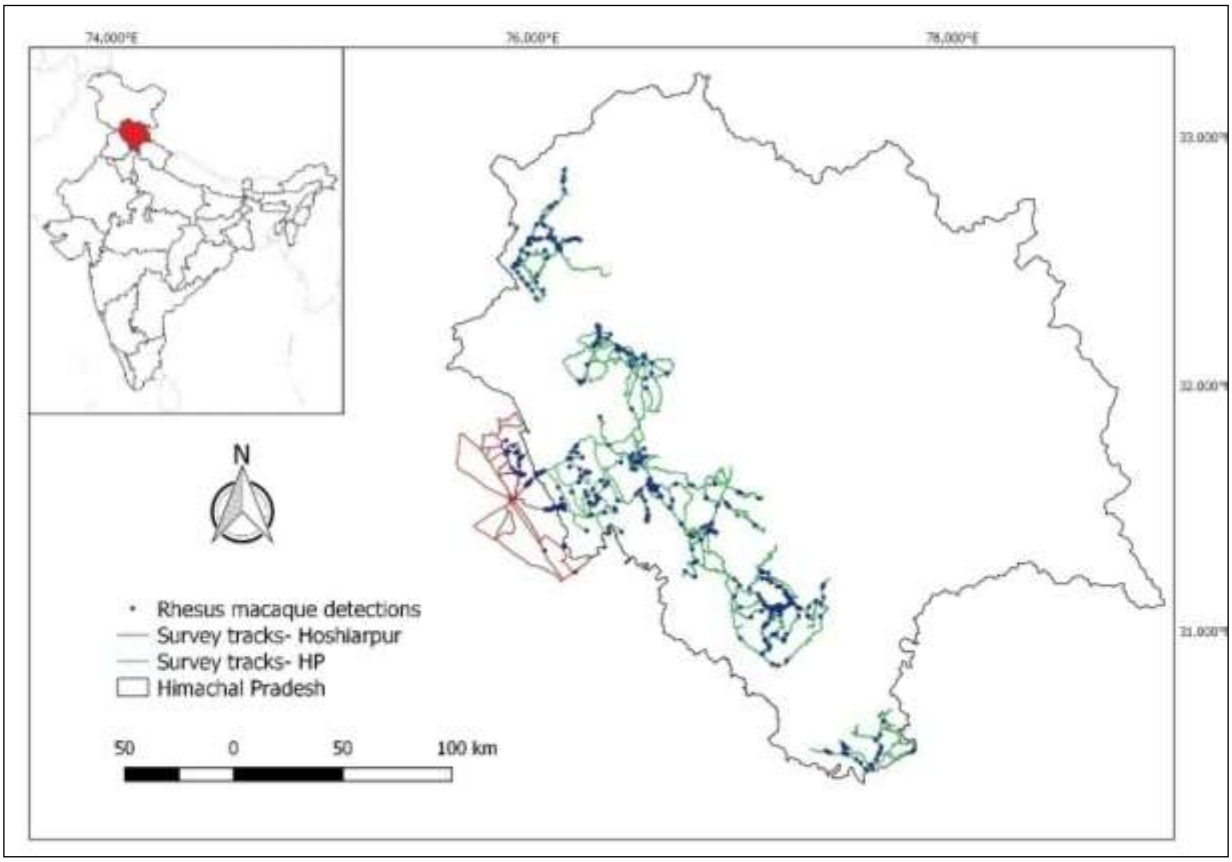


**Figure 2.1**. Survey tracks and rhesus macaque detections in the study site in Himachal Pradesh and the control site of Hoshiarpur in Punjab.

All existing roads within this fixed distance from these sterilisation centers were surveyed for rhesus macaque groups by traveling on a motorbike with a speed of ≤30 kmph between 06:00 hr and 18:00 hr. Each trail was recorded from the start point to the endpoint with the help of the track record option in the handheld global positioning system (Garmin-GPSMAP 64). A total effort of 11,119.2 km was made during the survey.

For each detection of the rhesus macaque, a considerable amount of time was spent with each group and recorded the geocoordinates of the group location using handheld GPS, the number of individuals detected, and the age-sex of the individuals. The individuals were recorded by visual observation and were classified into different age-sex categories based on physical appearance i.e., adults (females >5 years, males>6 years), sub-adults (≥3 years but not adult), juveniles (1-3 years) and infants (< 1 year). The individuals in the group were counted when the group made a coordinated movement across a road gap, or canopy or was seen roosting in a single line. Groups seen in the same occurrence point were avoided from recounting.

**Analysis**

All sampling trials and detections of rhesus macaques were mapped with the help of digital toposheets obtained from the Survey of India by the Himachal Pradesh Forest Department, using QGIS 2.16.1 and ARC GIS 10.8.1 (Figure 2.1).

Population characteristics: A total of 436 detections were obtained during the survey. Encounter rate, mean group size, and total number of individuals were computed using these detections. To analyse other population characteristics considering age-sex individuals, two detections were removed (one each from Salapper and Tutikandi) due to implausible age-sex data (many unidentified individuals). Population characteristics were analysed using Microsoft Excel 2007 and IBM SPSS Statistics 23. ANOVA was used to test the significance of the population characteristics. The segregated data of Himachal Pradesh and the control group (Hoshiarpur, Punjab) were compared to check the difference using the Mann-Whitney U test.

# Results

## Hamirpur

We detected 735 macaque individuals (116 adult males, 271 adult females, 103 sub-adults, 140 juveniles, and 96 infants) in 45 groups in 848.2 km of effort (Appendix 2.1. A) that provided the encounter rate of 0.05 groups/km and 0.87 macaques/km. The mean group size of the macaque was $16.33 \pm 12.74_{SD.}$ The percentage composition of adults was 52.65% (adult males- 15.78%; adult females- 36.87%) and immature was 46.12% (sub-adults – 14.01%; juveniles-19.05%; infants-13.06%). Rhesus macaque groups with ≤10 individuals were 17, which is followed by 14 groups under 11-20 individuals, 10 groups under 21-30 individuals, two groups under 31-40 individuals, and one group each under 41-50 and ≥51individuals (Figure 2.2).

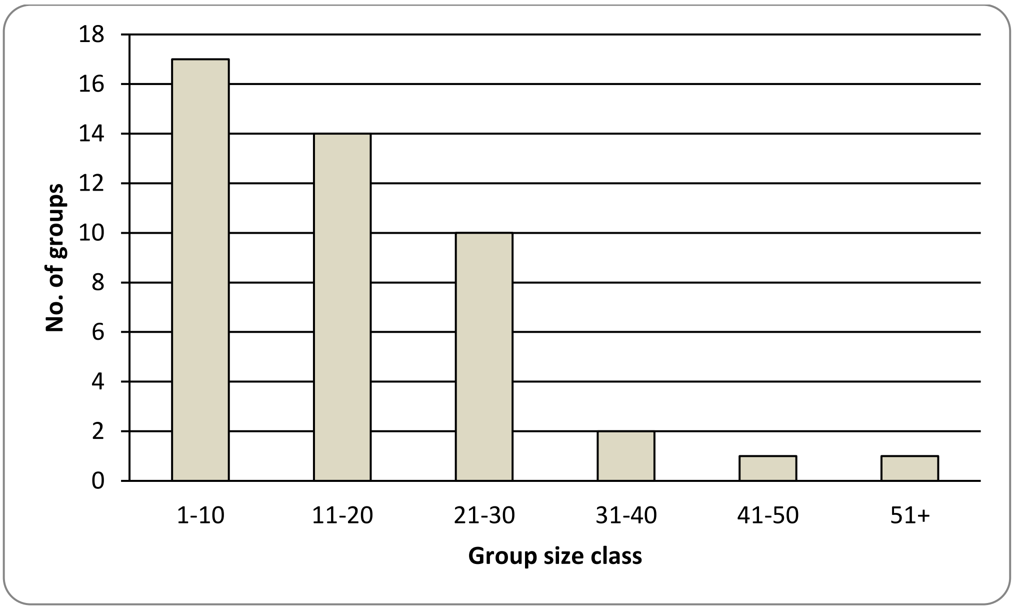


**Figure 2.2.** The number of rhesus macaque groups in different group size classes in Hamirpur, Himachal Pradesh (N=45).

The observed groups had $6.02\pm4.97_{SD}$ adult females followed by juveniles ($3.12\pm3.26_{SD}$), adult males ($2.58\pm1.50_{SD}$), sub-adults ($2.29\pm2.24_{SD}$), and infants ($2.14\pm2.05_{SD}$) (Figure 2.3). The mean number of adult females per adult male was $2.26\pm1.51_{SD}$, infants per adult female were $0.34\pm0.24_{SD}$, immature per adult female was $1.30\pm.75_{SD}$, and adults per immatures were $1.46\pm1.00_{SD}$.

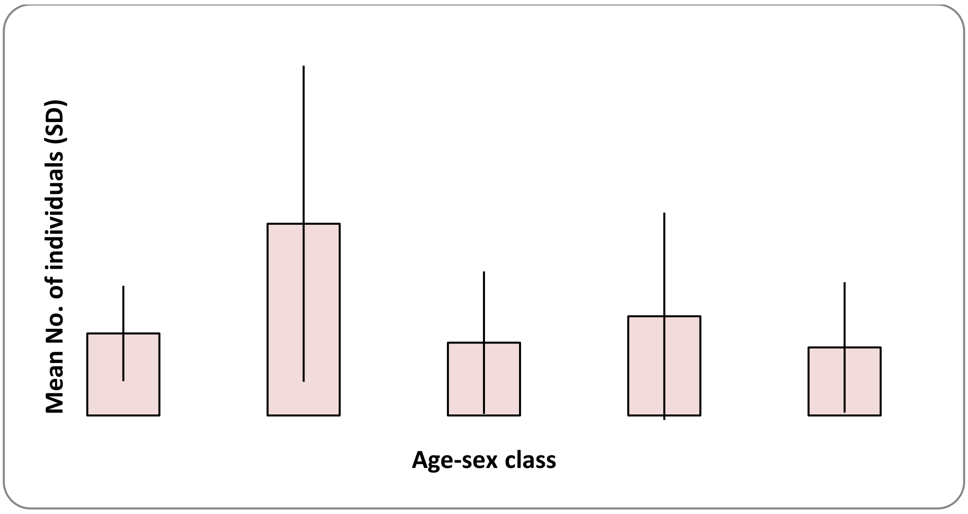


**Figure 2.3**. Mean group composition of rhesus macaque in Hamirpur, Himachal Pradesh (N=45). (AM: adult male; AF: adult female; SA: sub-adult; JUV: juvenile; INF: infant).

## Gopalpur

We detected 673 macaque individuals (93 adult males, 210 adult females, 107 sub-adults, 133 juveniles, and 125 infants) in 40 groups in 1638.7 km of effort (Appendix 2.1. B) that provided the encounter rate of 0.02 groups/km and 0.41 macaques/km. The mean group size of the macaque was $16.83 \pm 12.01_{SD}$. The percentage composition of adults was 45.02% (adult males- 13.82%; adult females- 31.20%) and immature was 54.83% (sub-adults – 16.49%; juveniles-19.76%; infants-18.57%).

Rhesus macaque groups with ≤10 individuals were 15, which is followed by 11 groups ranging from 21-30 individuals, 10 groups under the range of 11-20 individuals, and one group each under the range of 41-50 individuals and 41- 50 individuals (Figure 2.4). The observed groups had $2.33 \pm 1.41_{SD}$ adult males, $5.25 \pm 4.04_{SD}$ adult females, $2.78 \pm 2.16_{SD}$ sub-adults, $3.33 \pm 2.93_{SD}$ juveniles, and $3.13 \pm 2.56_{SD}$ infants (Figure 2.5). The mean number of adult females per adult male was $2.11 \pm 1.17_{SD}$, infants per adult female were $0.61 \pm 0.20_{SD}$, immature per adult female was $1.73 \pm .0.58_{SD}$, and adults per immatures were $0.82 \pm 0.29_{SD}$.

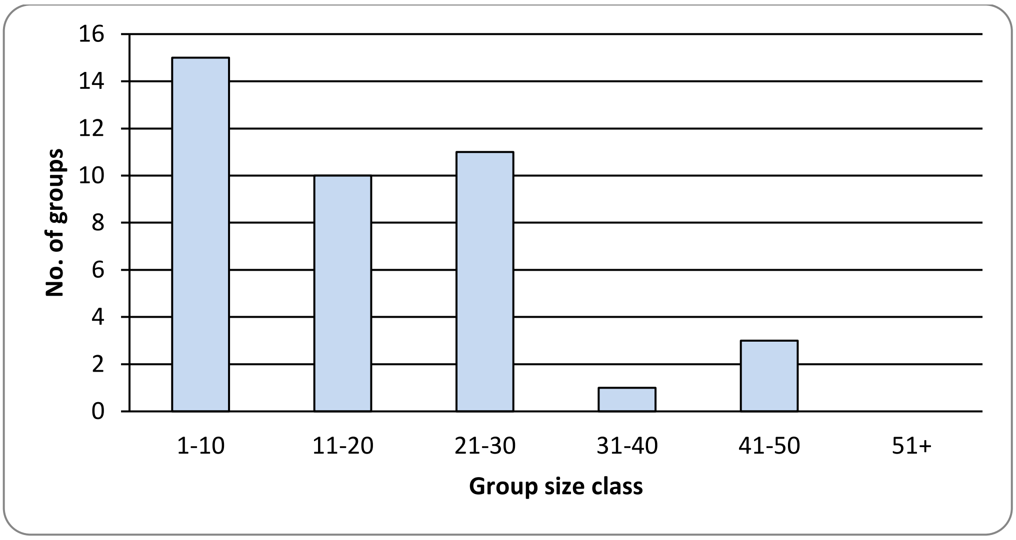


**Figure 2.4**. The number of rhesus macaque groups in different group size classes in Gopalpur, Himachal Pradesh (N=40).

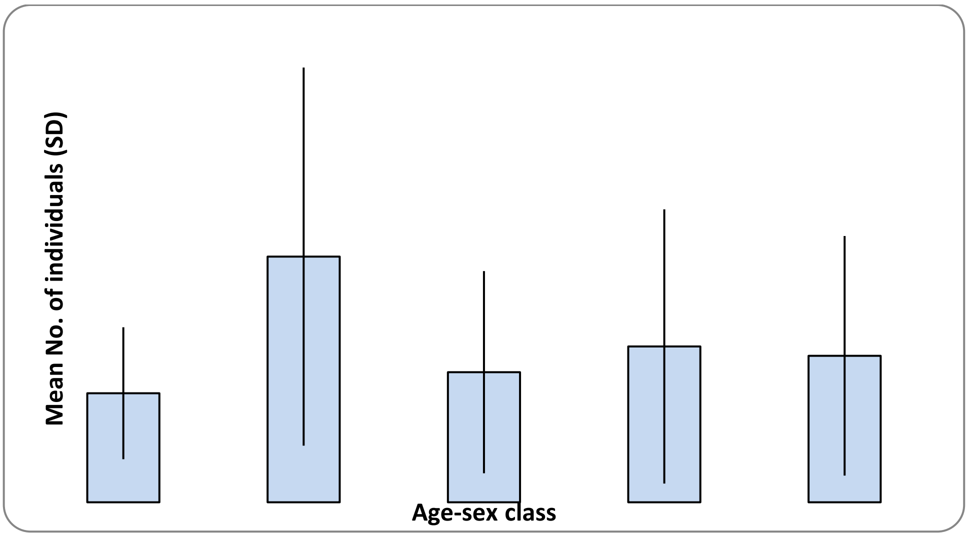


**Figure 2.5**. Mean group composition of rhesus macaque in Gopalpur, Himachal Pradesh (N=40). (AM: adult male; AF: adult female; SA: sub-adult; JUV: juvenile; INF: infant).

## Shimla

We detected 1813 macaque individuals (296 adult males, 612 adult females, 204 sub-adults, 399 juveniles, and 271 infants) in 106 rhesus macaque groups in 1940.9 km of effort (Appendix 2.1. C) that provided the encounter rate of 0.06 groups/km and 0.93 macaques/km. The mean group size of the macaque was $17.10 \pm 14.06_{SD}$. The percentage composition of adults was 50.22% (adult males- 16.37%; adult females- 33.85%) and immature was 48.39% (sub-adults – 11.21%; juveniles-22.14%; infants-15.04%).

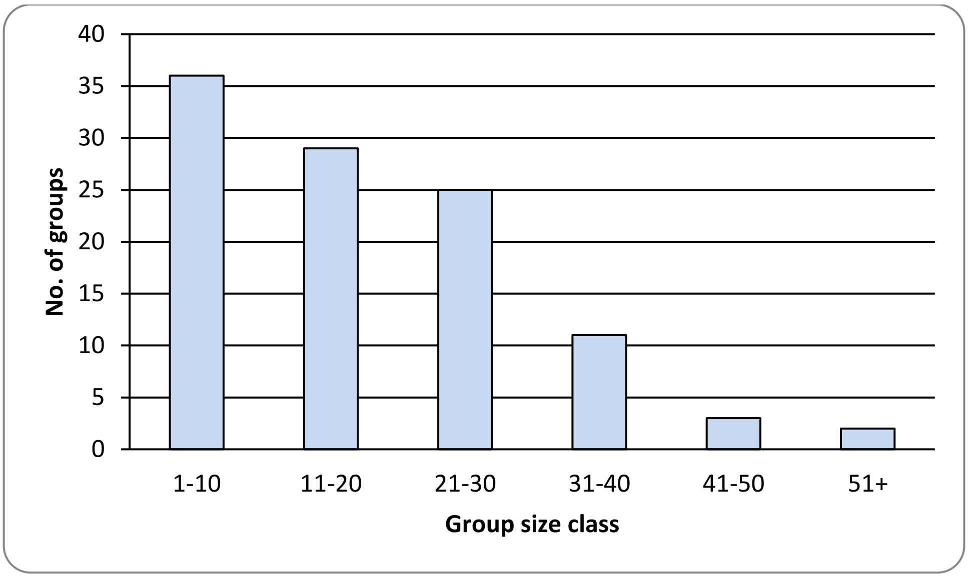


**Figure 2.6**. The number of rhesus macaque groups in different group size classes in Shimla, Himachal Pradesh (N=106).

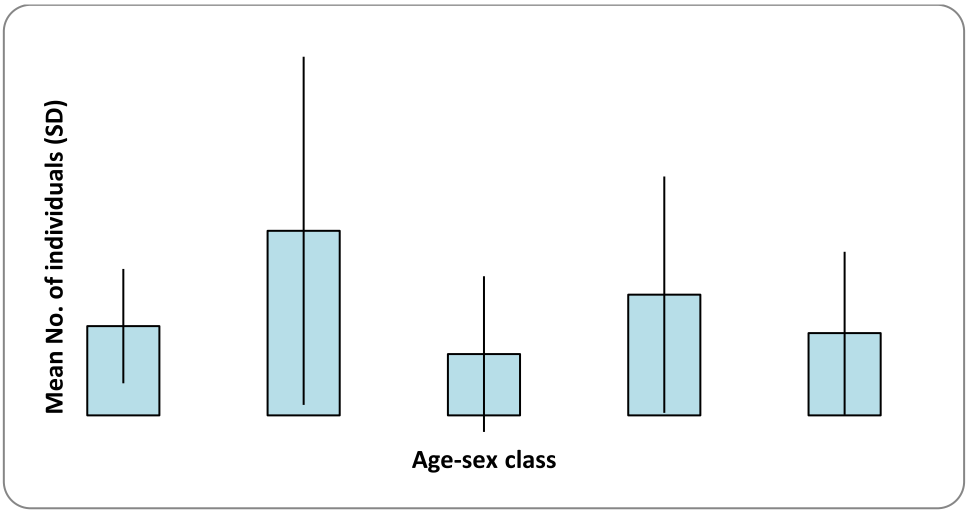


**Figure 2.7.** Mean group composition of rhesus macaque in Shimla, Himachal Pradesh (N=105). (AM: adult male; AF: adult female; SA: sub-adult; JUV: juvenile; INF: infant).

Rhesus macaque groups with ≤10 individuals were 36, which is followed by groups ranging from 11-20 individuals with 29 groups, 25 groups under 21-30 individuals, 11 groups under 31-40 individuals, 3 groups under 41-50 individuals, and two groups under for ≥51 individuals (Figure 2.6). The observed groups had 2.81±1.80$_{SD}$ adult males, 5.81±5.48$_{SD}$ adult females, 1.92±2.45$_{SD}$ sub-adults, 3.80±3.72$_{SD}$ juveniles, and 2.59±2.56$_{SD}$ infants (Figure 2.7). The mean number of adult females per adult male was 1.91±1.50$_{SD}$, infants per adult female were 0.43±0.28$_{SD}$, immature per adult female was 1.43±0.66$_{SD}$, and adults per immature were 1.15±0.80$_{SD}$.

## Chamba

We detected 957 macaque individuals (148 adult males, 342 adult females, 79 sub-adults, 241 juveniles and 128 infants) in 58 rhesus macaque groups in 2301.2 km of effort (Appendix 2.1. D) that provided the encounter rate of 0.03 groups/km and 0.41 macaques/km. The mean group size of the macaque was 16.50±10.74$_{SD}$.

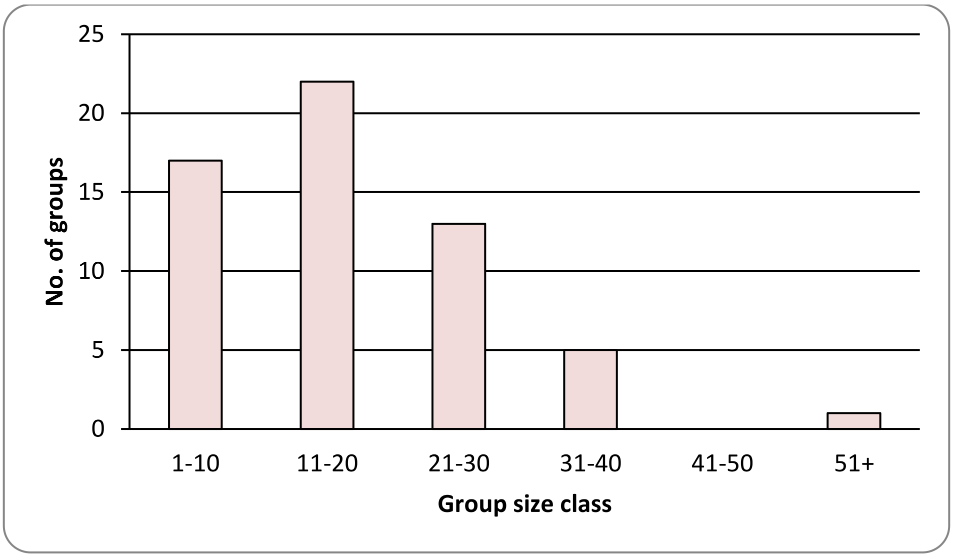


**Figure 2.8**. The number of rhesus macaque groups in different group size classes in Chamba, Himachal Pradesh (N=58).

The percentage composition of adults was 51.20% (adult males- 15.47%; adult females- 35.74%) and immature was 46.81% (sub-adults – 8.26%; juveniles-25.18%; infants-13.38%). Rhesus macaque groups with 11-20 individuals were 22, which is followed by 17 groups under ≤10 individuals, 13 groups under 21-30 individuals, 5 groups under 31-40 individuals, and one group under 51≤ individuals (Figure 2.8). The observed groups had 2.56±1.48$_{SD}$ adult males, 5.90±3.58$_{SD}$ adult females, 1.36±1.77$_{SD}$ sub-adults, 4.16±2.86$_{SD}$ juveniles, and 2.21±2.03$_{SD}$ infants (Figure 2.9). The mean number of adult females per adult male was 2.26±1.25$_{SD}$, infants per adult female were 0.32±0.24$_{SD}$, immature per adult female was 1.20±0.54$_{SD}$, and adults per immature were 1.28±0.92$_{SD}$.


**Figure 2.9**. Mean group composition of rhesus macaque in Chamba, Himachal Pradesh (N=58). (AM: adult male; AF: adult female; SA: sub-adult; JUV: juvenile; INF: infant).

