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