## Paonta Sahib

We detected 398 macaque individuals (71 adult males, 145 adult females, 35 sub-adults, 88 juveniles, and 53 infants) in 26 rhesus macaque groups in 796.2 km of effort (Appendix 2.1. E) that provided the encounter rate of 0.03 groups/km and 0.50 macaques/km. The mean group size of the macaque was $15.31 \pm 8.62_{SD}$. The percentage composition of adults was 54.27% (adult males- 17.84%; adult females- 36.43%) and immature was 44.22% (sub-adults – 8.79%; juveniles-22.11%; infants-13.32%). Rhesus macaque groups with 11-20 individuals were 13, which is followed by seven groups under ≤10 individuals, and three groups each under 21-30 individuals and 31-40 individuals (Figure 2.10). The observed groups had $2.74 \pm 1.46_{SD}$ adult males, $5.58 \pm 3.77_{SD}$ adult females, $1.35 \pm 1.42_{SD}$ sub-adults, $3.39 \pm 2.29_{SD}$ juveniles, and $2.04 \pm 1.51_{SD}$ infants (Figure 2.11). The mean number of adult females per adult male was $2.07 \pm 1.36_{SD}$, infants per adult female were $0.36 \pm 0.18_{SD}$, immature per adult female was $1.46 \pm 0.99_{SD}$, and adults per immatures were $1.40 \pm 0.66_{SD}$.

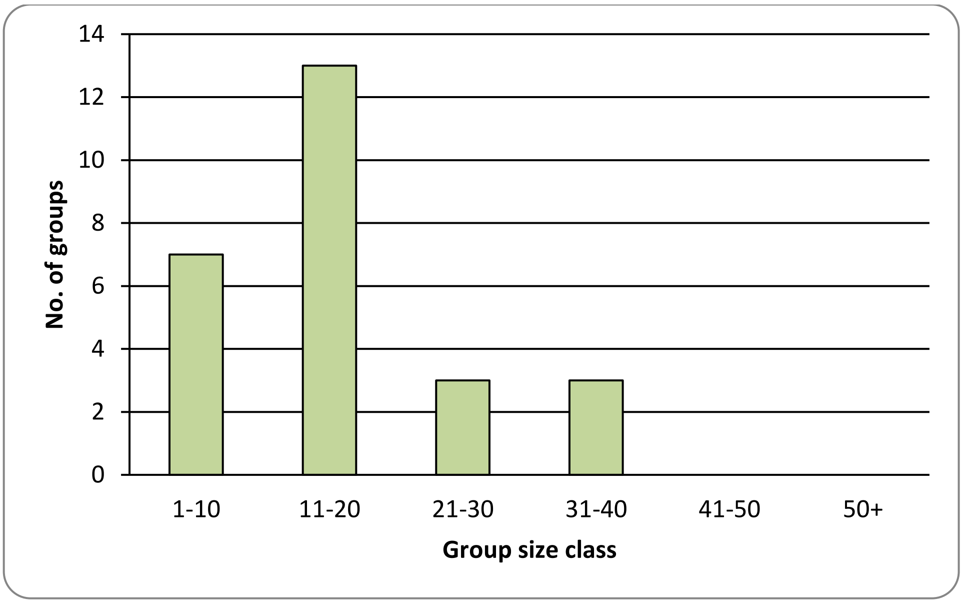


**Figure 2.10**. The number of rhesus macaque groups in different group size classes in Paonta Sahib, Himachal Pradesh (N=26).


**Figure 2.11**. Mean group composition of rhesus macaque in Paonta Sahib, Himachal Pradesh (N=26). (AM: adult male; AF: adult female; SA: sub-adult; JUV: juvenile; INF: infant).

## Mandi

We detected 803 macaque individuals (135 adult males, 310 adult females, 71 sub-adults, 190 juveniles, and 90 infants) in 41 rhesus macaque groups in 2030 km of effort (Appendix 2.1. F) that provided the encounter rate of 0.02 groups/km and 0.40 macaques/km. The mean group size of the macaque was $19.59 \pm 19.46_{SD}$. The percentage composition of adults was 55.85% (adult males- 16.86%; adult females- 38.99%) and immature was 43.90% (sub-adults – 8.93%; juveniles-23.65%; infants-11.32%). Rhesus macaque groups with 11-20 individuals were 15, which is followed by 13 groups under ≤10 individuals, eight groups under 21-30 individuals, two groups each under 31-40 and 41-50 individuals, and one group under ≥51 individuals (Figure 2.12). The observed groups had $3.35 \pm 2.79_{SD}$ adult males, $7.75 \pm 8.38_{SD}$ adult females, $1.78 \pm 2.44_{SD}$ sub-adults, $4.70 \pm 5.07_{SD}$ juveniles, and $2.25 \pm 2.32_{SD}$ infants (Figure 2.13).

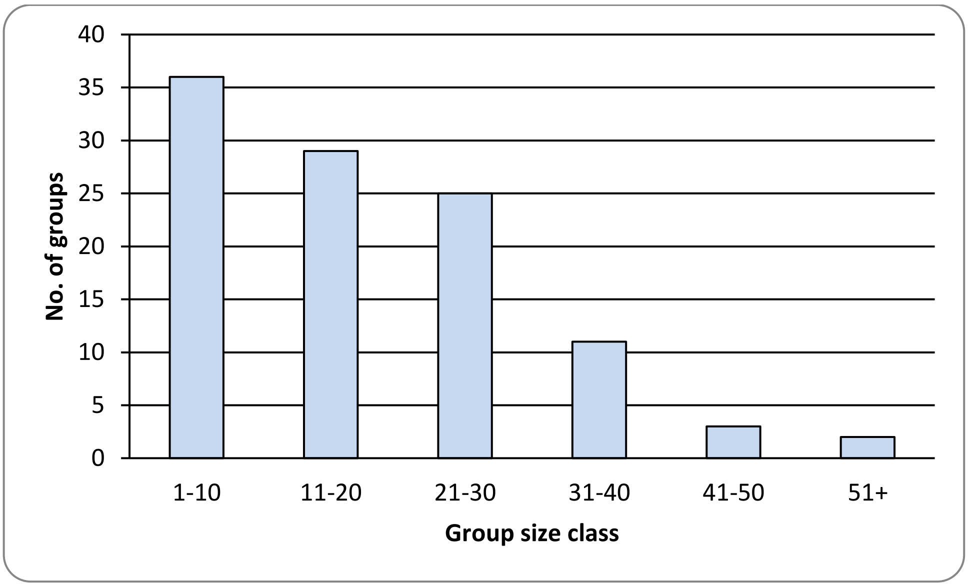


**Figure 2.12.** The number of rhesus macaque groups in different group size classes in Mandi, Himachal Pradesh (N=41).

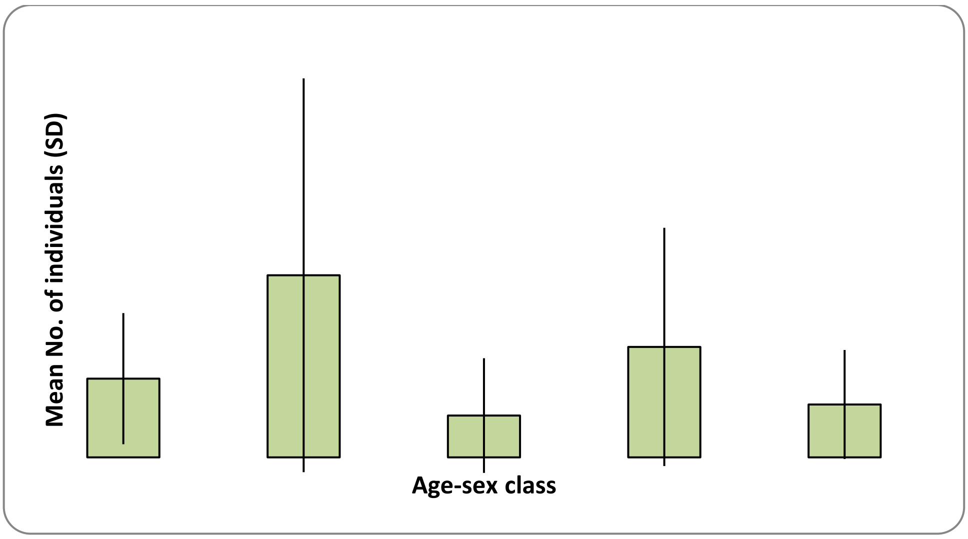


**Figure 2.13**. Mean group composition of rhesus macaque in Mandi, Himachal Pradesh (N=40). (AM: adult male; AF: adult female; SA: sub-adult; JUV: juvenile; INF: infant).

The mean number of adult females per adult male was 2.35±1.35$_{SD}$, infants per adult female were 0.29±0.20$_{SD}$, immature per adult female was 1.15±0.58$_{SD}$, and adults per immatures were 1.70±1.42$_{SD}$.

## Una

We detected 1015 macaque individuals (206 adult males, 377 adult females, 227 sub-adults, 88 juveniles, and 118 infants) in 75 rhesus macaque groups in 390 km of effort (Appendix 2.1. G) that provided the encounter rate of 0.19 groups/km and 2.60 macaques/km. The mean group size of the macaque was 13.53±7.30$_{SD}$. The percentage composition of adults was 57.44% (adult males- 20.30%; adult females- 37.14%) and immature was 42.66% (sub-adults – 22.37%; juveniles-8.67%; infants-11.63%). Rhesus macaque groups with ≤10 individuals were 33, which is followed by 29 groups under 11-20 individuals, 10 groups under 21-30 individuals, and three groups under 31-40 individuals (Figure 2.14).

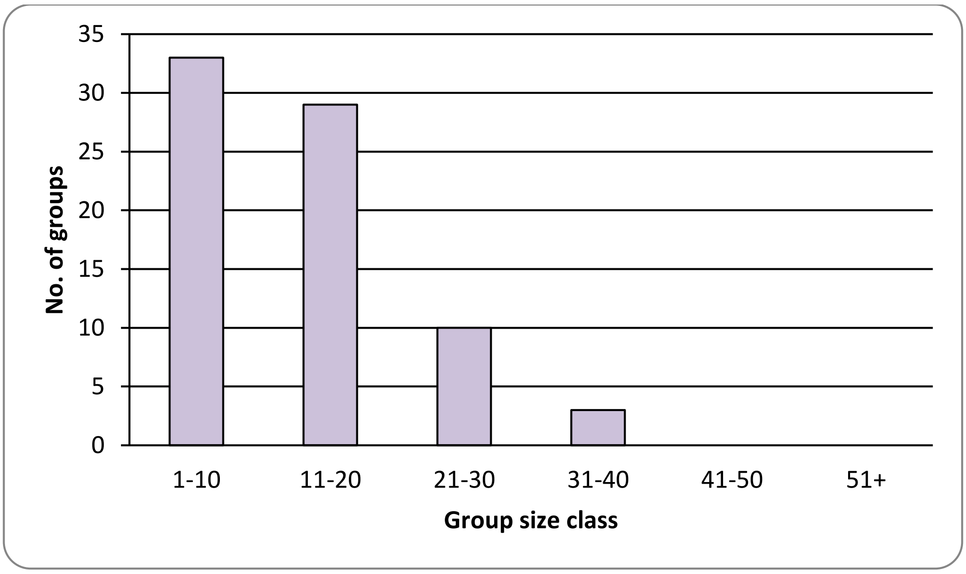


**Figure 2.14**. The number of rhesus macaque groups in different group size classes in Una, Himachal Pradesh (N=75).

The observed groups had 2.75±1.92$_{SD}$ adult males, 5.03±3.02$_{SD}$ adult females, 3.03±2.06$_{SD}$ sub-adults, 1.17±1.52$_{SD}$ juveniles, and 1.57±1.58$_{SD}$ infants (Figure 2.15). The mean number of adult females per adult male was 2.23±1.39$_{SD}$, infants per adult female were 0.34±0.35$_{SD}$, immature per adult female was 1.36±1.03$_{SD}$, and adults per immature were 1.76±1.22$_{SD}$.

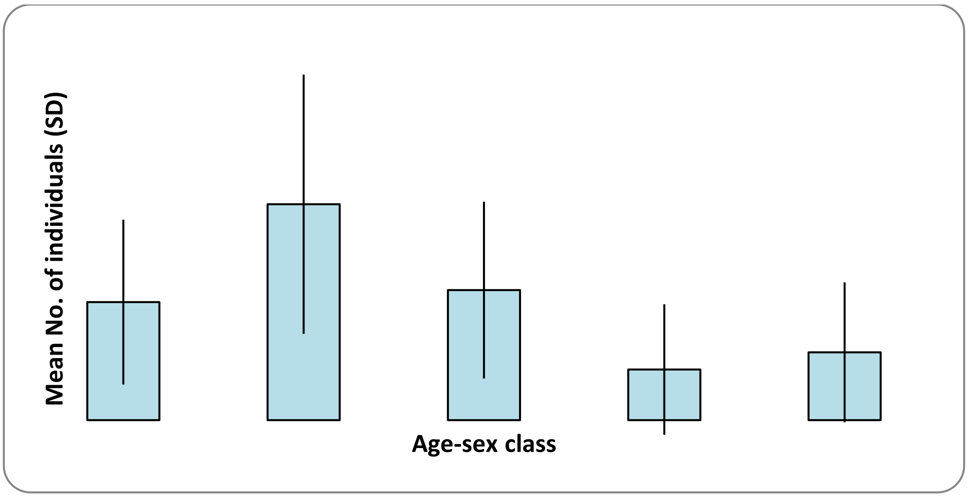


**Figure 2.15**. Mean group composition of rhesus macaque in Una, Himachal Pradesh (N=75). (AM: adult male; AF: adult female; SA: sub-adult; JUV: juvenile; INF: infant).

## All locations of Himachal Pradesh

A total of 6394 macaque individuals were counted (1065 adult males, 2267 adult females, 830 sub-adults, 1279 juveniles, and 881 infants) in 391 rhesus macaque groups in 9945.2 km of effort that provided the encounter rate of 0.04 groups/km and 0.64 macaques/km. The mean group size of the macaque was $16.35\pm12.62_{SD}$. The rhesus macaque groups had $8.56\pm6.46_{SD}$ adults and $7.68\pm6.64_{SD}$ immature; composed of $2.73\pm1.82_{SD}$ adult males, $5.82\pm4.96_{SD}$ adult females, $2.13\pm2.23_{SD}$ sub-adults, $3.28\pm3.40_{SD}$ juveniles and $2.27\pm2.21_{SD}$ infants (Figure 2.16). A significant variation in the mean number of individuals of sub-adults ($\chi^2$= 22.96, *df*= 6, p>0.00), juveniles ($\chi^2$=81.33, *df*= 6, p> 0.00), and infants ($\chi^2$= 13.04, *df*= 6, p> 0.01) (Table 1), were observed among the seven different sites (Chamba, Gopalpur, Hamirpur, Mandi, Paonta Sahib, Shimla, and Una) in Himachal Pradesh (Table 2.1).

The number of groups observed tends to decrease in relation to the increasing group size. Rhesus macaque groups with ≤10 individuals were 138, which is followed by 132 groups under 11-20 individuals, 80 groups under 21-30 individuals, 27 groups under 31-40 individuals, nine groups under 41-50 individuals, and five groups under ≥51 individuals (Figure 2.17).

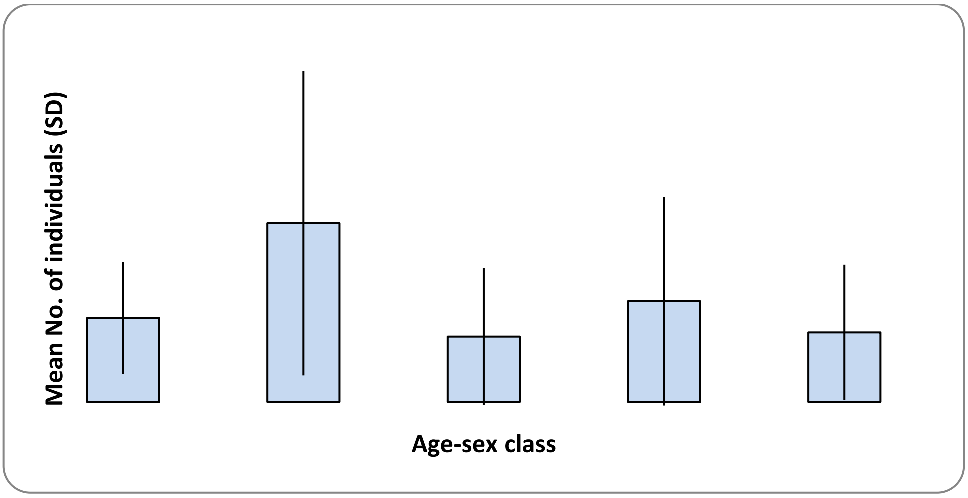


**Figure 2.16**. Mean group composition of rhesus macaque in Himachal Pradesh (N=389). (AM: adult male; AF: adult female; SA: sub-adult; JUV: juvenile; INF: infant).

**Table 2.1**. Mean group composition of rhesus macaque in different sample sites in Himachal Pradesh (N=389). (AM: adult male; AF: adult female; SA: sub-adult; JUV: juvenile; INF: infant). **Significant at the level of p≥0.01

| Site | Mean age sex individuals (SD) | | | | |
|---|---|---|---|---|---|
| | **AM** | **AF** | **SA** | **JUV** | **INF** |
| Chamba (58) | 2.56±1.48 | 5.90±3.58 | 1.37±1.77 | 4.16±2.86 | 2.21±2.03 |
| Gopalpur (40) | 2.33±1.41 | 5.25±4.04 | 2.78±2.16 | 3.33±2.93 | 3.13±2.56 |
| Hamirpur (45) | 2.58±1.5 | 6.03±4.97 | 2.29±2.24 | 3.12±3.26 | 2.14±2.05 |
| Mandi (40) | 3.35±2.79 | 7.75±8.38 | 1.78±2.44 | 4.70±5.07 | 2.25±2.32 |
| Paonta Sahib (26) | 2.74±1.46 | 5.58±3.77 | 1.35±1.42 | 3.39±2.29 | 2.04±1.51 |
| Shimla (105) | 2.81±1.8 | 5.81±5.48 | 1.93±2.45 | 3.80±3.72 | 2.59±2.56 |
| Una (75) | 2.75±1.92 | 5.03±3.02 | 3.03±2.06 | 1.18±1.52 | 1.58±1.63 |
| **$\chi^2$ (*df*)** | **4.25 (6)** | **35.49 (6)** | **22.96 (6)** | **81.33 (6)** | **13.04 (6)** |
| **p value** | **0.26** | **0.19** | **0.00 *** | **0.00 *** | **0.01 *** |

The mean number of adult females per adult male was $2.14\pm1.39_{SD}$, infants per adult female were $0.38\pm0.28_{SD}$, immature per adult female was $1.36\pm0.83_{SD}$, and adults per immature were $1.39\pm1.03_{SD}$ (Table 2.2).

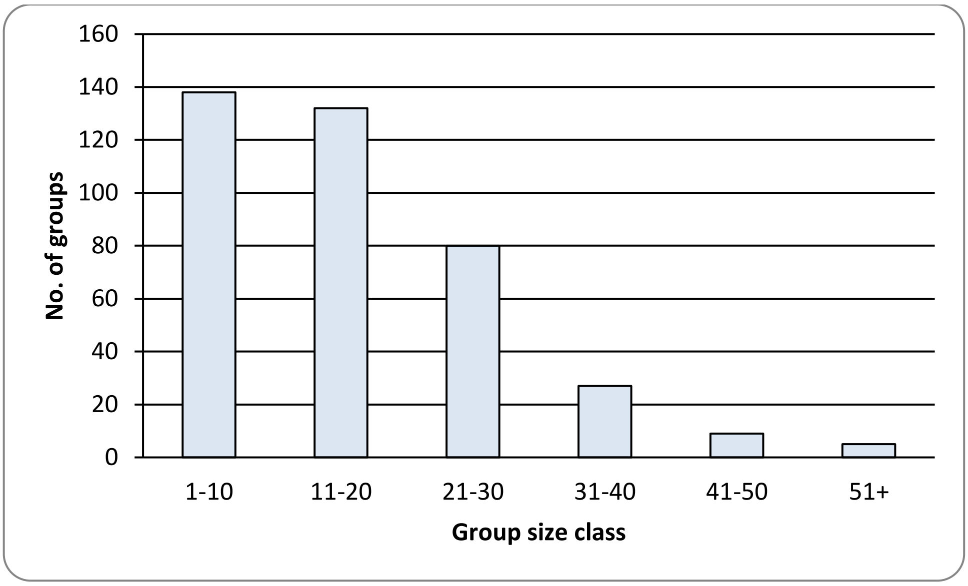


**Figure 2.17.** The number of rhesus macaque groups in different group size classes in Himachal Pradesh (N=391).

**Table 2.2**. Age-sex ratios observed in different sampling sites in Himachal Pradesh (N=389). (AM- adult male; AF- adult female; IN- infant; Ad- adults; Im- immature).

| **Site** | **Mean age-sex ratio (SD)** | | | |
|---|---|---|---|---|
| | **AM:AF** | **AF:IN** | **AF:Im** | **Im:Ad** |
| Chamba | 2.26±1.25 | 0.32±0.24 | 1.20±0.54 | 1.28±0.92 |
| Gopalpur | 2.11±1.17 | 0.61±0.20 | 1.73±0.58 | 0.82±0.29 |
| Hamirpur | 2.26±1.51 | 0.34±0.24 | 1.30±0.75 | 1.46±1.00 |
| Mandi | 2.35±1.35 | 0.29±0.20 | 1.15±0.58 | 1.70±1.42 |
| Paonta Sahib | 2.07±1.36 | 0.36±0.18 | 1.46±0.99 | 1.40±0.66 |
| Shimla | 1.91±1.50 | 0.43±0.28 | 1.43±0.91 | 1.15±0.80 |
| Una | 2.23±1.39 | 0.34±0.35 | 1.36±1.03 | 1.76±1.22 |
| **H P** | **2.14±1.39** | **0.38±0.28** | **1.36±0.83** | **1.39±1.03** |

The R-squared value of the relationship between adult males and adult females is 0.59, adult females and infants are 0.49, adult females and immature are 0.69, and immature to adults is 0.69 (Figure 2.18).

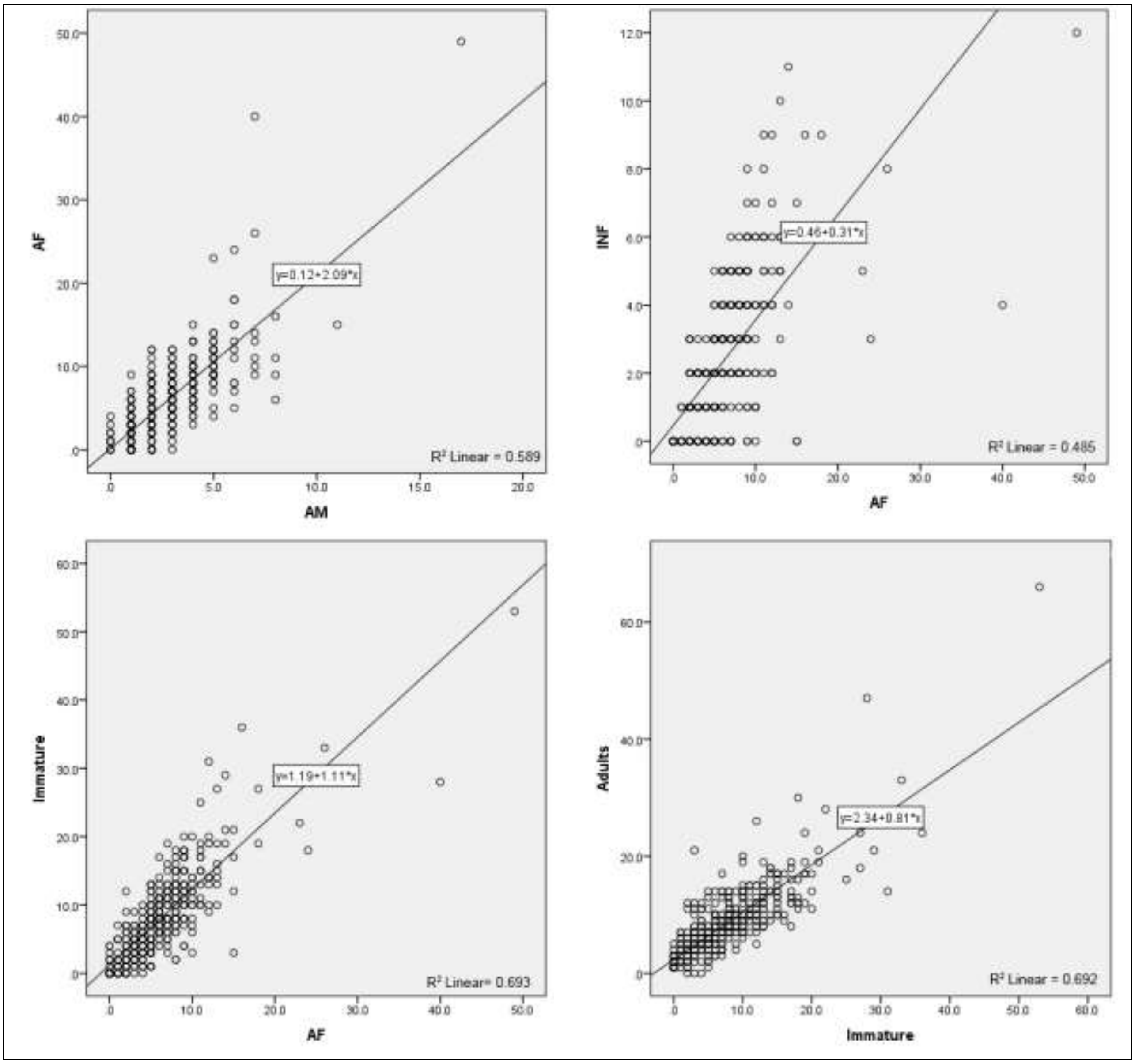


**Figure 2.18**. Relationship between the number of different age sex individuals observed in Himachal Pradesh (N=389). (AM: adult male, AF: adult female, INF: infant)

Individuals of different age-sex categories and group sizes were all positively correlated with significance at the level of $p \leq 0.01$. With an increase in the group size, the number of adult males, adult females, sub-adults, juveniles, and infants tends to increase significantly thus showing a strong positive correlation (Table 2.3).

**Table 2.3**. Correlation matrix depicting the relationship between different age-class individuals in Himachal Pradesh (N=389); **Correlation is significant at the 0.01 level (2-tailed). (AM- adult male; AF- adult female; SA- sub-adult; Juv- juvenile; Inf- infant).

| | AF | SA | JUV | INF | Adults | Immature | TOTAL |
|---|---|---|---|---|---|---|---|
| **AM** | .767** | .503** | .657** | .544** | .871** | .686** | .811** |
| **AF** | 1 | .583** | .790** | .696** | .984** | .832** | .945** |
| **SA** | | 1 | .474** | .506** | .589** | .747** | .696** |
| **JUV** | | | 1 | .697** | .791** | .903** | .887** |
| **INF** | | | | 1 | .687** | .860** | .808** |
| **Adults** | | | | | 1 | .832** | .954** |
| **Immature** | | | | | | 1 | .957** |

## Control group – Hoshiarpur

We detected 1310 macaque individuals (192 adult males, 526 adult females, 147 sub-adults, 297 juveniles and 148 infants) in 45 rhesus macaque groups in 1174 km of effort (Appendix 2.1.H) that provided the encounter rate of 0.38 groups/km and 1.12 macaques/km. The mean group size of the macaque was $29.11 \pm 25.28_{SD}$. The rhesus macaque groups had $15.96 \pm 14.46_{SD}$ adults and $13.16 \pm 11.34_{SD}$ immature; composed of $4.27 \pm 3.95_{SD}$ adult males, $11.69 \pm 10.79_{SD}$ adult females, $3.27 \pm 4.31_{SD}$ sub-adults, $6.60 \pm 5.68_{SD}$ juveniles and $3.29 \pm 2.64_{SD}$ infants (Figure 2.19). The percentage composition of adults was 54.81% (adult males- 14.66%; adult females- 40.15%) and immature was 45.19% (sub-adults – 11.22%; juveniles- 22.67%; infants-11.30%).

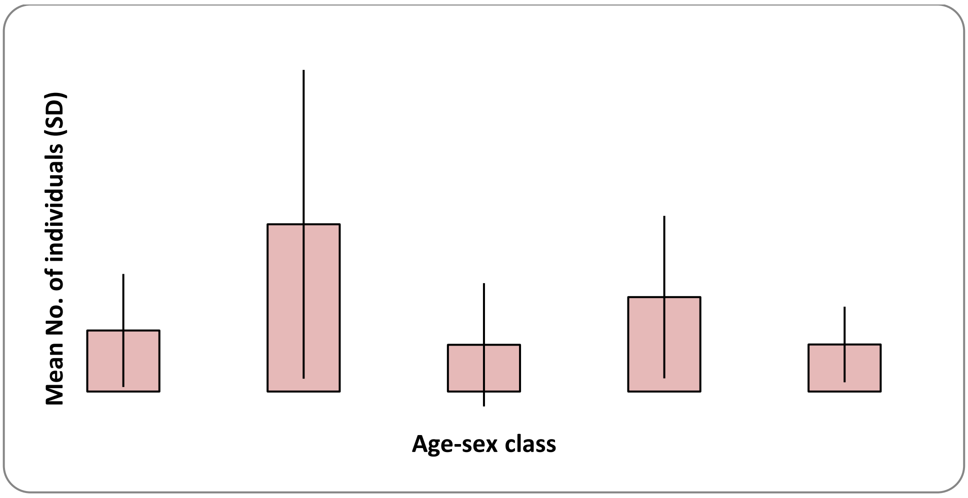


**Figure 2.19**. Mean group composition of rhesus macaque in Hoshiarpur, Punjab (N=45). (AM: adult male; AF: adult female; SA: sub-adult; JUV: juvenile; INF: infant).

Rhesus macaque groups with 11-20 individuals were 16, which is followed by eight groups under 31-40 individuals, seven groups under 1-10 individuals, five groups under 41-50 individuals, five groups under ≥51 individuals, and four groups under 21-30 individuals (Figure 2.20). The mean number of adult females per adult male was $2.94 \pm 1.30_{SD}$, infants per adult female were $0.31 \pm 0.18_{SD}$, immature per adult female was $1.16 \pm 0.51_{SD}$, and adults per immature were $1.37 \pm 0.59_{SD}$.

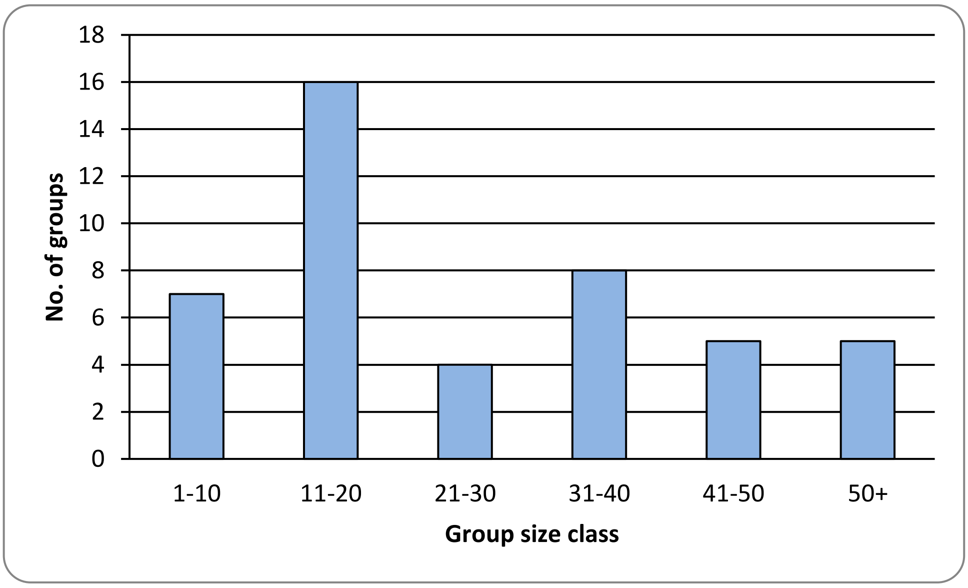


**Figure 2.20**. The number of rhesus macaque groups in different group size classes in Hoshiarpur, Punjab (N=45).

The R squared value of the relationship between adult male and adult female is 0.82, adult females and infants are 0.47, adult females and immature are 0.85 and immature to adults are 0.84 (Figure 2.21).

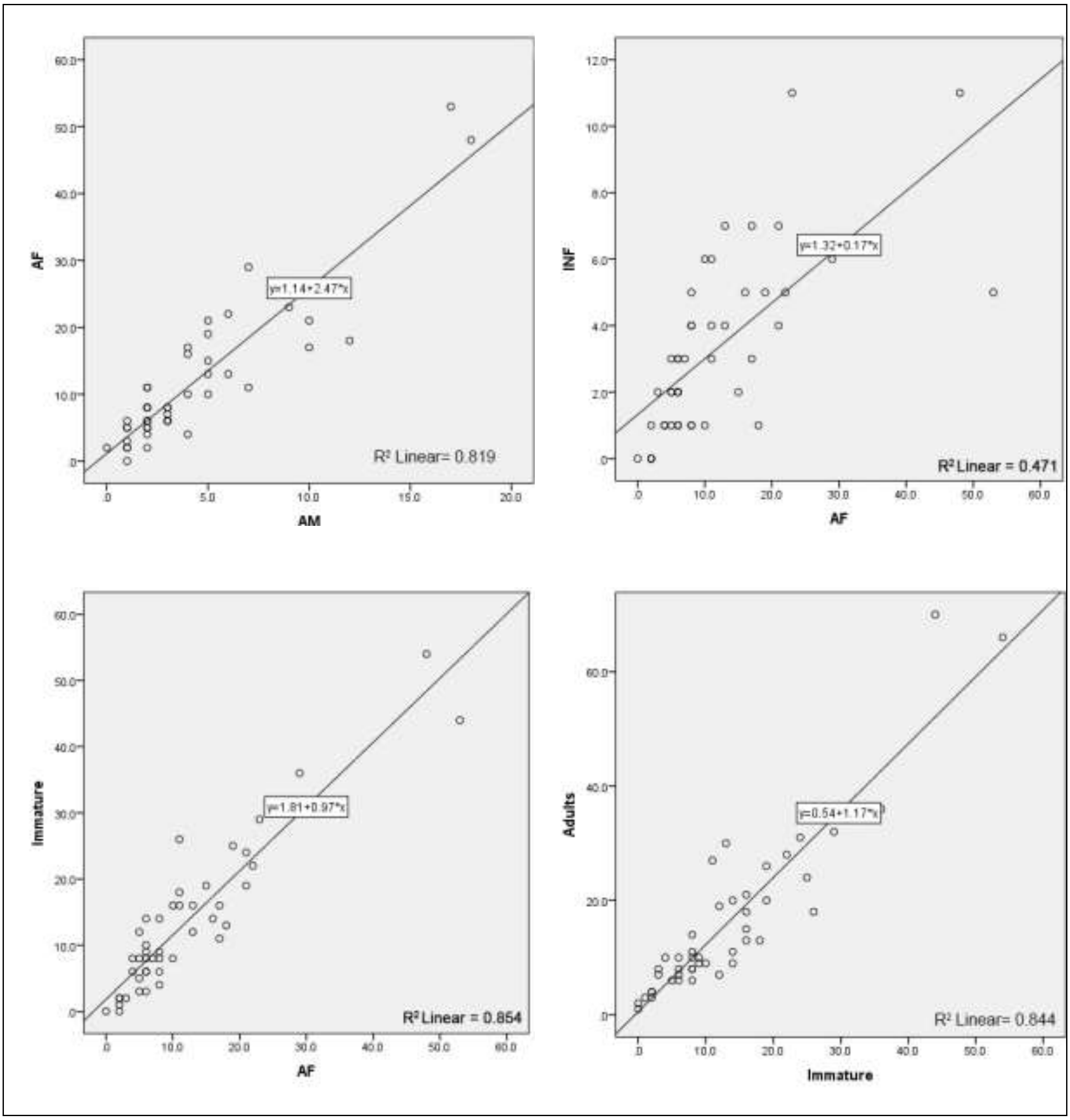


**Figure 2.21.** Relationship between number of different age-sex individuals observed in Hoshiarpur, Punjab (N=45). (AM: adult male, AF: adult female, INF: infant)

Individuals of different age-sex categories and group sizes were all positively correlated ($p \leq 0.01$). With an increase in the group size, the number of adult males, adult females, sub-adults, juveniles, and infants tends to increase significantly thus showing a strong positive correlation (Table 2.4).

**Table 2.4.** Correlation matrix depicting the relationship between different age-class individuals in Hoshiarpur, Punjab (N=45); **Correlation is significant at the 0.01 level (2-tailed). (AM- adult male; AF- adult female; SA- sub-adult; Juv- juvenile; Inf- infant).

| | AF | SA | JUV | INF | Adults | Immature | TOTAL |
|---|---|---|---|---|---|---|---|
| AM | .998** | .991** | .996** | .994** | .999** | .997** | .998** |
| AF | 1 | .995** | .998** | .995** | 1.000** | .999** | 1.000** |
| SA | | 1 | .992** | .987** | .994** | .995** | .995** |
| JUV | | | 1 | .994** | .998** | .999** | .999** |
| INF | | | | 1 | .995** | .996** | .996** |
| Adults | | | | | 1 | .999** | 1.000** |
| Immature | | | | | | 1 | 1.000** |

## Comparison between the macaque population in Himachal Pradesh and Hoshiarpur, Punjab:

The percent number of groups between the study site (Himachal Pradesh) and the control site (Hoshiarpur) showed significant variation in some of the group size classes i.e.,1-10 ($G = 5.77$, $df = 1$, $p < 0.05$), 41-50 ($G = 6.42$, $df = 1$, $p < 0.05$), and ≥51 ($G = 9.93$, $df = 1$, $p < 0.01$) (Table 5). Whereas groups with medium-ranging group sizes (11-20, 21-30, and 31-40) did not exhibit any significant variation compared to the control population (Table 2.5).

Mann-Whitney U test to determine the difference between the percentage of age-sex individuals of the sterilized population (Himachal Pradesh) against the control population (Hoshiarpur, Punjab) (Table 2.6). The results indicate that a significant variation among the percent of adult males ($U= 6615.50$, $Z= -2.69$, $p < 0.01$), adult females ($U= 5777.00$, $Z=-3.74$, $p < 0.00$) and juveniles ($U= 6622.50$, $Z= -2.70$, $p < 0.01$) whereas, percentage of sub-adults, infants, adults, and immature did not show any significant variation. The age-sex ratios showed a significant variation for AM:AF ($U= 5233.50$, $Z= -4.04$, $p < 0.00$) meanwhile other ratios; AF:IN (adult female: infant), AF:Im (adult female: immature) and Im:Ad (immature: adult) did not vary significantly (Table 2.7).

**Table 2.5.** Test to determine the difference between the percent of groups of various size classes of rhesus macaque observed in sterilized populations (Himachal Pradesh [Chamba, Gopalpur, Hamirpur, Mandi, Paonta Sahib, Shimla, and Una]) against control population (Hoshiarpur, Punjab).(AM- adult male; AF- adult female; IN- infant; Ad- adults; Im- immature).

| Group size | H P % (n=391) | Hoshiarpur % (n=45) | Test results |
|---|---|---|---|
| **1-10** | 35.29 | 15.56 | G = 5.77, df = 1, p <0.05 |
| **11-20** | 33.76 | 35.56 | G = 0.03, df = 1, p = 0.98 |
| **21-30** | 20.46 | 8.89 | G = 3.43, df = 1, p =0.17 |
| **31-40** | 6.91 | 17.78 | G = 4.59, df = 1, p = 0.10 |
| **41-50** | 2.30 | 11.11 | G = 6.42, df = 1, p <0.05 |
| **51+** | 1.28 | 11.11 | G = 9.93, df = 1, p <0.01 |

**Table 2.6**. Mann-Whitney U test to determine difference between percentages of age-sex individuals observed in sterilized population (Himachal Pradesh) against control population (Hoshiarpur, Punjab). (AM- adult male; AF- adult female; IN- infant; Ad- adults; Im- immature)

| Age-sex class | H P % (n=389) | Hoshiarpur % (n=45) | Test results |
|---|---|---|---|
| AM | 16.68 | 14.66 | U= 6615.50, Z= -2.69, p <0.01 |
| AF | 35.53 | 40.15 | U= 5777.00, Z=-3.74, p <0.00 |
| SA | 12.99 | 11.22 | U= 8227.00, Z= -0.67, p =0.51 |
| JUV | 20.03 | 22.67 | U= 6622.50, Z= -2.70, p <0.01 |
| INF | 13.82 | 11.30 | U= 8500.50, Z= -0.32, p =0.75 |
| Ad | 52.20 | 54.81 | U= 8442.50, Z= -0.39, p =0.70 |
| Im | 46.84 | 45.19 | U= 8693.50, Z= -0.07, p= 0.94 |

**Table 2.7**. Mann-Whitney U test to determine difference between mean age-sex ratios observed in sterilized population (Himachal Pradesh) against control population (Hoshiarpur, Punjab). (AM- adult male; AF- adult female; IN- infant; Ad- adults; Im- immature)

| Age-sex class | Mean age-sex ratio | | Test results |
|---|---|---|---|
| | H P (n=389) | Hoshiarpur (n=45) | |
| AM:AF | 1: 2.14 | 1: 2.94 | U= 5233.50, Z= -4.04, p <0.00 |
| AF:IN | 1: 0.38 | 1: 0.31 | U= 6480.50, Z= -1.59, p =0.11 |
| AF:Im | 1: 1.36 | 1: 1.16 | U= 6306.50, Z= -1.83, p =0.07 |
| Im:Ad | 1: 1.39 | 1: 1.37 | U= 6336.50, Z= -1.34, p =0.18 |

## Discussion

Sterilization and translocation of macaques have been practiced in Himachal Pradesh for almost one and a half decades. With the approval of the Central Government, the culling of the macaque was allowed at identified regions in the state from 2018 (Khanna 2019; Sharma 2020). One of the consequences of such measures on macaque was high number of smaller groups and very few with higher group sizes in Himachal Pradesh than in the control population of Hoshiarpur. Also, the mean group size of macaques in Himachal Pradesh (16.40) is lower than in Hoshiarpur (29.10). Even the mean group size of macaques in Himachal Pradesh is much lower than the earlier records e.g., 33.10 in 1980 (Tiwari and Mukherjee 1982), 32 in Shimla of Himachal Pradesh (Pirta et al. 1997; Ciani 1984). The mean group size of macaques in Himachal Pradesh is much lesser than in many other locations in its distribution range i.e., lesser than the 35 locations of the 44 locations (Appendix 2.2). This clearly indicates that the drop in the mean group size of macaques within Himachal Pradesh over the period, and also lesser than the many other locations is the consequence of the sterilisation program and also the randomisation of the macaques while capturing and releasing of the macaques.

A few aspects of the social organisation showed some variation from the earlier records in the same population, control population, or other populations. The current adult male-adult female ratio of 1:2.14 is much lesser than the earlier ratio (1:4.69 in 1980: Tiwari and Mukherjee 1982), and 1:2.94 in the control population (Hoshiarpur). Immature-adult sex ratios were observed high in the current study compared to previous studies with an average of 1.75 adults per immature. Surprisingly the control population exhibited a higher ratio

(1.99 adults per immature). Chaudhari et al. (2006) recorded 1.79 adults per immature in Jalpaiguri and 2.03 adults per immature in Darjeeling, West Bengal. Tiwari and Mukherjee (1982) recorded a ratio of 2.54 adults per immature in Jammu and Kashmir, and also Mukherjee et al. (1993) recorded a ratio of 1.85 adults per immature in Tripura, India. All previous studies showed a lower immature: adult ratio compared to the present study. Similarly, the percentage of adult males is higher in the population whereas the percentage of infants recorded tends to be lower when compared to previous studies. The skewed groups and odd ratios of individuals among the groups also may be the result of randomisation that occurred in the rhesus macaque population.

# Chapter III

# Relatedness of rhesus macaques sterilised in each sterilisation centres of Himachal Pradesh

## Introduction

During the study, and as mentioned in the first two chapters, many groups have highly skewed age-sex composition. This has led to documenting the process of capturing macaques for sterilization and later release of them. The macaques are captured by a certain community who are known to capture the macaque. These people are provided with an incentive of Rs. 300.00/macaque initially, later the incentive was increased to Rs. 1000.00/macaque. These people capture the macaques and bring them to the sterilization center, where they are paid the money, meanwhile, the location of the capture is noted as mentioned by the people. After the sterilization, the macaques are released back by the department. However, the capturing and release of the macaque are not monitored. And in most cases, a few macaques are captured from their social group, after they were brought to the sterilization center, the macaques were kept in separate cages. After the sterilization of the individuals, the pooled individuals are released back to the assumed captured location. This has led us to think of a high degree of randomization of macaque individuals from various groups and locations. We hypothesized that the macaques in each sterilization center should be closely related and individuals from different centers should form separate clusters. To verify this, we studied the relatedness of individuals from each sterilization center.

## Methods and analysis

A total of 25 samples of Rhesus Macaques from 6 locations of Himachal Pradesh were selected for whole genome analysis. High-quality genomic DNA was isolated from blood samples using the Qiagen DNeasy Blood and Tissue Kit. We quantified the genomic DNA extract using a high-sensitivity double-stranded DNA assay in Qubit 4 (Thermo Fisher Scientific, USA). DNA concentration was diluted to 20ng/ul, and one microgram of DNA was taken as input for library preparation using the Illumina Truseq DNA PCR-free library preparation kit. The input DNA was first randomly sheared into 350bp fragments using the Covaris ultra-sonicator. The ends of the fragmented DNA were repaired and dA-tailed prior to ligation using unique dual (UD) indexing adaptors for Illumina (IDT, USA). The adaptor-ligated library fragments were size-selected and purified with SPRI beads (Beckman Coulter, USA). The fragment sizes of the libraries were verified using Agilent Bioanalyzer high-sensitivity DNA chip. The libraries were quantified using a qPCR library validation kit (Takara Bio, USA) and the concentrations were adjusted before pooling with other libraries. The pooled libraries were denatured into single-stranded DNA before loading onto a patterned flow cell and sequenced for 30x coverage on the Novaseq platform. The whole genome sequence reads were compared using MASHTREE pipeline to infer relationships between samples based on genome-wide shared SNPs (Katz et al., 2019). The tree was visualized and analyzed on the iTOL web server (https://itol.embl.de/).

## Results

We observed 4 major clusters in the unrooted neighbor-joining tree (Figure 3.1). Mahalat and Dharampur samples from Una form the most distinct population clusters with 2-3 sub-groups with limited gene flow. Whereas, samples from Jogindernagar, Dindoo, Jhandutta, and Puanta Sahib form mixed clusters indicating gene flow among these populations (Figure 3.2).

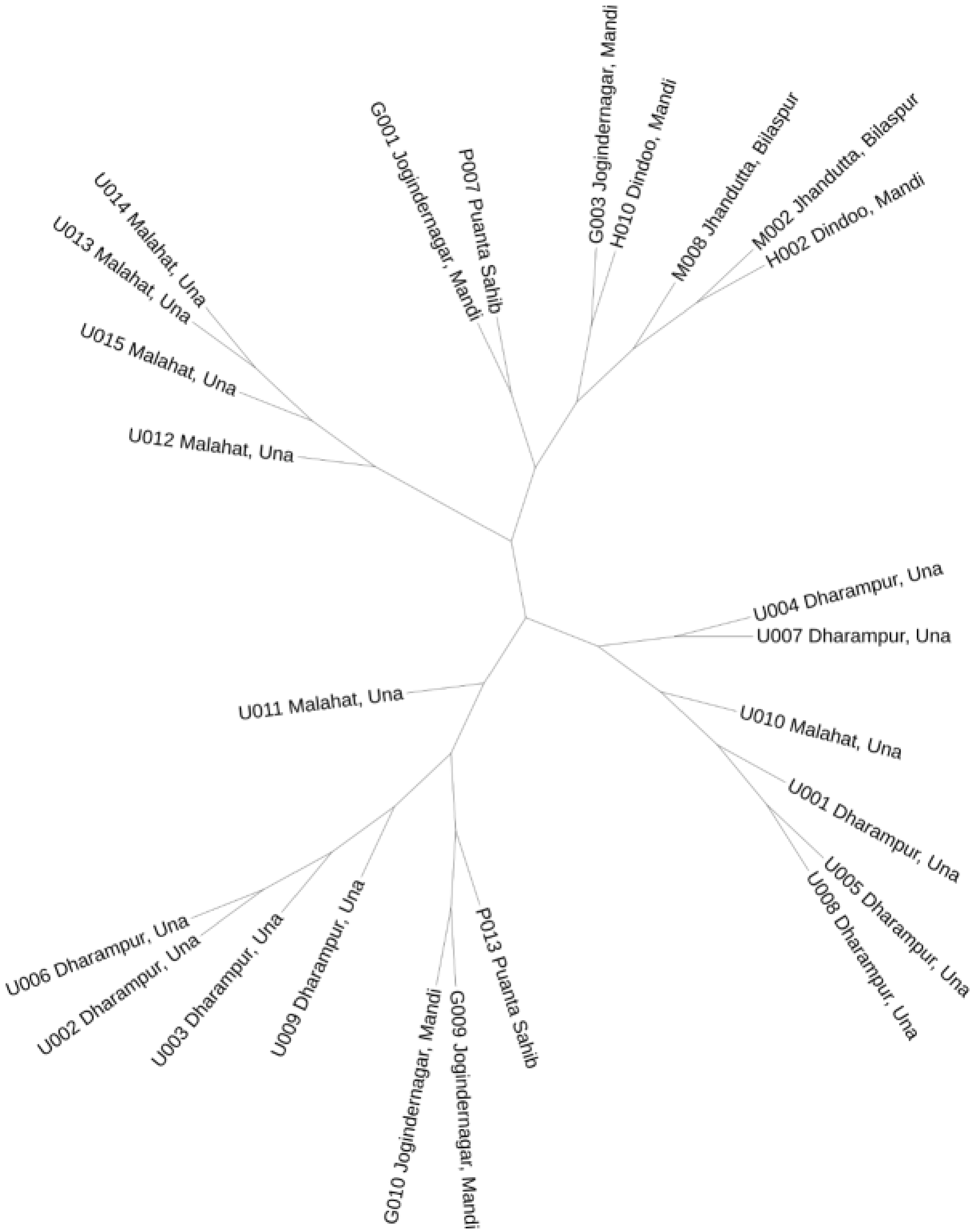


**Figure 3.1.** Unrooted Neighbour-joining tree of Rhesus Macaques

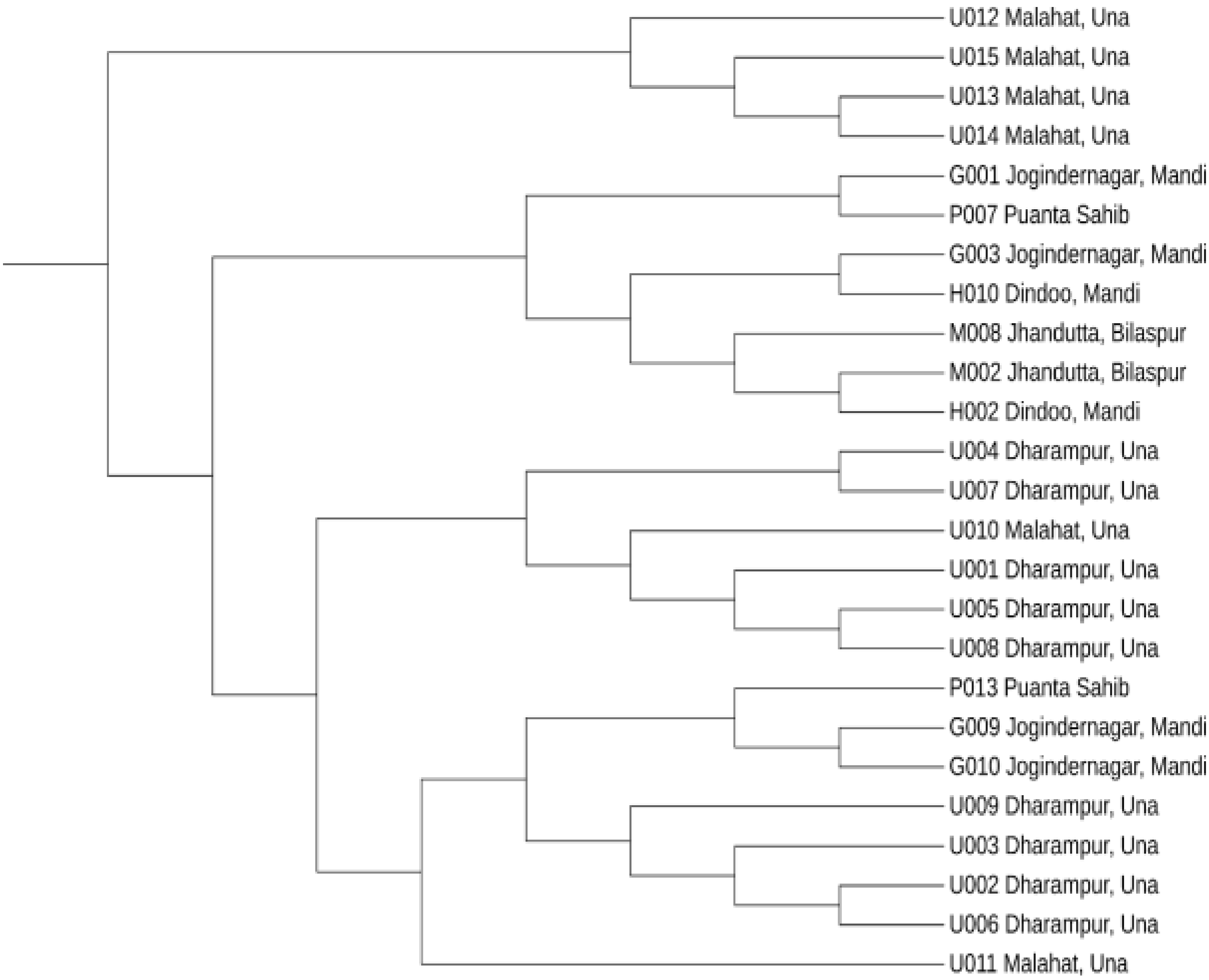


**Figure 3.2.** Rooted Neighbour-joining tree of Rhesus Macaques

## Discussion

The study found four major clusters, however, these clusters include few individuals from the other cluster or sterilisation centres. This confirms the randomisation of macaques during the capture and release of them. Such randomisation of individuals also probably has affected the group composition and their interactions in the social groups.

**Chapter-IV**

# Changes in the social organisation in select population of rhesus macaque

## Introduction

Sterilization of rhesus macaque was expected to have an impact on their social organization due to decreased birth rate. However, the partial capturing of individuals from a social group, shuffling of the individuals from different groups, and releasing of them back presumed captured location would have a randomization effect. This also has some impact on the social organization of the macaque population. To understand the consequences of these effects, we monitored the social organization of select groups for about 15 months. The findings of changes in the social organization of the rhesus macaque populations are presented in this chapter.

## Methodology

We selected the rhesus macaque population between Una and Hamirpur to monitor their social organization (Figure 4.1). We surveyed rhesus macaque groups by traveling on a motorbike with a speed of ≤30 kmph between 06:00 hr and 18:00 hr. Recording of rhesus macaque groups after repeated visits, we identified 18 groups of macaques for the long monitoring for their age-sex. Each group was identified and given a specific ID based on the location and identified individuals in the group. The individuals were recorded by visual observation and were classified into different age-sex categories based on physical appearance i.e., adults (females >5 years, males >6 years), sub-adults (≥3 years but not adult), juveniles (1-3 years) and infants (<1 year). Individuals of the group were counted when the group made a coordinated movement across a road, gap, or canopy or seen roosting in a single line. The data on the social organization of these groups were monitored from April 2021 to June 2022.

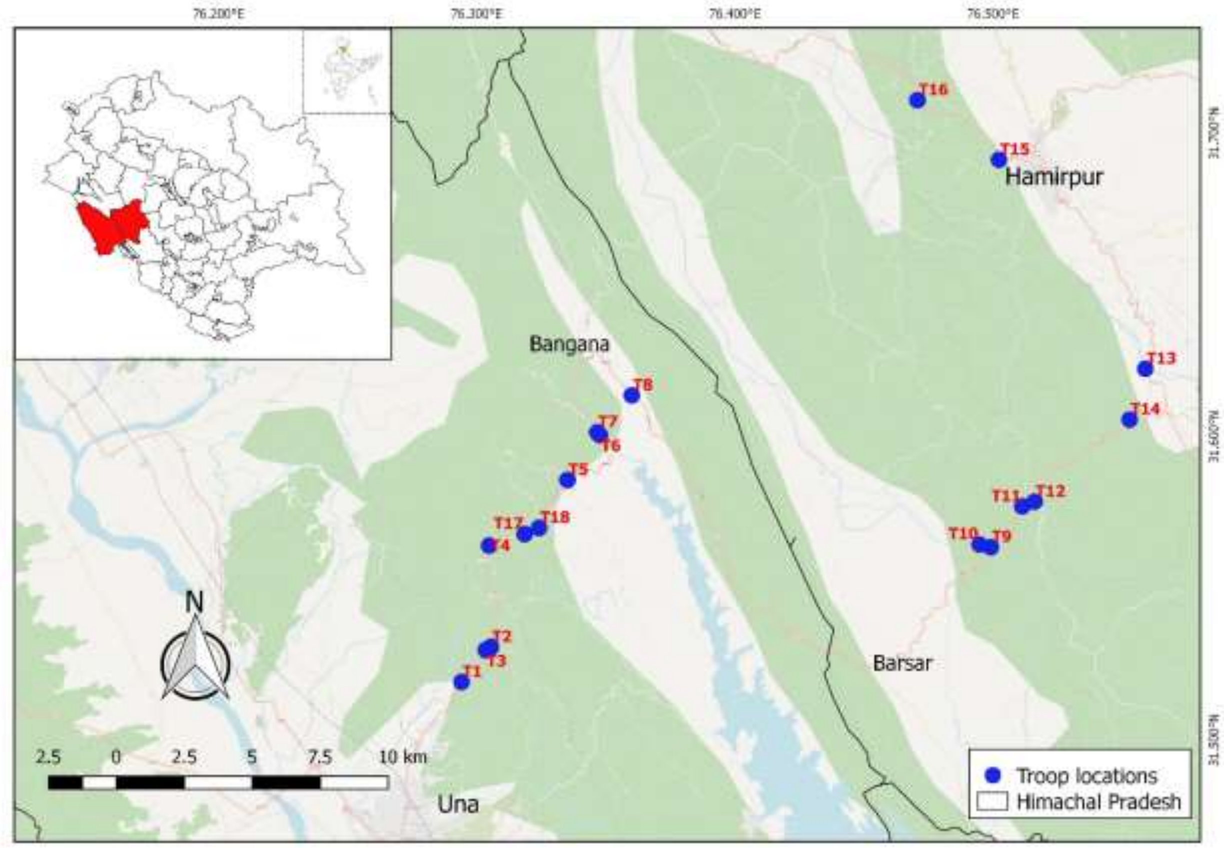


**Figure 4.1.** Rhesus macaque along the road between Una and Hamirpur in Himachal Pradesh

## Results

We selected 18 rhesus macaque groups (Appendix 4.1) along the road between Una and Hamirpur in Himachal Pradesh for the year-round monitoring of their age-sex characteristics (Figure 4.1). Of the 18 groups selected, we could obtain details on age-sex of the individuals for 17 groups. Of the 17 groups, one group was all-male band with one adult male, five sub-adult males, and five juvenile males, and the rest 16 are bisexual groups (Table 4.1).

**Table 4.1.** The initial age-sex individuals in the select rhesus macaque groups along Una and Hamirpur road, Himachal Pradesh. AM: adult male; AF: adult female; SAM: subadult female; JUV: juvenile; INF: infant; IMM: immature**.**

| **Troop ID** | **AM** | **AF** | **SAM** | **JUV** | **INF** | **IMM** | **Total** |
|---|---|---|---|---|---|---|---|
| T1 | 2 | 7 | 0 | 2 | 3 | 5 | 14 |
| T2 | 2 | 6 | 1 | 2 | 2 | 4 | 13 |
| T4 | 2 | 13 | 1 | 5 | 2 | 7 | 23 |
| T5 | 2 | 9 | 0 | 5 | 3 | 8 | 19 |
| T6 | 1 | 9 | 1 | 6 | 6 | 12 | 23 |
| T7 | 1 | 0 | 5 | 5 | 0 | 5 | 11 |
| T8 | 2 | 6 | 0 | 3 | 2 | 5 | 13 |
| T9 | 1 | 9 | 2 | 6 | 5 | 11 | 23 |
| T10 | 1 | 5 | 1 | 2 | 2 | 4 | 11 |
| T11 | 4 | 24 | 1 | 12 | 10 | 22 | 51 |
| T12 | 2 | 6 | 0 | 5 | 3 | 8 | 16 |
| T13 | 2 | 5 | 1 | 2 | 1 | 3 | 11 |
| T14 | 11 | 41 | 7 | 28 | 17 | 45 | 104 |
| T15 | 2 | 8 | 1 | 4 | 2 | 6 | 17 |
| T16 | 2 | 7 | 0 | 0 | 1 | 1 | 10 |
| T17 | 2 | 15 | 0 | 1 | 1 | 2 | 19 |
| T18 | 3 | 7 | 0 | 1 | 2 | 3 | 13 |

**The initial social organization of select groups of rhesus macaque**: The total number of individuals in the 16 social groups was 380. The group size varied from 11 to 104, with a mean group size of $23.75 \pm 23.51_{SD}$, the group size significantly varied between the groups ($t = 4.041$, $df = 15$, $p < 0.001$) (Table 4.2). The 16 social groups include 31 males, 177 females, 21 sub-adult males, 89 juveniles, and 62 infants (151 immature). The average percent of adult males in the group was 10.73 but varied from 4.10 to 24.53, similarly, the adult female was 44.23 and varied from 35.09 to 73.17, the sub-adult male was 5.53, and varied from 0 to 8.97, the juvenile was 24.52, and varied from 0 to 31.99, the infant was 14.99 and varied from 4.88 to 26.67 (Table 4.3).

**Table 4.2.** Initial percent composition of age-sex individuals in each identified group

| Group ID | %AM | %AF | %SAM | %JUV | %INF | %IMM |
|---|---|---|---|---|---|---|
| T1 | 20.00 | 42.00 | 4.00 | 16.00 | 18.00 | 34.00 |
| T2 | 15.53 | 47.57 | 7.77 | 13.59 | 15.53 | 29.13 |
| T3 | 12.86 | 42.86 | 1.43 | 24.29 | 18.57 | 42.86 |
| T4 | 9.84 | 56.83 | 2.73 | 21.86 | 8.74 | 30.6 |
| T5 | 10.96 | 47.26 | 2.05 | 25.34 | 14.38 | 39.73 |
| T6 | 4.1 | 36.92 | 2.56 | 29.74 | 26.67 | 56.41 |
| T7 | 12.5 | 0 | 43.75 | 43.75 | 0 | 43.75 |
| T8 | 14.81 | 46.3 | 1.85 | 22.22 | 14.81 | 37.04 |
| T9 | 4.92 | 39.34 | 5.46 | 30.6 | 19.67 | 50.27 |
| T10 | 9.68 | 48.39 | 3.23 | 19.35 | 19.35 | 38.71 |
| T11 | 7.61 | 46.45 | 2.28 | 23.35 | 20.3 | 43.65 |
| T12 | 11.7 | 35.09 | 6.43 | 30.41 | 16.37 | 46.78 |
| T13 | 19.05 | 47.62 | 4.76 | 19.05 | 9.52 | 28.57 |
| T14 | 7.8 | 37.71 | 8.97 | 31.99 | 13.52 | 45.51 |
| T15 | 13.21 | 49.06 | 1.89 | 22.64 | 13.21 | 35.85 |
| T16 | 20.83 | 70.83 | 0 | 0 | 8.33 | 8.33 |
| T17 | 12.2 | 73.17 | 1.22 | 8.54 | 4.88 | 13.41 |
| T18 | 24.53 | 52.83 | 0 | 7.55 | 15.09 | 22.64 |
| Overall | 10.73 | 44.23 | 5.53 | 24.52 | 14.99 | 39.48 |

**Changes in the age-sex individuals between April 2021 and June 2022**: We excluded one more group with the highest group size that is more than 100 that showed high variation in the age-sex individuals, further, each time the collected the data fully on all the individuals was also not sure, thus we removed that group from many of the analyses. We related the mean number of age-sex individuals in the group to their mean group size (Figure 4.2), which indicates that the increase in the number of females ($R^2$ = 0.80) and immature ($R^2$ = 0.82) with an increase in the group size is significant while the adult males is not ($R^2$ = 0.02). The increase in the number of infants with an increase in the adult females in the groups is not significant ($r_s$ = 0.121, N = 14, p = 0.679) (Figure 4.3).

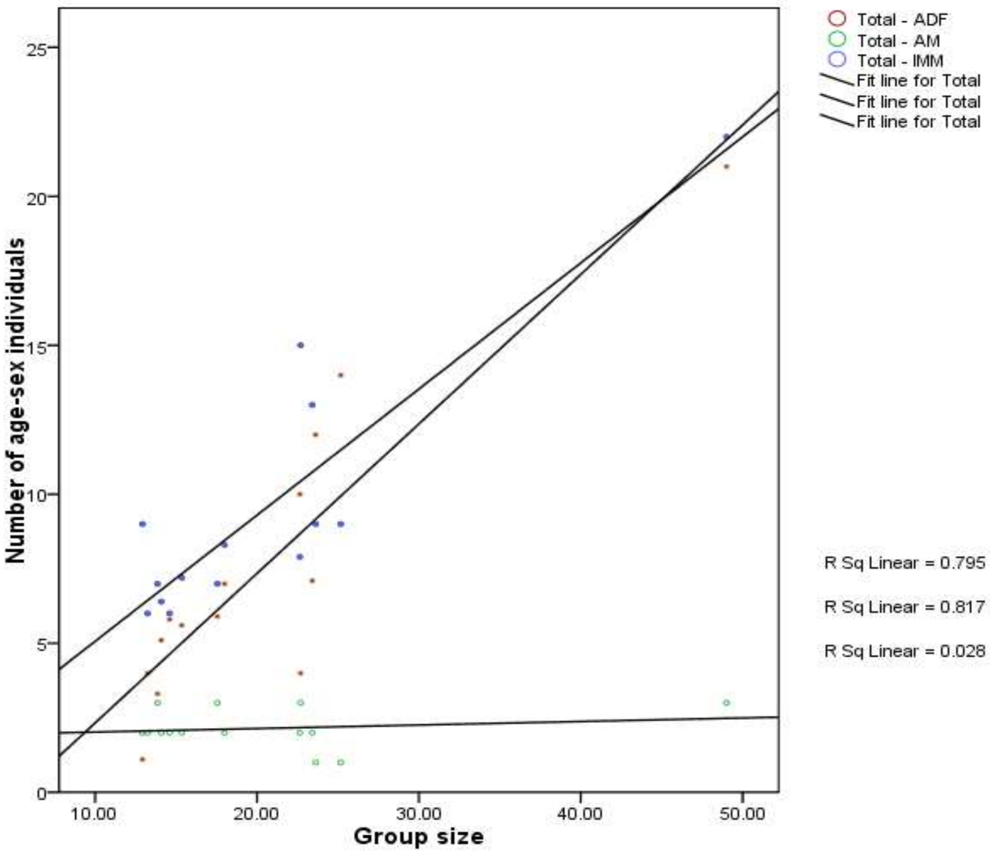


**Figure 4.2**. Relation between age-sex individuals in the group with their respective group size

We also recorded a male band of rhesus macaque with one adult male, five sub-adult males, and five immature males. This male band was observed in the same locality for almost 10 months but with high variation in age group i.e., later one more adult male joined, but both of them disappeared in March 2022, similarly, subadult males decreased over a period, and remained two by the end of the study, and however, only one juvenile male disappeared by the end of the study.

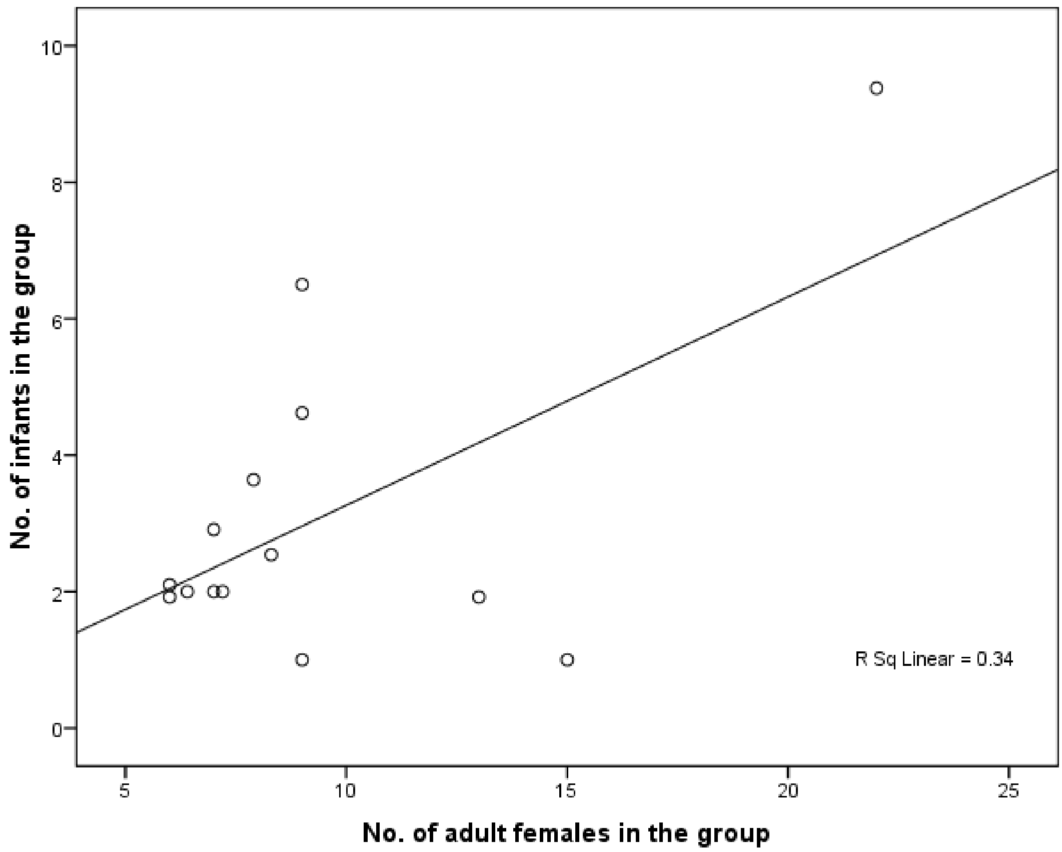


**Figure 4.3.** The relationship between the number of adult females and the number of infants in the group.

The mean number of adult females to adult males was $4.50 \pm 2.18_{SD}$ that varied between 2.02 and 9.00 (Figure 4.4), significantly between the groups ($F_{14,166} = 42.54$, $p < 0.000$). Similarly, the number of infants to adult females varied between 0.06 and 0.72 ($0.33 \pm 0.17_{SD}$) (Figure 4.5) that varied significantly ($F_{14,166} = 102.05$, $p < 0.000$), and the number of immatures per adult female varied between 0.12 and 1.61 ($0.84 \pm 0.42_{SD}$) (Figure 4.6) that varied significantly ($F_{14,166} = 168.84$, $p < 0.000$).

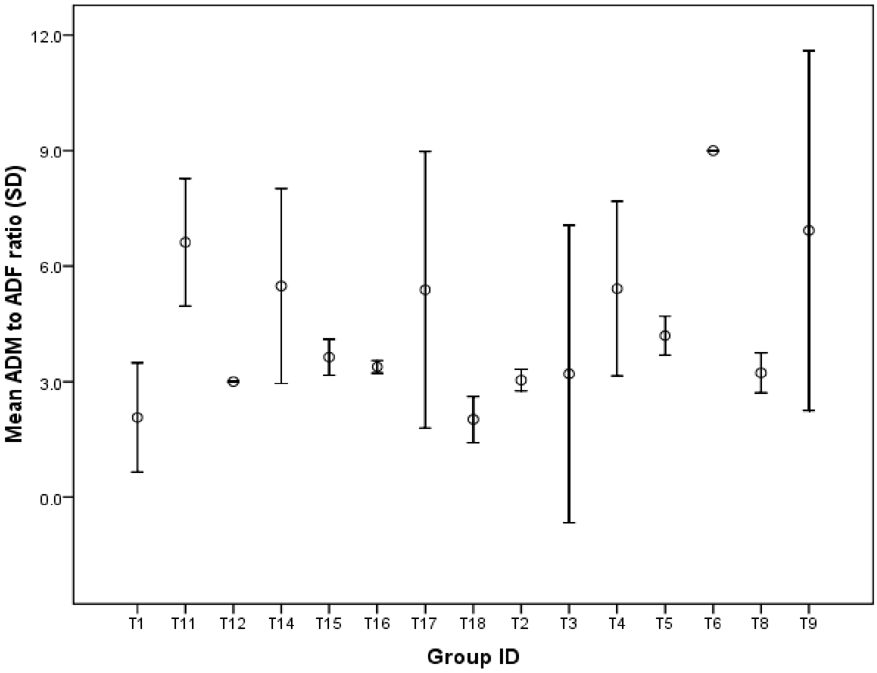


**Figure 4.4.** Mean adult male to adult female ratios of select groups of rhesus macaque for fifteen months period

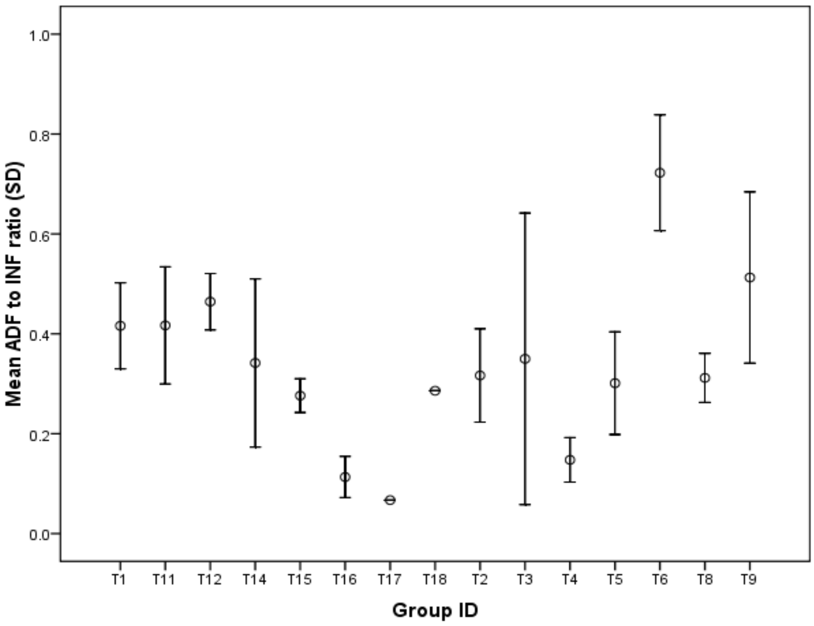


**Figure 4.5.** Mean adult female to Infant ratios of select groups of rhesus macaque for fifteen months period

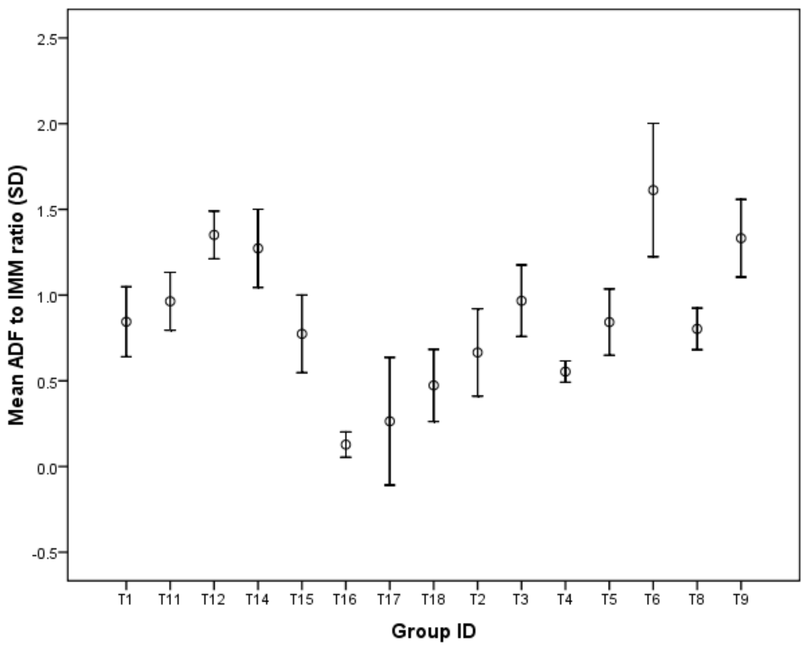


**Figure 4.6.** Mean adult female to Immature ratios of select groups of rhesus macaque for fifteen months period

## Discussion

The groups in macaque societies are social units with individuals of their kins of a few generations, especially of females. Although males remain in the group but, they also disperse to the other groups. Females are often seen to remain with the native group, however, occasionally they also disperse. Apart from births and deaths, fission and fusion, the dispersal of individuals also contributes to the changes in the social organization of the groups, however, such changes are of a slow process except for the fission and fusion of groups. The randomization of individuals can lead to various changes in long-evolved social organization and group sizes in the population.

The record of an all-male band of rhesus macaque is unique and not reported from most of its range is one of such consequences. Rhesus macaque lives in a bisexual group and occasionally males disperse at the age of subadult or adult stage. One or two males spend time together temporarily; however, our observation shows a formation of all-male bands with juvenile, sub-adult, and adult males, that remained for nine months is unusual.

The high variation in the age-sex ratios and percent composition of age-sex individuals of the group in the population indicates a possible impact of randomization of individuals.

Although, it is not apparent that many groups show high variation in the percent age-sex individuals and age-sex ratios within a group over the period. This indicates that the possibility of loose social organization may be due to unrelated individuals.

Although, all the groups had infants, but many groups had very less infants to adult females that may be due to sterilized individuals in the group, however, the high number of individuals or immatures in certain groups also shows that sterilization has not been achieved adequately. However, monitoring these populations for a longer period and understanding the relatedness of the individuals in these groups would help in understanding the impact of the sterilization activities on their population.

# Chapter-V

# Activity budget and behaviour of rhesus macaque

## Introduction

Rhesus macaques live in a social group where the individuals interact with each other and are gregarious. The individuals bond with each other and it is expressed through many behavioural forms. The ongoing management practices such as sterilization, translocation and culling of the species as conflict resolution would possibly influence their social structure and behavioural pattern. These consequences of such management practices are important in understanding for the management of the species in the future.

A study of the way individuals behave in the social group is necessary to understand how changes and modifications from external factors affect the species. The social behavior of the rhesus macaque groups plays a major role in the survival and fitness of an individual (Krebs & Davies, 2009). Like most of the group-living primates, macaques live in a linear hierarchy society with female philopatry (Chapais 2004). In such a hierarchical society, rank plays a major role in the reproductive success of males, in turn, helps to employ the reproductive strategies against group members (Wrangham 1980; Kappeler and van Schaik 2002). The high correlation between dominance rank and mating success in males indicates that the dominant males get more access to receptive females than the subordinates by involving in intra-sexual competition for mate resources (e.g., *M. fuscata*: Soltis et al. 2001; *M. mulatta*: Melnick 1987; *M. fascicularis*: de Ruiter et al. 1994). On the other hand, in female philopatry society, females stay in a natal group with their close kin and the youngest infant acquires a social rank just below her mother, thus competition becomes higher between the females (Chapais 2004). In such conditions, high-ranking females impose their dominance over subordinate females to monopolize food and mate resources as alternative reproductive strategies to increase their relative reproductive success (Soltis 2004).

The six months of gestation and prolonged lactation period in macaques make the parental investment highly skewed towards females, where males only contribute by fertilizing the ova with relatively low-cost sperm and involve in little or no parental care (Trivers 1972). As a result, the reproductive success of males' increases with siring offspring by accessing the receptive females, therefore, the strategy is to mate more receptive females by monopolizing the mate resources. While the reproductive success in females depends on the fecundity as well as the survival of the infants (Kappeler & van Schaik 2004; Soltis 2004). Thus, they involved in polyandrous and promiscuous mating (e.g., *M. fuscata*: Soltis *et al*. 1999; *M. mulatta*: Bercovitch 1997; *M. nemestrina*: Oi 1996; *M. sylvanus*: Small 1990), where they mate with multiple males to increase the paternity confusion (van Schaik et al. 2000; Hestermann et al. 2001). Such selective mate choice by females ultimately acts as a conflict of interest between sexes and leads to inter-sexual competition (Trivers 1972). Consequently, both sexes adopt different sexual strategies and counter-strategies to increase their reproductive success against each other (Clutton-Brock 1974; de Waal & Luttrell 1989).

The polyandrous mating strategy can secure infant survival by reducing the chance of infanticide by manipulating the paternity assessment of males (Kappeler & van Schaik 2004; Soltis 2004). The access to valuable resources increases to females and her offspring by having more male mating partners that increase the survivability of infants (Hrdy 1986). On the other hand, males are inclined to mate with females when the chances of fertilizing her egg are high since the copulation requires high energy (Bercovitch 1997). In contrast, females adopt various counterstrategies to conceal the fertile phase by making ovulation unpredictable (Soltis 2004). In seasonal breeders, females become fertile only in a distinct period, males may get the environmental cue to identify the discreet mating season. In case of non-seasonal breeders, females can conceive at any time of the year.

We studied two groups of rhesus macaques having few sterilised individuals in Himachal Pradesh to understand the effects of sterilization on their behaviour including their reproductive behaviour.

## Methodology

This study was conducted on two groups (T1 and T2) of rhesus macaque, located in Una, Himachal Pradesh (N 31° 17’ 52”- 31° 52’ 0’’, E 75° 58’ 2”- 76° 28’ 25” (Figure 5.1). The area exhibits warm and temperate weather with an average annual rainfall of 1260mm and an average annual temperature of 21.6° C (climate-data.org). Study area is mixed with agricultural, forest and rural landscapes.

The T1 and T2 groups were followed from June 2021 to August 2022 (Table 5.1). All individuals in both the group were identified by their facial features and other distinct morphological characteristics (Pal et al. 2018). The macaques were classified into four age-classes i.e., adults (females >5 years, males >6 years), sub-adults (≥ 3 years but not adult), juveniles (1-3 years) and infants (< 1 year).

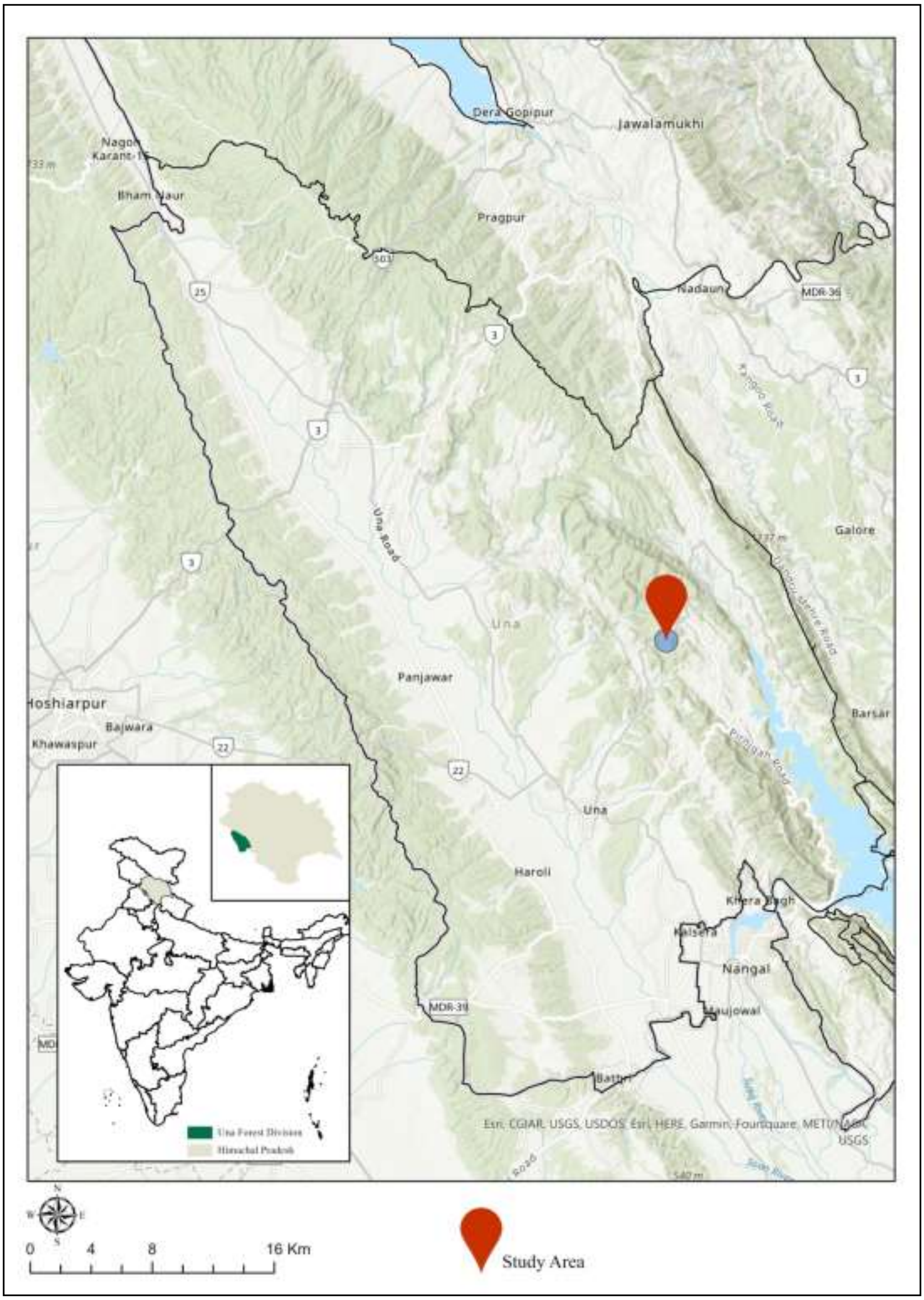


**Figure 5.1**. The rhesus macaque study groups (T1 and T2) in Una district of Himachal Pradesh.

During the study period, 22 individuals were recorded in T1 group i.e., adult males (BAB, PGY, NH, OWL), adult females (MTR, ALN, GRT, ES, NN, LF, CHN, LE, LUT, BRD, 3E, BIL, GRY, SF, BO), juvenile female (KID), and Infants (MI, NI). 117 individuals were recorded in T2 group i.e., adult males (HED, LC, MP, 1E), adult females (HMP, LMP, SM, BM, SHD, PRT, AB), juvenile (APU), and infants (SMI, BMI, S2, B2). Other than these two troops, a male band was also identified consisting of 3 sub adult males and 6 juvenile males in which behavioral data was not collected

**Table 5.1**. Individuals of the two select groups of rhesus macaque for the intensive study on their activity budget and behaviour

| **T1** | | | | **T2** | | | |
|---|---|---|---|---|---|---|---|
| **Sl. No.** | **Individual** | **ID** | **Age-sex class** | **Sl. No.** | **Individual** | **ID** | **Age-sex class** |
| 1 | Baba | **BAB** | AM | 1 | Head | **HED** | AM |
| 2 | Pygmy | **PGY** | AM | 2 | Lipcut | **LC** | AM |
| 3 | Mother | **MTR** | AF | 3 | Map | **MP** | AM |
| 4 | Alien | **ALN** | AF | 4 | Hump | **HMP** | AF |
| 5 | Growth | **GRT** | AF | 5 | Limp | **LMP** | AF |
| 6 | Eyespot | **ES** | AF | 6 | Small mom | **SM** | AF |
| 7 | No neck | **NN** | AF | 7 | Big mom | **BM** | AF |
| 8 | Long face | **LF** | AF | 8 | Shade | **SHD** | AF |
| 9 | Chan | **CHN** | AF | 9 | Parrot | **PRT** | AF |
| 10 | Lee | **LE** | AF | 10 | Angry bird | **AB** | AF |
| 11 | Luttappi | **LUT** | AF | 11 | Appu | **APU** | JUV-male |
| 12 | Bird | **BRD** | AF | 12 | S.Infant | **SMI** | INF |
| 13 | 3rd eye | **3E** | AF | 13 | B.Infant | **BMI** | INF |
| 14 | Billy | **BIL** | AF | 14 | 1 Eye | **1E** | AM |
| 15 | Grey | **GRY** | AF | 15 | Big mom infant | **B2** | INF |
| 16 | Small face | **SF** | AF | 16 | Small mom infant | **S2** | INF |
| 17 | Bow | **BO** | AF | **Nearby group** | | | |
| 18 | Kiddo | **KID** | Juv | **Sl. No.** | **Individual** | **ID** | **Age-sex class** |

| | | | |
|---|---|---|---|
| 19 | Infant | **MI** | In |
| 20 | No Hand | **NH** | AM |
| 21 | OWL | **OWL** | AM |
| 22 | New Infant | **NI** | |

| **Unimales** | | | |
|---|---|---|---|
| **Sl. No.** | **Individual** | **ID** | **Age-sex class** |
| 1 | Oldmonk | **OM** | AM |
| 2 | Thunder | **TDR** | AM |
| 3 | Owl | **OWL** | AM |

| | | | |
|---|---|---|---|
| 1 | No hand | **NH** | AM |
| 2 | Yellow | **YLW** | SAM |
| 3 | Devil | **DVL** | SAM |
| 4 | Cut tail | **CT** | SAM |
| 5 | Rambo | **RMB** | Juv-male |
| 6 | Little guy | **LG** | Juv-male |
| 7 | Juv 1 | | Juv-male |
| 8 | Juv 2 | | Juv-male |
| 9 | Juv 3 | | Juv-male |
| 10 | Juv 4 | | Juv-male |

*Data collection*

First two months of the study period was spent on habituating the groups, and to identify the individuals. Both the groups were continuously followed from dawn (06:00 AM) to dusk (06:00 PM), until the group moved to inaccessible area or roosting. When groups were not in sight, that period was not included in the observation hours. Group count and demography data were collected weekly while all individuals were crossing roads or moving in single line. Behavioural data was collected using scan, focal and ad-libitum sampling methods (Altmann, 1974). Scan sampling was done for 10 minutes once in every 30 minutes. During the scan period, all visible individuals were scanned and their activities were recorded. For each scan, location, individual id, and activities were recorded. Locations were recorded using a Garmin GPS. Group dispersion during each scan was also recorded. An ethogram was prepared prior to data collection by identifying the individuals and classifying the behaviors (Table 5.2).

**Table 5.2**. Ethogram to collect the data using scan and focal sampling for rhesus macaque

| Sl. No. | Behavior | ID | Description |
|---|---|---|---|
| 1 | Feeding | **Re** | Foraging, handling, processing, or ingesting of any food materials by the individual |
| 2 | Resting | **Mo** | An individual remains stationary, recumbent or sitting, standing; eyes opened or closed; sleep or awake |
| 3 | Moving | **Fe** | An individual moves at any pace from one location to |

| | | | |
|---|---|---|---|
| | | | another (Includes jumping, walking, climbing, swimming) |
| 4 | Self-grooming | **Sg** | An individual looks for or brushes its own body with one or both hands inspecting for any insects or other foreign particles and removing them directly with mouth (bite) or hand picking |
| 5 | Allo-grooming | **Ag** | An individual looks for or brushes the body of another individual with one or both hands, inspecting for insects or any foreign particles and removing them by hand picking or mouth (bite) |
| 6 | Mutual-grooming | **Mg** | Grooming involving two or more individuals where one of the receiver grooms back either the groomer or another individual simultaneously |
| 7 | Self-play | **Sp** | An individual playing alone. Forms of play include moving, jumping, rolling etc. |
| 8 | Social play | **Sop** | Two or more individuals engaging in playing with each other. Includes moving, jumping, rolling, non-aggressive chasing & wrestling etc. |
| 9 | Object play | **Op** | An individual playing with any object such as cloth, stick etc. |
| 10 | Attack/chase | **A/C** | One individual charge, fights or involves in a threatening locomotive pursuit with another individual (Also could involve more than one individual in both sides) |
| **Frequency** | | | |
| 1 | Drink | **Dr** | Intake of water |
| 2 | Scratch | **Sc** | Individual scratches its body with hands or legs |
| 3 | Yawn | **Ya** | Gaping movement of mouth displaying teeth’s |
| 4 | Invite groom | **Ig** | One individual invite other individual for grooming by presenting the body in a manner to gain attention of the other |
| 5 | Approach | **Ap** | An individual moving towards other individual in a normal pace & approaching them |
| 6 | Follow | **Fo** | An individual following other individual in proximity |
| 7 | Dominance mount | **Dm** | An individual climbing on the hindquarters of other in display of dominance |
| 8 | Submissive mount | **Sm** | Individuals act mounting dominant individual with fear grimace and screech without intromission |
| 9 | Play mount | **Pm** | During the play, exhibiting the mount without intromission |

| Aggressive | | | |
|---|---|---|---|
| 10 | Chase | **Ch** | An individual chases another individual and the pursuit continues for few seconds |
| 11 | Charge | **Chr** | An individual charges at another individual and stops |
| 12 | Push | **Pu** | An individual pushes another animal out of the way |
| 13 | Retreat | **Rt** | An individual moves away from charge, chase, push or other aggressive occurrence |
| 14 | Threat | **Th** | An individual aggressively stare at other by open mouth with or without flashing its teeth in order to threaten the other individual |
| 15 | Fight | **Ft** | Two or more individuals involving in physical combat |
| 16 | Flee | **Fle** | An individual walks in pace or runs away from an individual in response to the approach or proximity from the other individual |
| 17 | Barred teeth | **Bt** | Retracts the lips and exposes the teeth |
| 18 | Lip smack | **Ls** | Quick opening and closing of mouth causing lips to smack together and make a noise |

Reproductive behavior: Reproductive behavioral data were collected with all-occurrence sampling (Altmann 1974). Two observers followed the two study groups till December 2021 and later from March 2022 a single observer carried out the observation till August 2022, by keeping adult males of the group as a focal animal. All possible copulatory behaviour events were thus recorded. The identity of interacting individuals along with the occurrence and frequency of reproductive behaviors like mating approach or mating initiation by male and female, the occurrence of mating, duration of mating, the total number of thrusts in mating, mating with ejaculation, copulation call and post-copulatory behavior of male and female were recorded (Kowalewski and Garber 2010). A mating was considered when there was a mounting with intromission and sequence of pelvic thrusts (Jones 1985). The genital inspection by a male, anogenital presentation and reaching back by a female was considered as mating initiation approaches (Soltis et al. 1997). Ejaculatory mating was determined by observing the presence of ejaculation pause (Engelhardt et al. 2005). Mate guarding or consort ship, individual migrations and data on other infrequent behaviors were collected by *ad libitum* sampling method (Altmann 1974). In this fission-fusion macaque society, more than 30 consecutive days present of a new individual and absent of a resident individual in the group were considered as immigration and emigration event respectively.

Social behaviors: The *ad libitum* sampling methods were used to collect the social interaction data like agonistic and affiliative approaches between individuals. In case of agonistic approaches, all information like the identity of aggressor and receiver, aggressor behavior, receiver response, the degree of aggression, retreat behavior, the identity of winner and loser were recorded (Beisner et al. 2011).

*Data analysis*

The scan sample data was plotted in Microsoft Excel 2016 and converted the frequencies to percentage data. This data was used to compare activities within and between the groups using IBM SPSS Statistics 23 and Microsoft Excel 2016.

A combined total of 534.30 h of observation was made to collect the data on reproductive behavior of T1 and T2 groups. The ejaculation rate was estimated as the number of ejaculatory matings in each observation and comparing with the total matings occurred. By back-calculation, the different reproductive phases of females were estimated from the date of parturition, where the gestation period was kept as 164 days (Fooden 2006; Girard-Buttoz et al. 2014). Reproductive phases of females were divided into three classes with six 30 days (a month) interval for each class, i.e., pre-conception, post-conception, and post-parturition periods. From 180 days (six months) before the birth up to the parturition day was considered as post-conception period. Six months prior to the post-conception period was considered as pre-conception period and six months after the date of parturition was projected as a post-parturition period. IBM SPSS statistics 23 were used to carry out the analysis. The percentage of individuals involved in mating (adult males and adult females) was calculated. The mean duration as well as the range of mating by the males was examined. The mating dyadic and mating rate of individuals were projected.

## Results

*Group dynamics*

Initially, the T1 group had 19 individuals with 2 adult males, 15 adult females, and 2 immatures. An adult male (NH) which was considered as a solitary, after continuously being in proximity of the group joined the T1 group in October 2021. In December, a set of individuals i.e., one adult male (OWL), two sub-adult male (YLW and CT), and six juvenile males which were in proximity, joined the T1 group. The two sub-adult males and six juveniles were not seen later in the February 2022, reducing the number of total individuals to 21 but used to see them continuously in proximity. During the end of May 2022, an infant was born for the adult female named MTR in the T1 group which was the only one birth recorded in T1 group during the study period (Table 5.3).

**Table 5.3.** Group dynamics of T1 and T2 groups in Una, Himachal Pradesh, during the study period. (AM- adult male, AF- adult female, SAM- sub-adult male, JUV- juveniles, INF- Infants)

| | Month | Troop ID | AM | AF | SAM | JUV | INF | Total |
|---|---|---|---|---|---|---|---|---|
| **T1** | | | | | | | | |
| | Apr-21 | **T1** | 2 | 15 | | 1 | 1 | 19 |
| | Jun-21 | **T1** | 2 | 15 | | 1 | 1 | 19 |
| | Jul-21 | **T1** | 2 | 15 | | 1 | 1 | 19 |
| | Aug-21 | **T1** | 2 | 15 | | 1 | 1 | 19 |
| | Sep-21 | **T1** | 2 | 15 | | 1 | 1 | 19 |
| | Oct-21 | **T1** | 3 | 15 | | 1 | 1 | 20 |
| | Nov-21 | **T1** | 3 | 15 | | 1 | 1 | 20 |
| | Dec-21 | **T1** | 4 | 15 | 2 | 7 | 1 | 29 |
| | Feb-22 | **T1** | 4 | 15 | | 1 | 1 | 21 |
| | Mar-22 | **T1** | 4 | 15 | | 1 | 1 | 21 |
| | Apr-22 | **T1** | 4 | 15 | | 1 | 1 | 21 |
| | May-22 | **T1** | 4 | 15 | | 2 | 1 | 22 |
| | Jun-22 | **T1** | 4 | 15 | | 2 | 1 | 22 |
| | Jul-22 | **T1** | 4 | 15 | | 2 | 1 | 22 |
| | Aug-22 | **T1** | 4 | 15 | | 2 | 1 | 22 |
| **T2** | | | | | | | | |
| | Apr-21 | **T2** | 3 | 7 | | 1 | 2 | 13 |
| | Jun-21 | **T2** | 3 | 7 | | 1 | 2 | 13 |
| | Jul-21 | **T2** | 3 | 7 | | 1 | 2 | 13 |
| | Aug-21 | **T2** | 3 | 7 | | 1 | 2 | 13 |
| | Sep-21 | **T2** | 3 | 7 | | 1 | 2 | 13 |
| | Oct-21 | **T2** | 3 | 7 | | 1 | 2 | 13 |
| | Nov-21 | **T2** | 4 | 7 | | 1 | 2 | 14 |
| | Dec-21 | **T2** | 4 | 7 | | 1 | 2 | 14 |
| | Feb-22 | **T2** | 4 | 7 | | 1 | 2 | 14 |
| | Mar-22 | **T2** | 4 | 7 | | 1 | 2 | 14 |
| | Apr-22 | **T2** | 4 | 7 | | 1 | 2 | 14 |
| | May-22 | **T2** | 4 | 7 | | 3 | 2 | 16 |
| | Jun-22 | **T2** | 4 | 7 | | 3 | 2 | 16 |
| | Jul-22 | **T2** | 4 | 7 | | 3 | 2 | 16 |
| | Aug-22 | **T2** | 4 | 7 | | 3 | 2 | 16 |

The T2 group consisted of 7 females, 3 males, and 3 immatures. An adult male (1E) which was never observed in proximity before, joined the T2 group in November 2021 increasing the total number of individuals to 14. During the study period 2 adult females (BM and SM) from T2 had given birth once. No deaths were recorded during the entire study period in both T1 and T2 groups. These are the variations observed in the demography of the groups.

*Activity pattern*

A total of 7203 activity records from T1 group and 2959 activity records from T2 group from the month of August 2021 to August 2022, were used for analysis. A total of 431:30 hr of observation was made for T1 group and 171:00 hr of observation was made for T2 group. The activities were classified to Resting, Moving, Feeding, Grooming, Playing and agonistic interactions (Figure 5.2).

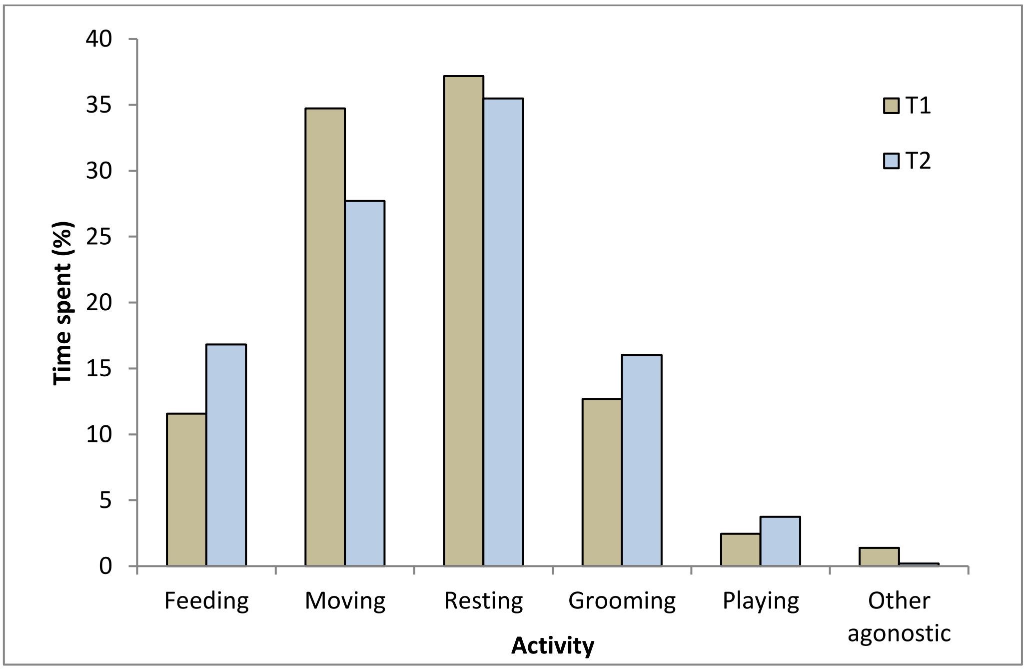


**Figure 5.2**. Depicting the activity pattern of T1 and T2 groups in the study area

The study period was classified into 3 seasons, winter (November to April), summer (April to July) and monsoon (July to November). Both the T1 and T2 groups spent more time in Resting (T1- 37.19%, T2-35.49%) and Moving (T1- 34.72%, T2- 27.71%) (Figure 5.2). For T1, time spent on other behaviours are Grooming- 12.69%, Feeding- 11.55%, Playing- 2.46%

and agonistic behaviours- 1.37%. In the case of T2, times spent on other behaviours are Feeding- 16.83%, Grooming- 16.02%, Playing- 3.75% and agonistic behaviour- 0.20%. Time spent on different behaviours during the different timings of the day and month wise is depicted in Figure 5.3-5.8.

*Season wise activity pattern*

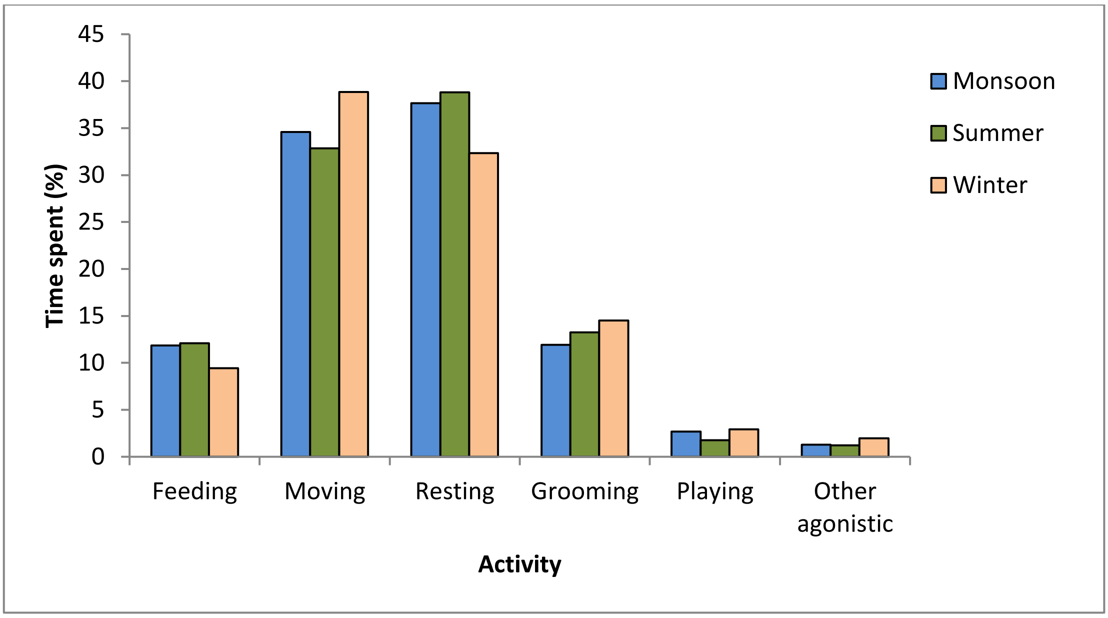


**Figure 5.3**. Season-wise activity pattern of T1 group

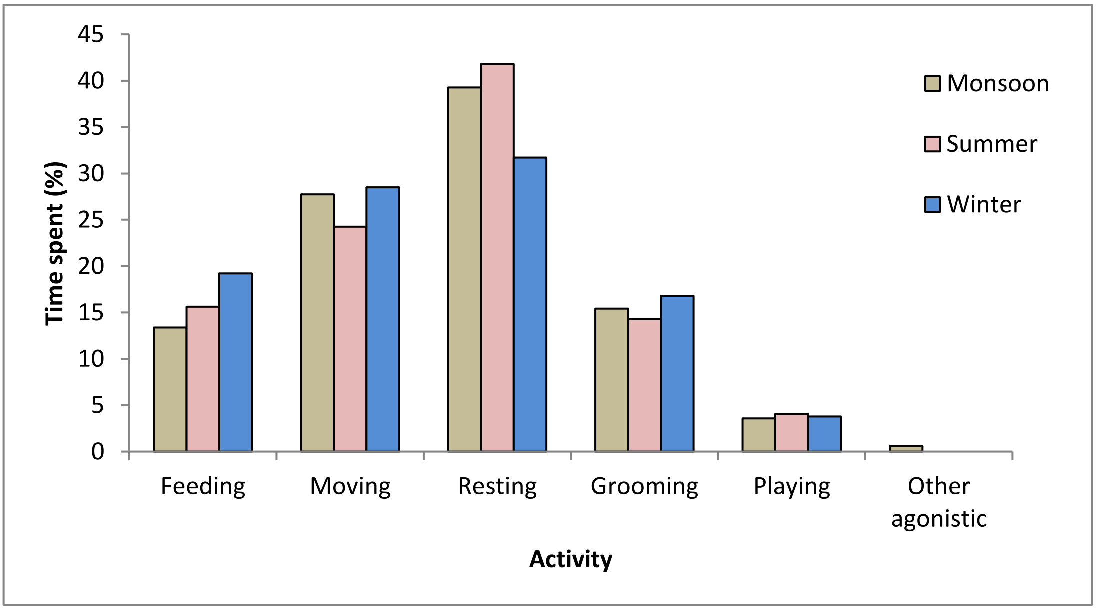


**Figure 5.4**. Season wise activity pattern of T2 group

*Day activity pattern*

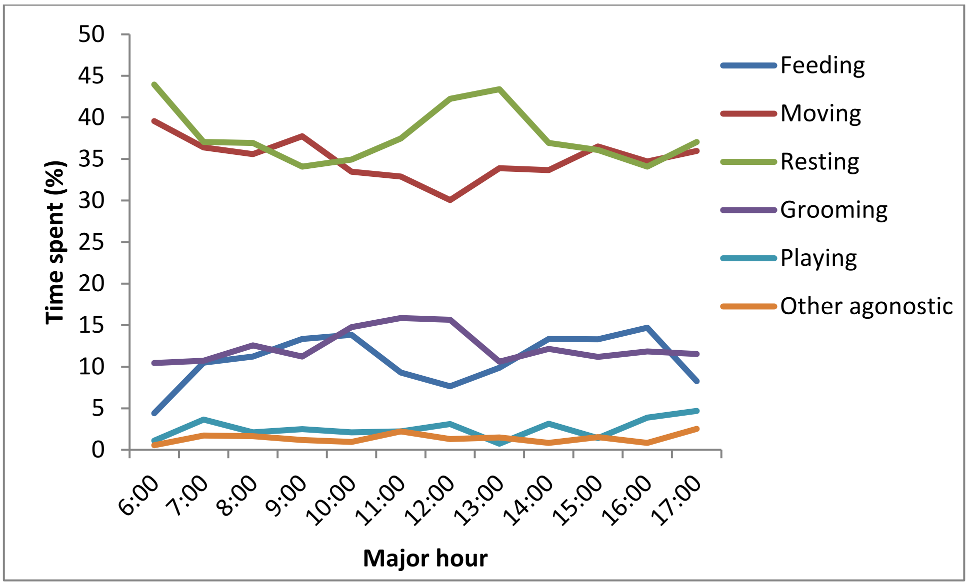


**Figure 5.5.** Day activity pattern of T1 group

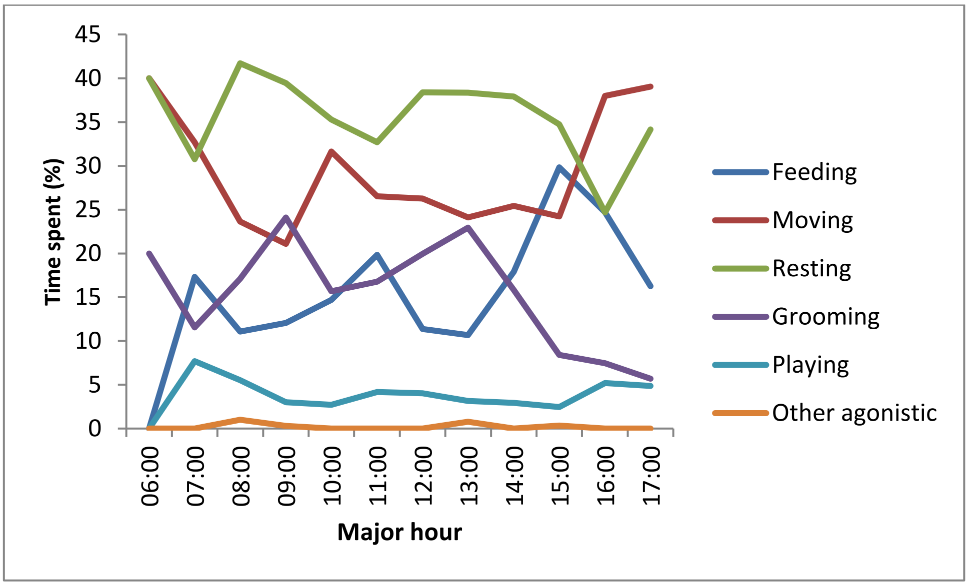


**Figure 5.6.** Day activity pattern of T2 group

*Month wise activity pattern*

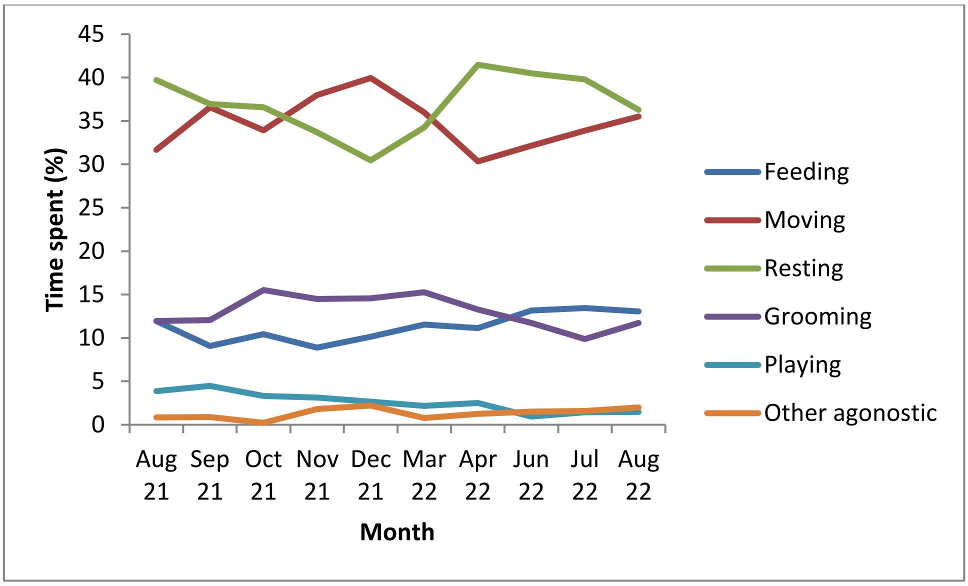


**Figure 5.7**. Month wise activity pattern of T1 group

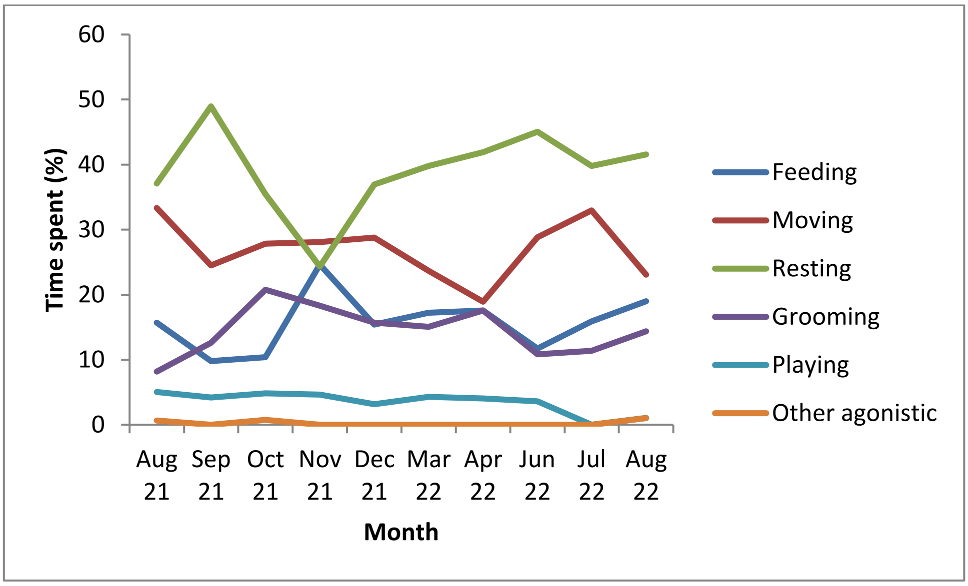


**Figure 5.8**. Month wise activity pattern of T2 group

*Group Dispersion*

The mean group spread (Mean±SD, N (in hectares)) of T1 ($0.11 \pm 0.01_{SD}$, N = 880) was much higher than the T2 group (0.09±0.00, N = 254) ($\chi^2$= 0.73, *df*= 1, p>0.00) (Figure 5.9, 5.10). In the case of T1 group, the mean group dispersion significantly varied across the seasons ($\chi^2$= 0.17, *df*= 2, p>0.00) and also across the months ($\chi^2$= 0.22, *df*= 9, p>0.00). The mean group dispersion for T2 significantly varied across month ($\chi^2$= 0.01, *df*= 9, p>0.00) as well as across during the day ($\chi^2$= 0.01, *df*= 9, p>0.00). Group spread across season, months and day are depicted in Figures 5.11-5.15.

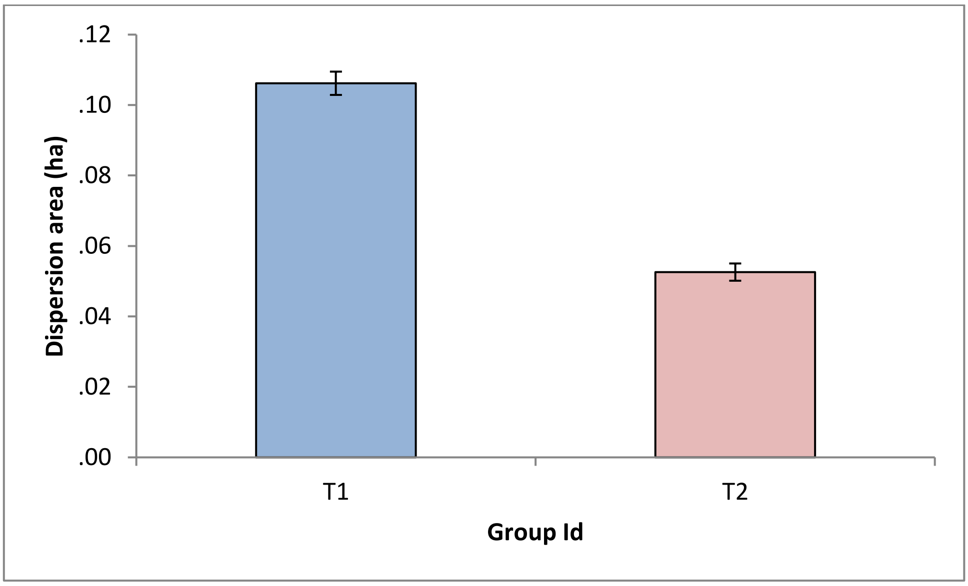


**Figure 5.9.** Group spread of T1 and T2 groups in the study area

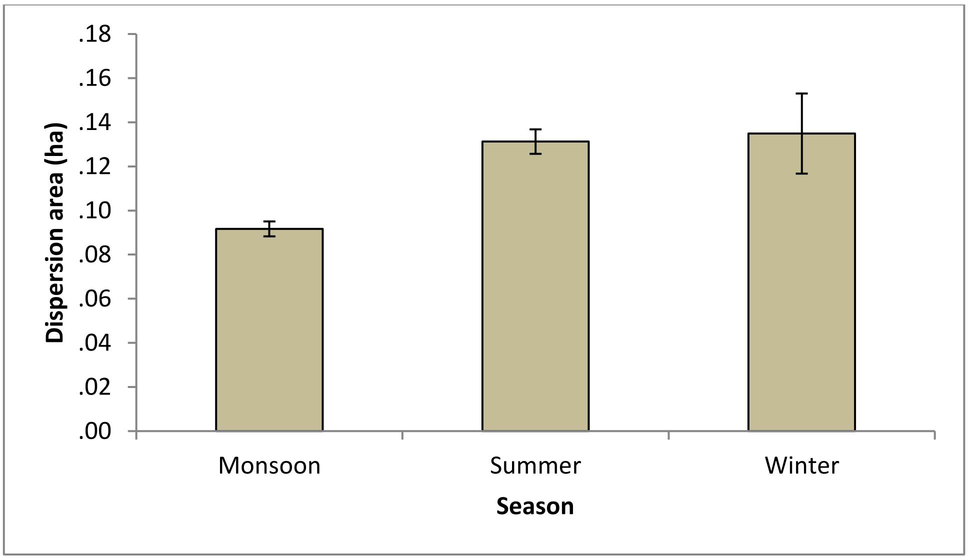


**Figure 5.10**. Season wise dispersion of T1 group

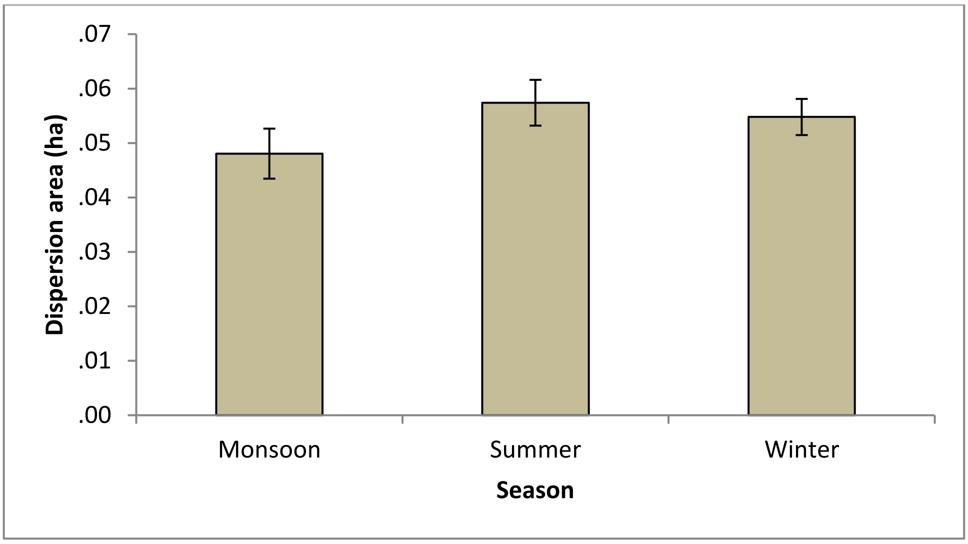


**Figure 5.11**. Season wise dispersion of T2 group

*Month wise group dispersion*

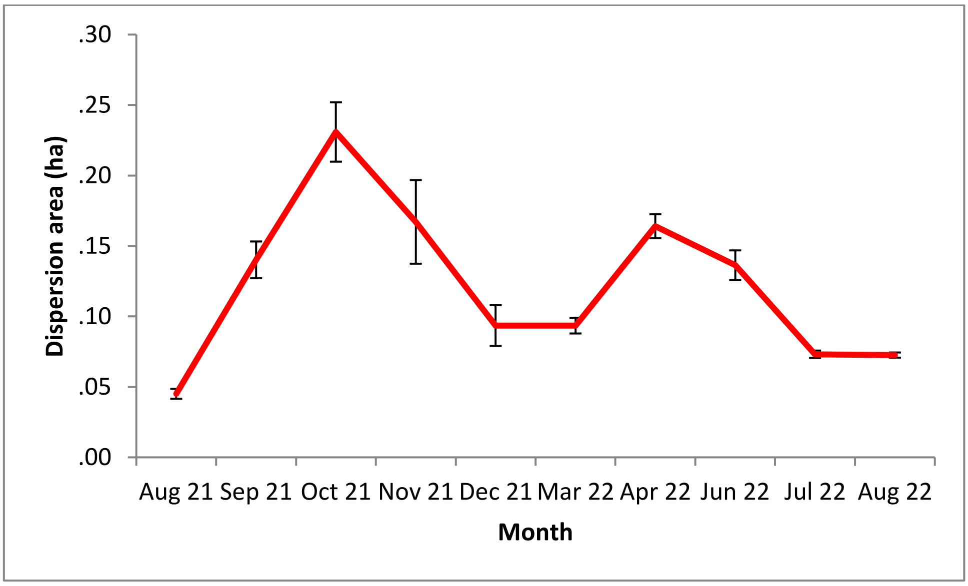


**Figure 5.12**. Month wise dispersion of T1 group

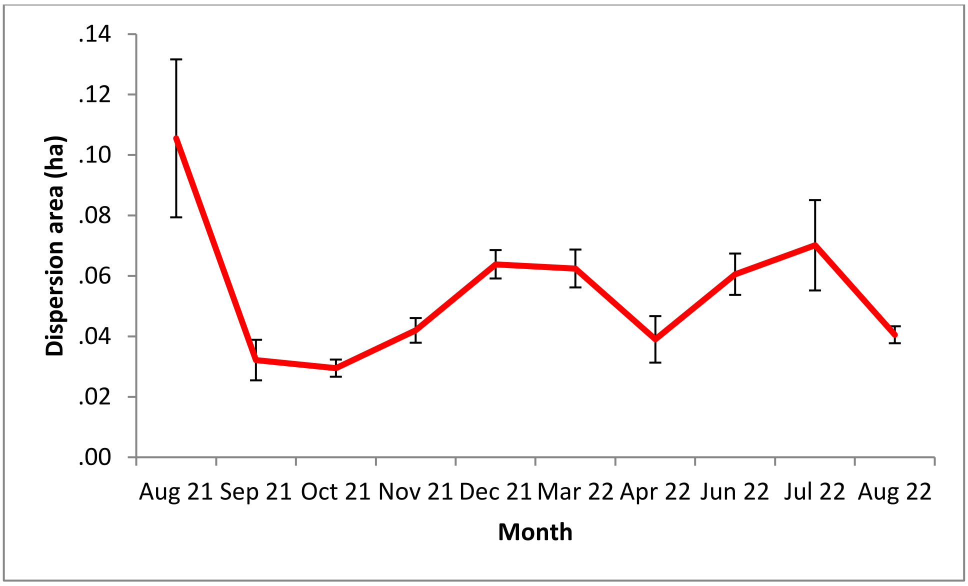


**Figure 5.13**. Month wise dispersion of T2 group

*Hourly group dispersion*

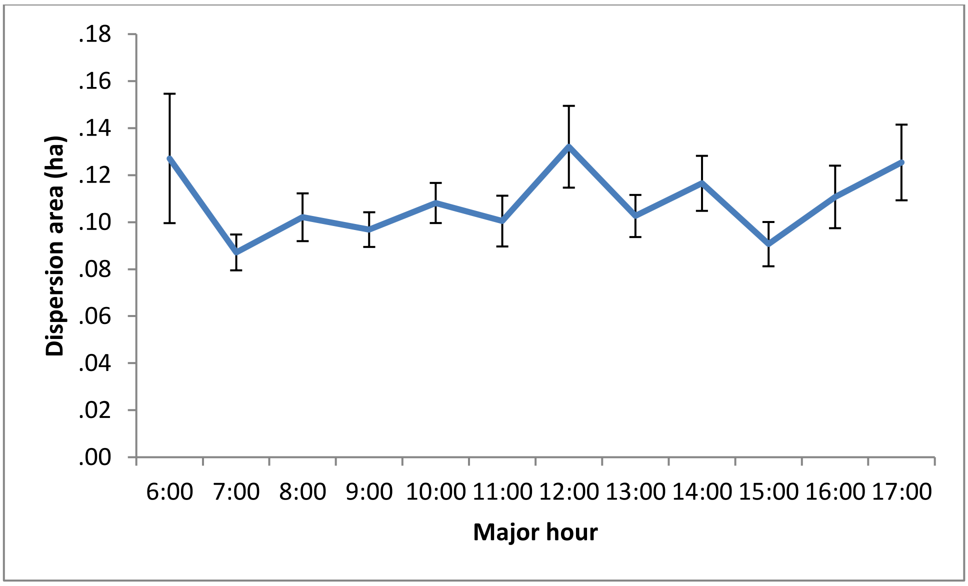


**Figure 5.14**. Hour wise wise dispersion of T1 group

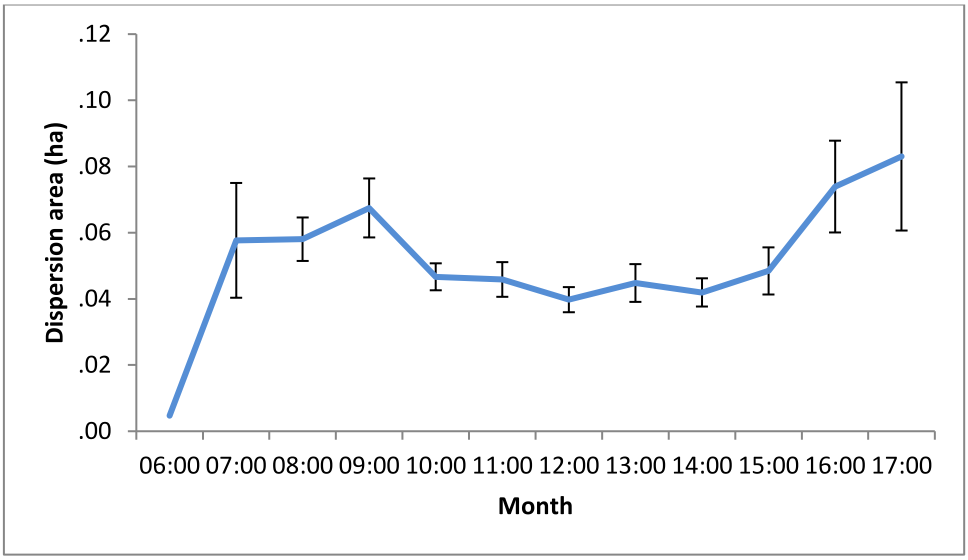


**Figure 5.15**. Hour wise dispersion of T2 group

*Reproductive behavior*

A combined total (T1 and T2) of 203:30 hrs of observation was made during the time period of October to December 2021. During this period, reproductive behaviours were observed in both T1 and T2 groups (Figure 5.16).

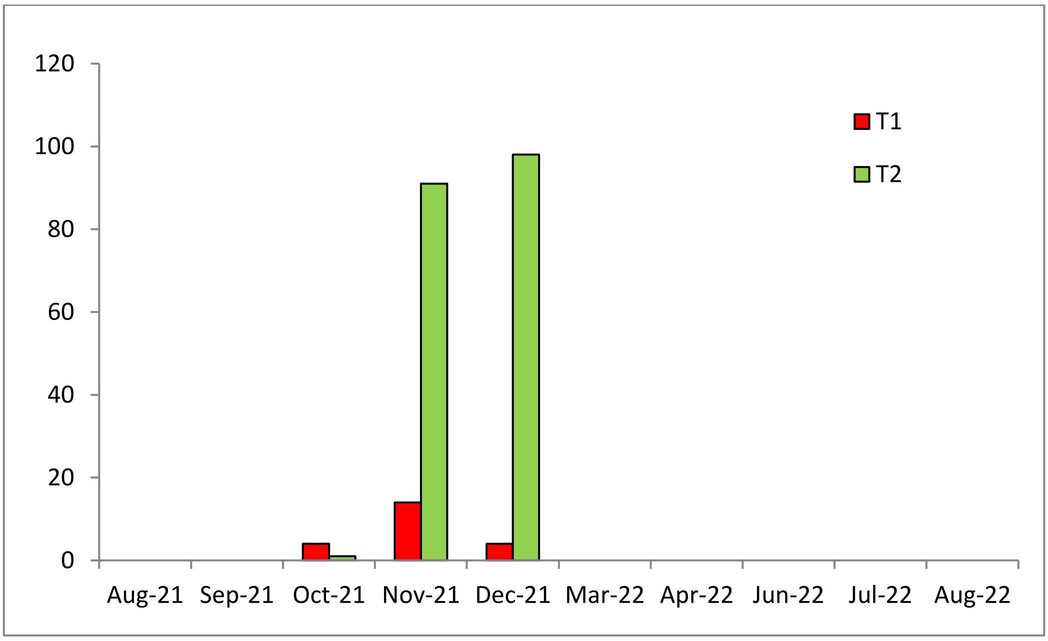


**Figure 5.16**. Number of mating observed for T1 and T2 groups during the study period.

For the T1 group, a total number of 22 matings (Figure 5.16) were recorded during the study period by two males (BAB and NH i.e., two males of the four males: 50%) and four females (MTR, SF, GRY and ES i.e., females: 26.67%), in which the NH was immigrated to the T1 group during the starting phase of reproductive behaviour The one adult male (OWL) which immigrated during the reproductive phase was not observed involving in mating.

For the T2 group, 190 matings were recorded by four males (HED, LC, 1E and MP), in which 1E joined the group in the reproductive phase (during November 2021) and six females (BM, SM, PRT, HMP, LMP and SHD). The percentage of males recorded mating is 100% whereas the percentage of females recorded mating is 85% in T2 group (Table 5.4, 5.5).

**Table 5.4.** The total number of mating dyadic's and the mating rate of individuals in T1 group during the study period (Total observation- 94:00 hrs)

| | **Male ID** | | | | **Total** | **Matings/ Observation hr** |
|---|---|---|---|---|---|---|
| **Female ID** | BAB | NH | PGY | OWL | | |
| MTR | **8** | 0 | 0 | 0 | **8** | **0.09** |
| GRY | 3 | **2** | 0 | 0 | **5** | **0.05** |
| ES | **4** | **1** | 0 | 0 | **5** | **0.05** |
| SF | 0 | **4** | 0 | 0 | **4** | **0.04** |
| NN | 0 | 0 | 0 | 0 | 0 | 0 |
| LF | 0 | 0 | 0 | 0 | 0 | 0 |
| CHN | 0 | 0 | 0 | 0 | 0 | 0 |
| LE | 0 | 0 | 0 | 0 | 0 | 0 |
| LUT | 0 | 0 | 0 | 0 | 0 | 0 |
| BRD | 0 | 0 | 0 | 0 | 0 | 0 |
| 3E | 0 | 0 | 0 | 0 | 0 | 0 |
| BIL | 0 | 0 | 0 | 0 | 0 | 0 |
| ALN | 0 | 0 | 0 | 0 | 0 | 0 |
| GRT | 0 | 0 | 0 | 0 | 0 | 0 |
| BO | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | **15** | **7** | 0 | 0 | **22** | **0.23** |
| **Matings/ Observation hr** | **0.16** | **0.07** | 0 | 0 | **0.23** | |

Of the three adult males in T1 group, only two males were observed mating. Of the 22 matings, the number of matings by BA (68.18%, N =15) was higher than other males (Table 4). The mean duration (Mean ± SD (N) in seconds) mating for individuals of T1, BAB 2.55±1.13 (15), NH 3.29±1.42 (7), ES 3.20±1.15 (5), GRY 2.54±0.55 (5), MTR 2.31±1.16 (8) and SF 3.50±1.96 (4). Ejaculations from single male (BA) was recorded with percentage ejaculation rate of 13.33% per mating.

**Table 5.5**. The total number of mating dyadic's and the mating rate of individuals in T2 group during the study period. (Total observation- 109:30 hrs)

| | **Male ID** | | | | | |
|---|---|---|---|---|---|---|
| **Female ID** | HED | LC | MP | 1E | **Total** | Matings/ Observation hr |
| BM | **60** | **31** | 0 | 0 | **91** | **0.83** |
| SM | **41** | **11** | 0 | 0 | **52** | **0.48** |
| HMP | 0 | **12** | **7** | 0 | **19** | **0.17** |
| PRT | 0 | **16** | 0 | 0 | **16** | **0.15** |
| LMP | 0 | **2** | **6** | **2** | **10** | **0.09** |
| SHD | 0 | **2** | 0 | 0 | **2** | **0.02** |
| AB | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | **101** | **74** | **13** | **2** | **190** | **1.74** |
| **Matings/ Observation hr** | **0.92** | **0.68** | **0.12** | **0.02** | **1.74** | |

Every adult male in T2 group were observed mating (Table 4). Of the 190 matings, the number of matings by HED (53.16%, N =101) was higher than other males (Table 5). The mean duration (Mean±SD (N) in seconds) of mating of individuals of T2, 1E 5.00±0.00 (2), HED 3.64±1.98 (101), LC 3.46±1.74 (74), MP 2.96±0.75 (13), BM 3.64±2.05 (91), HMP 2.92±0.68 (19), LMP 3.85±1.56 (10), PRT 3.63±1.58 (16, SHD 5.00±1.41 (2), SM 3.45±1.80 (52),

*Mating interference*

Three mating interference events were recorded within the T1 group, where two of the interference events were by other in individuals in the group and one interference event was by the stray dogs. Both mating interference by individuals within the group were one by an adult male (PGY) and another by adult female (ES). All three-interference event was successful in stoppage of the mating event.

Three mating interference events occurred within T2 group, in one which dog and another by another by an adult male (1E) where both mating interference events were unsuccessful. Another one interference event was by an adult male (HED) and adult female (BM) together initiated, which was successful.

## DISCUSSION

The dispersion data showcased a much higher dispersion area for T1 group compared to T2 group. Thus, the large variation in the dispersion area is unlikely to be the result of the group size and due to the incoherence of the individuals in the T1 group. This incoherence might have risen from the result of non-related individuals in the group. This might be the result of the capture and release of macaques for sterilization process where the individuals from different groups might have got mixed and to have a group of unrelated set of individuals compelled to remain as a group for their survival. The like many group-living primates, macaques show polygynandry mating system where mating success of male is skewed towards dominant rank as a result of mate monopolization (Kappeler & van Schaik 2002).

Reproductive strategies incorporate a multitude of mechanisms that have evolved to promote the reproductive success of individuals. Evolutionary perspectives tend to emphasize the advantages of male-male competition and female choice as mediators of differential reproduction. Males who spend more time in consort and mate with more females tend to sire more offspring (Bercovitch. 1997). During the study period, the immigrations of adult male to both the groups occurred during the reproductively active months (October to December 2021) from which we could reach an assumption that the immigrations of adult males are majorly associated with reproduction. From the recorded data it is visible that the percentage of individuals, especially the females involving in the mating events are comparatively very less. We could reach into a conclusion that the procreation ability is restricted to a single adult female in T1 group, and for two adult females in the T2 group. The influence of higher ranks in mate selection might only be the reason where a few other female individuals are involving in the mating events. This might be the result of a long-time failure in the ability to produce offspring's by the smaller ranking females. A study conducted in a recently sterilized population of long-tailed macaque in Bali, portrayed that the sterilized individuals devoted more time in social and sexual activities with adult males by reducing the time involved for resting and caring behaviours (Cambier, 2019). But our results tend to shed light on the long-term evolution of these characters resulted in selective mating of individuals while the sterilized individuals are showcasing less involvement in reproductive behaviours. The resources of mating with the procreative females might be restricted to the high-ranking males.

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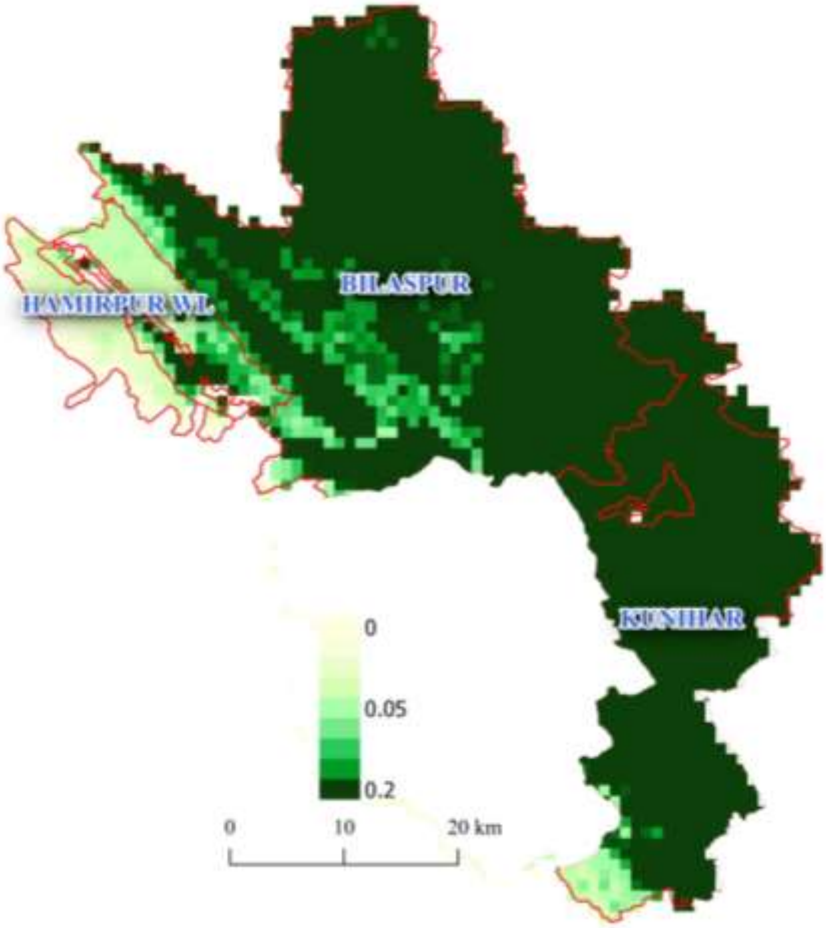
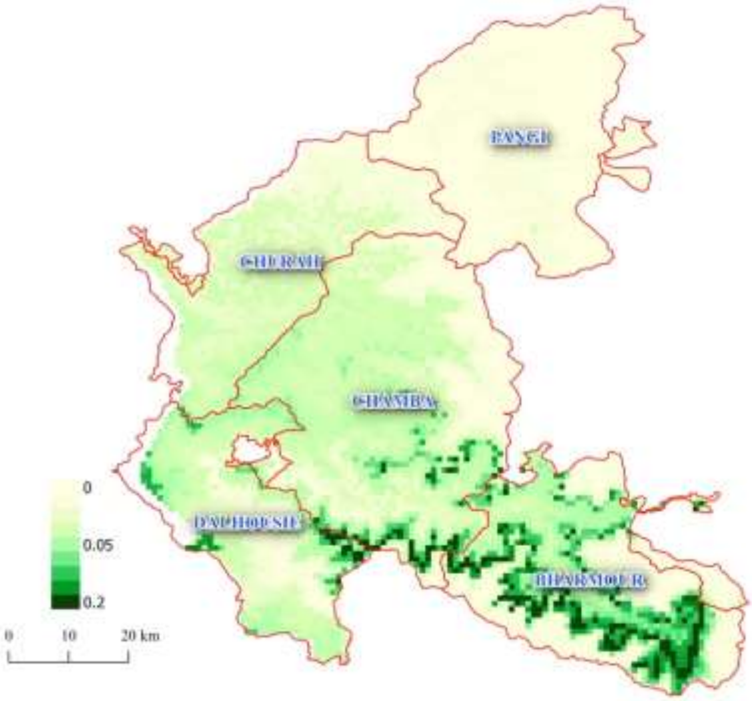
## Bilaspur Circle




| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **BILASPUR** | 0.14 | 33 | 13810 | 7992 |
| **KUNIHAR** | 1.04 | 38 | 6035 | 4332 |
| **Total** | | | **23923** | **12324** |

## Chamba Circle

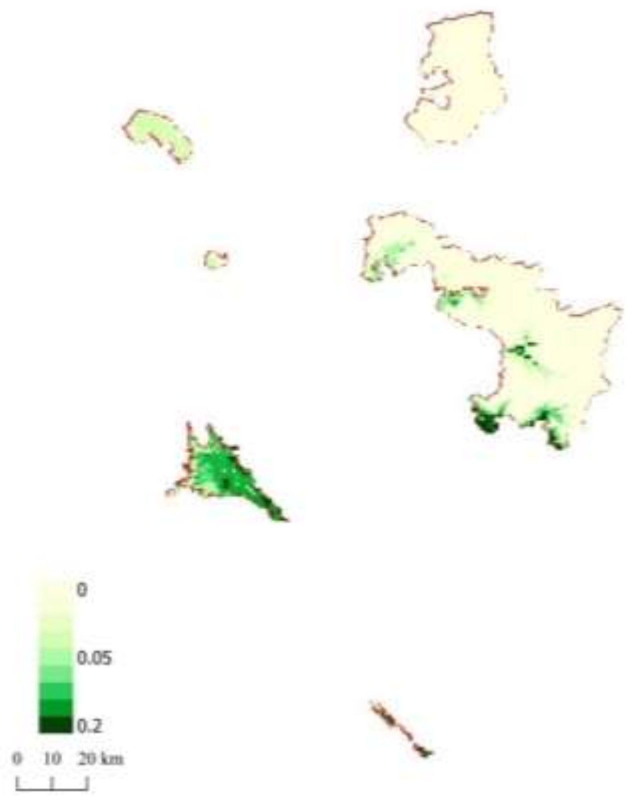



| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **BHARMAUR** | 0.06 | 35 | 1839 | 1921 |
| **CHAMBA** | 0.10 | 38 | 7888 | 4387 |
| **CHURAH** | 0.16 | 31 | 2756 | 3343 |
| **DALHOUSIE** | 0.25 | 40 | 10869 | 7329 |
| **PANGI** | | | 2764 | - |
| **Total** | | | **26116** | **16980** |

**Dharamshala Circle**

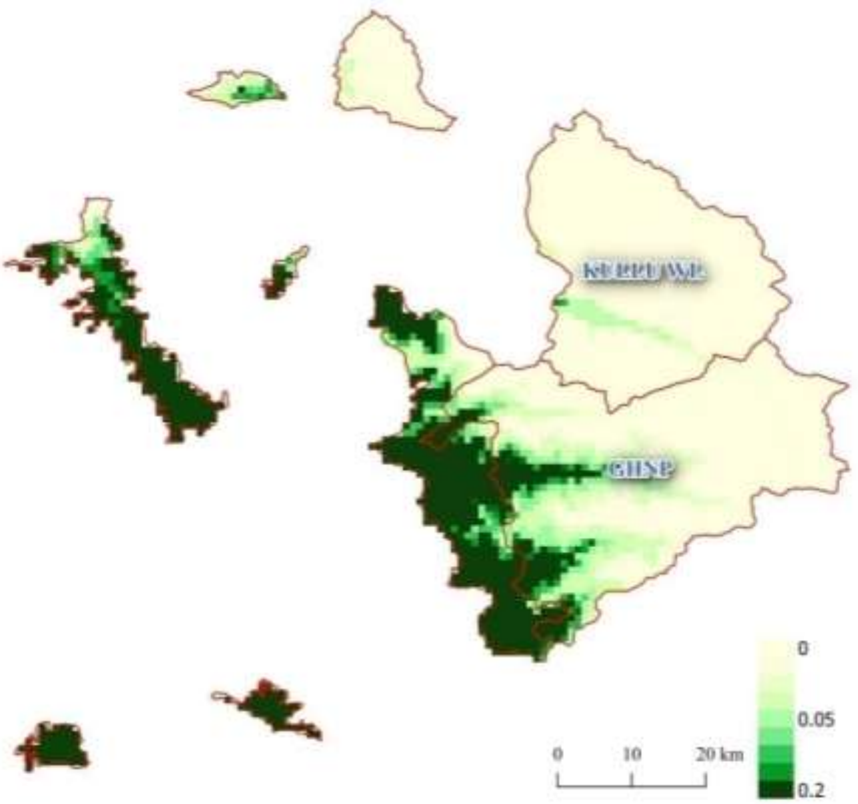

| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **DHARAMSHALA** | 0.09 | 36 | 8884 | 5097 |
| **NURPUR** | 0.15 | 30 | 14931 | 7718 |
| **PALAMPUR** | 0.13 | 31 | 8676 | 5735 |
| **Total** | | | **32491** | **18550** |

## Dharamshala Wildlife North Circle



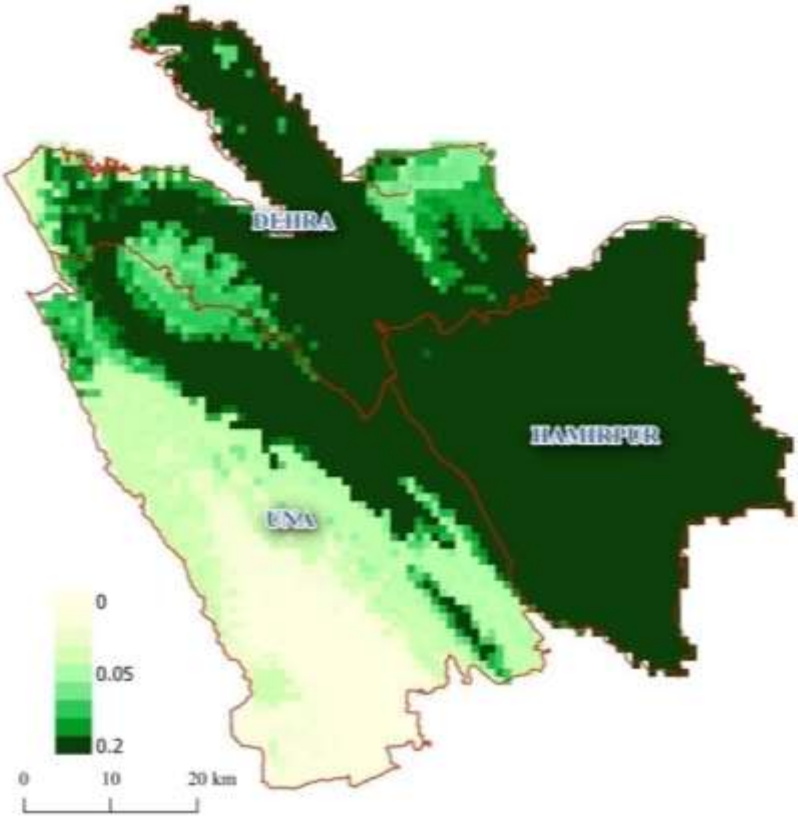

| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **CHAMBA WL** | 0.06 | 32 | 419 | 423 |
| **HAMIRPUR WL** | 0.03 | 10 | 154 | 37 |
| **Total** | | | **573** | **460** |

## GHNP Circle



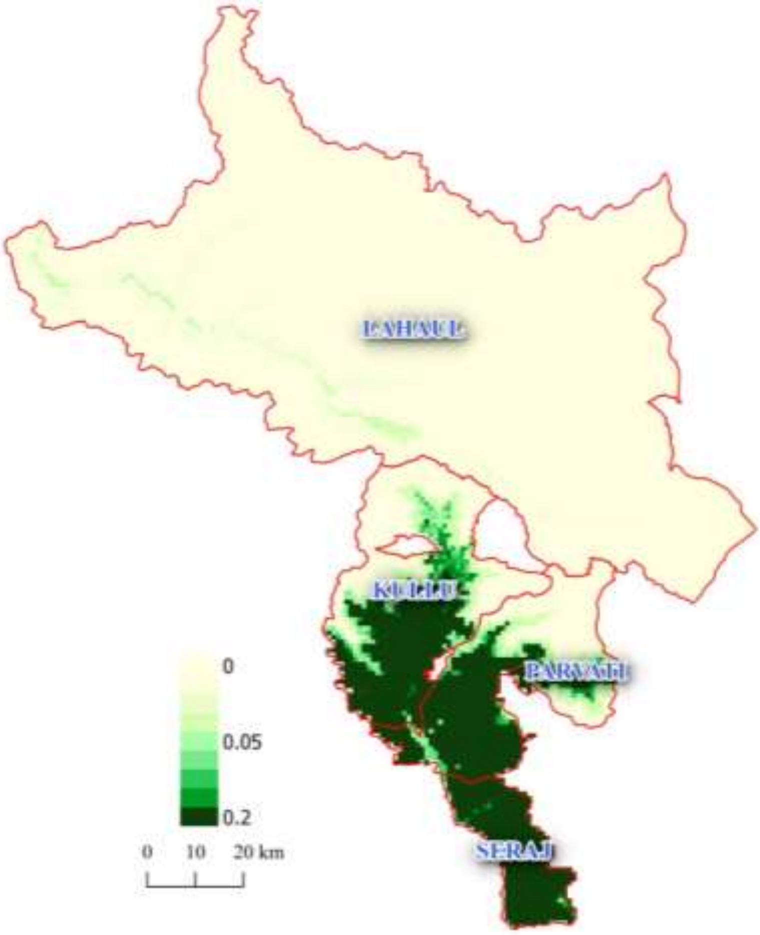

| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **GHNP** | 0.02 | 14 | 1231 | 162 |
| **KULLU WL** | 0.06 | 26 | 1611 | 969 |
| **Total** | | | **2842** | **1131** |

## Hamirpur Circle



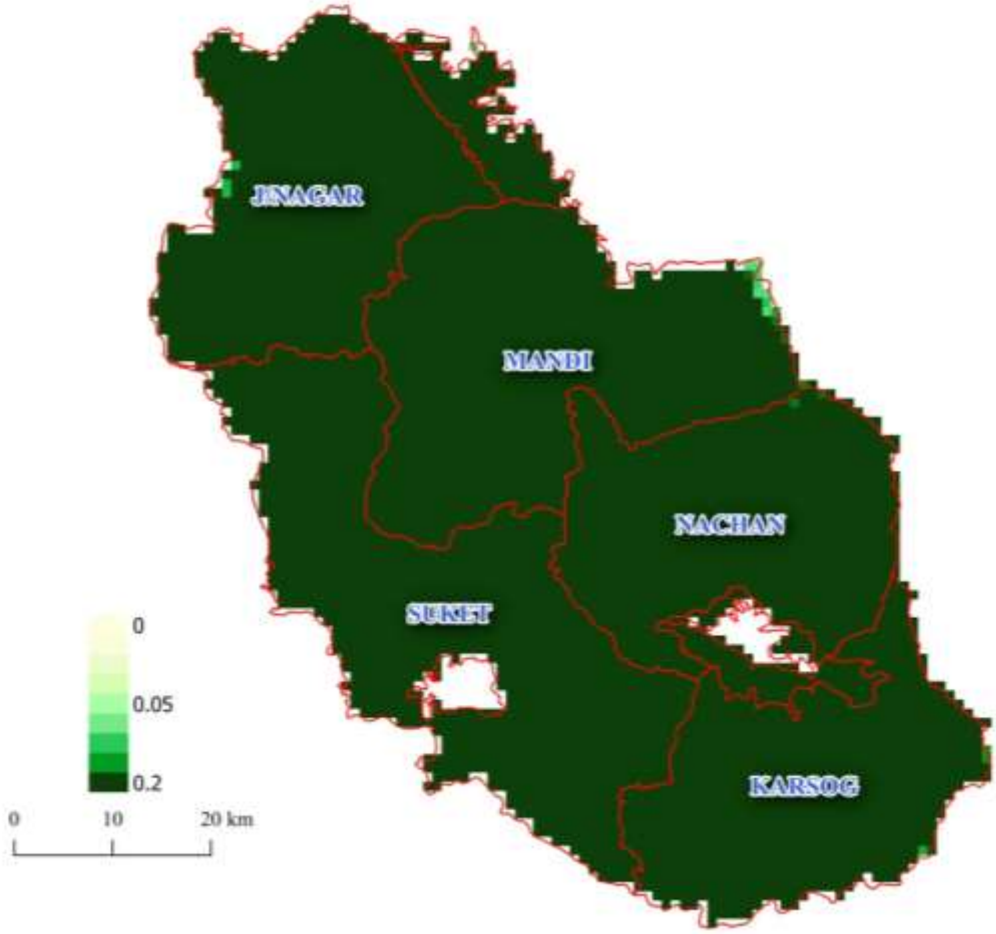

| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **DEHRA** | 0.01 | 35 | 6246 | 2981 |
| **HAMIRPUR** | 0.09 | 25 | 5541 | 3364 |
| **UNA** | 0.21 | 31 | 18174 | 10123 |
| **Total** | | | **29961** | **16468** |

**Kullu Circle**



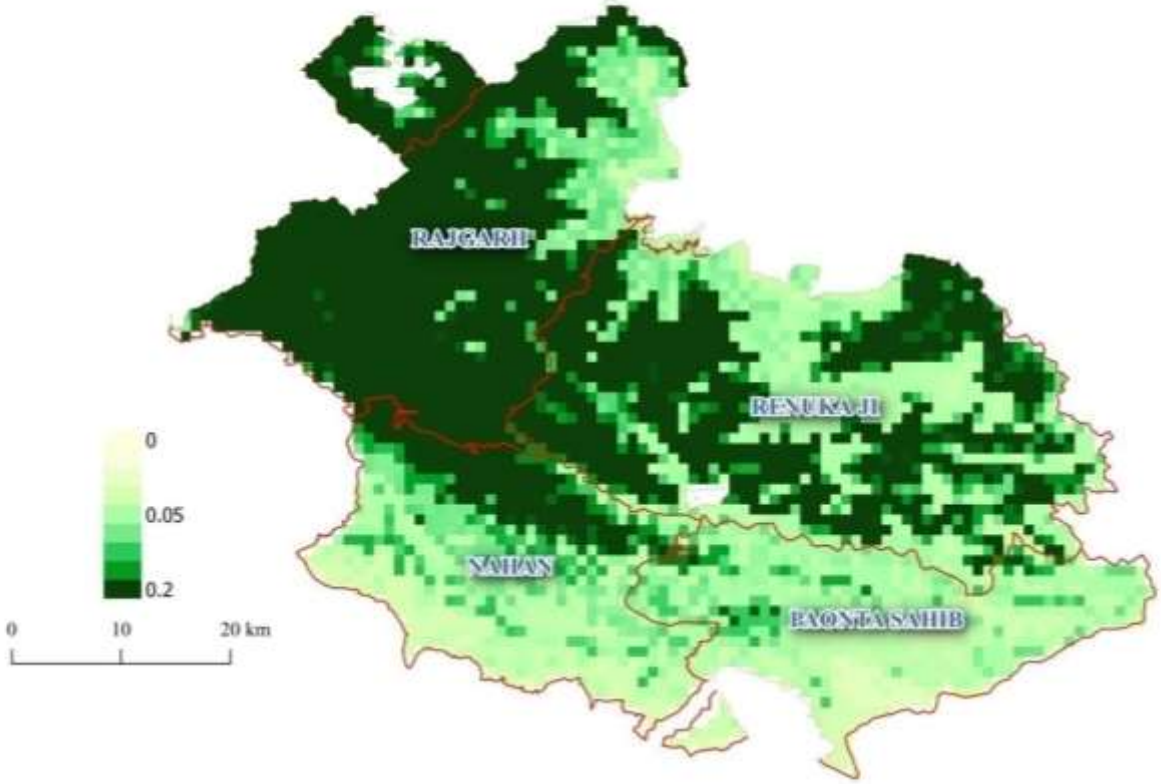

| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **KULLU** | 0.20 | 16 | 4075 | 2322 |
| **PARVATI** | 0.19 | 10 | 5964 | 1128 |
| **SERAJ** | 0.10 | 22 | 2451 | 1009 |
| **LAHAUL** | - | - | - | - |
| **Total** | | | **5564** | **4459** |

## Mandi Circle



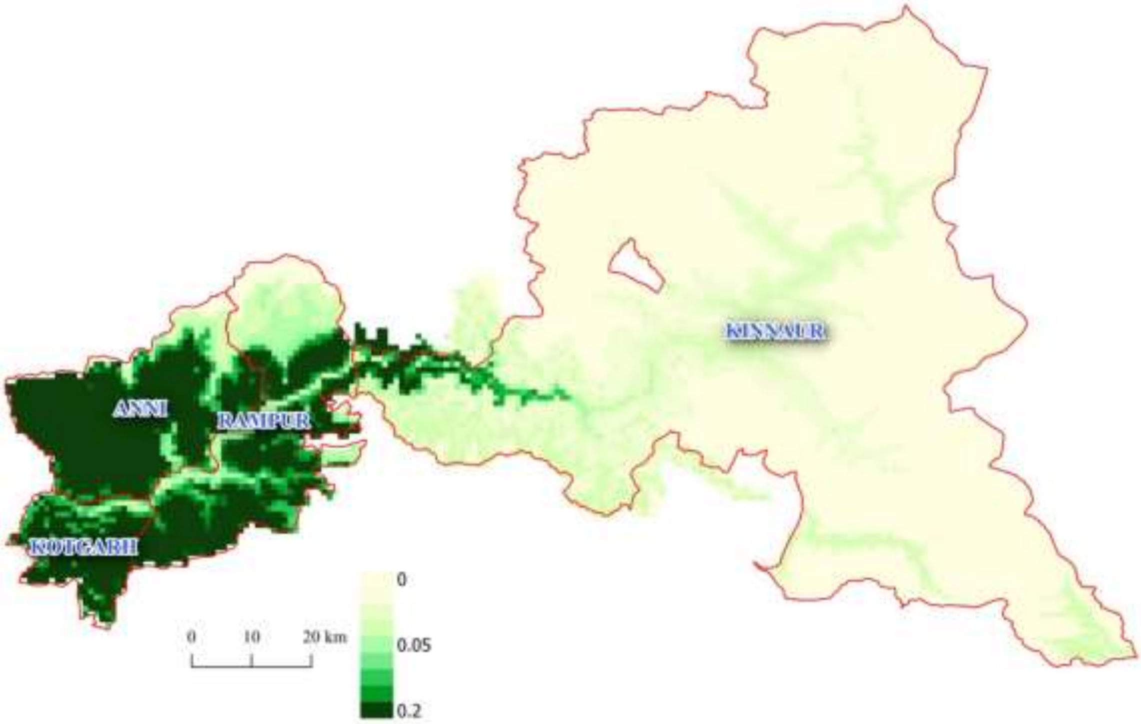

| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| JOGINDERNAGAR | 0.09 | 38 | 4609 | 2908 |
| KARSOG | 0.08 | 38 | 3611 | 1705 |
| MANDI | 0.13 | 38 | 4128 | 3921 |
| NACHAN | 0.12 | 34 | 3129 | 2529 |
| SUKET | 0.09 | 42 | 7797 | 4872 |
| Total | | | 23274 | 15935 |

## Nahan Circle



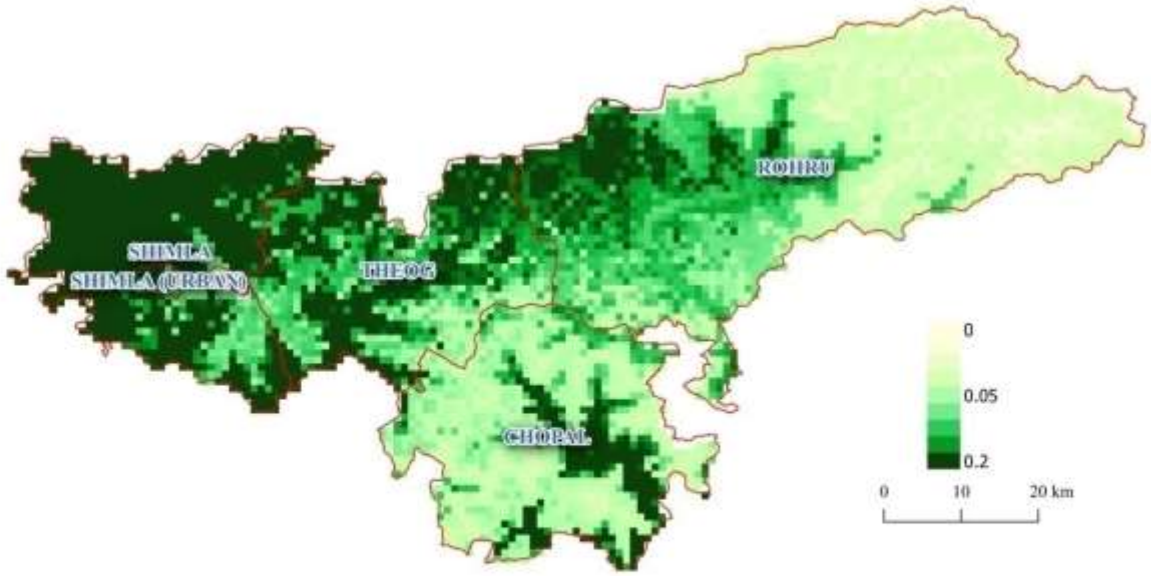

| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **NAHAN** | 0.13 | 39 | 5743 | 4270 |
| **PAONTA SAHIB** | 0.31 | 35 | 2546 | 5970 |
| **RAJGARH** | 0.06 | 38 | 9905 | 3141 |
| **RENUKA JI** | 0.06 | 27 | 12466 | 4810 |
| **Total** | | | **35979** | **18191** |

## Rampur Circle




| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **ANNI** | 0.07 | 23 | 3015 | 1214 |
| **KINNAUR** | 0.05 | 32 | 575 | 824 |
| **KOTGARH** | 0.51 | 16 | 730 | 2292 |
| **RAMPUR** | 0.18 | 27 | 2465 | 4147 |
| **Total** | | | **6785** | **8477** |

## Shimla Circle

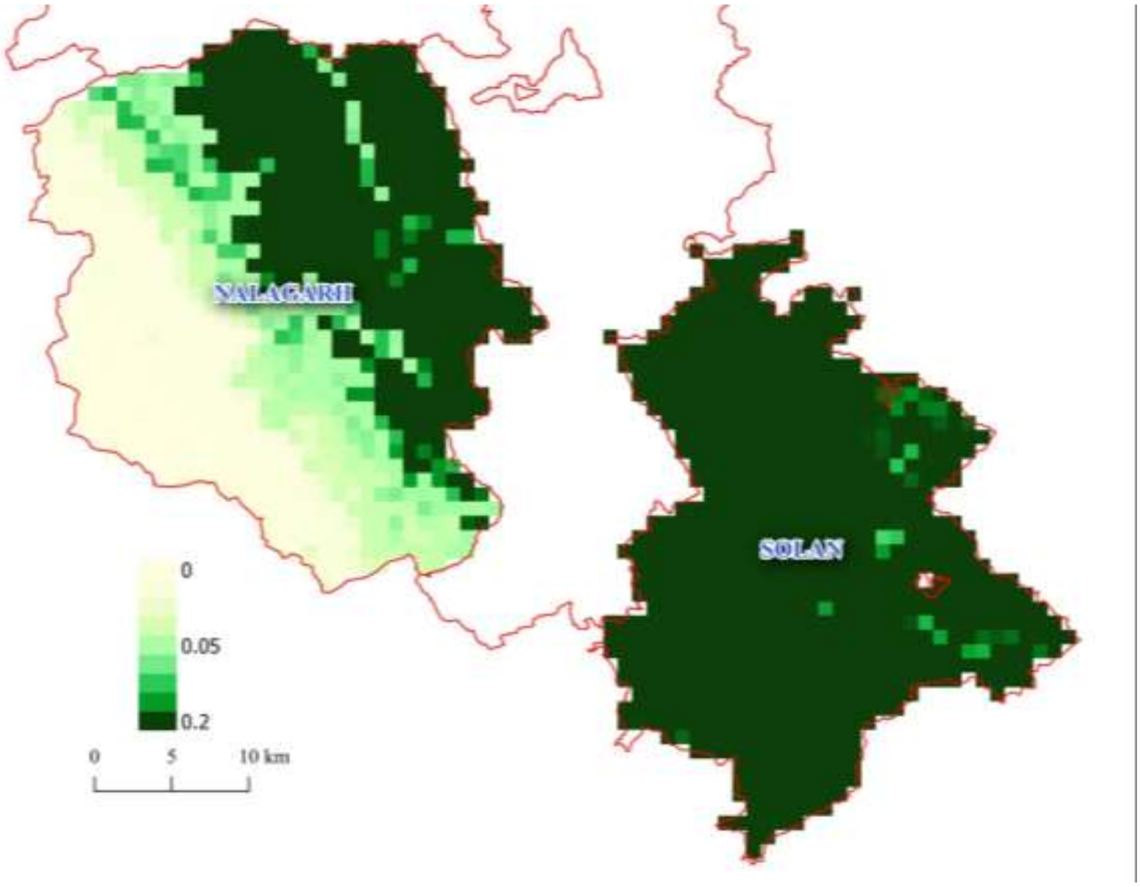



| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **CHOPAL** | 0.03 | 27 | 3293 | 624 |
| **ROHRU** | 0.01 | 49 | 4855 | 845 |
| **SHIMLA** | 0.16 | 38 | 5580 | 4144 |
| **SHIMLA URBAN** | 0.59 | 26 | 1166 | 1638 |
| **THEOG** | 0.20 | 21 | 2092 | 2698 |
| **Total** | | | **16986** | **9949** |

## Shimla Wildlife South


| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **SARHAN WL** | 0.18 | 29 | 673 | 1115 |
| **SHIMLA WL** | 0.17 | 22 | 964 | 670 |
| **Spiti** | - | - | - | - |
| **Total** | | | **1637** | **1785** |

## Solan Circle




| DIVISION | Density (strip area) | Average group size | 2015 | 2019 |
|---|---|---|---|---|
| **SOLAN** | 0.32 | 33 | 5319 | 6878 |
| **NALAGARH** | 0.16 | 38 | 3114 | 4856 |
| **Total** | | | **8433** | **11734** |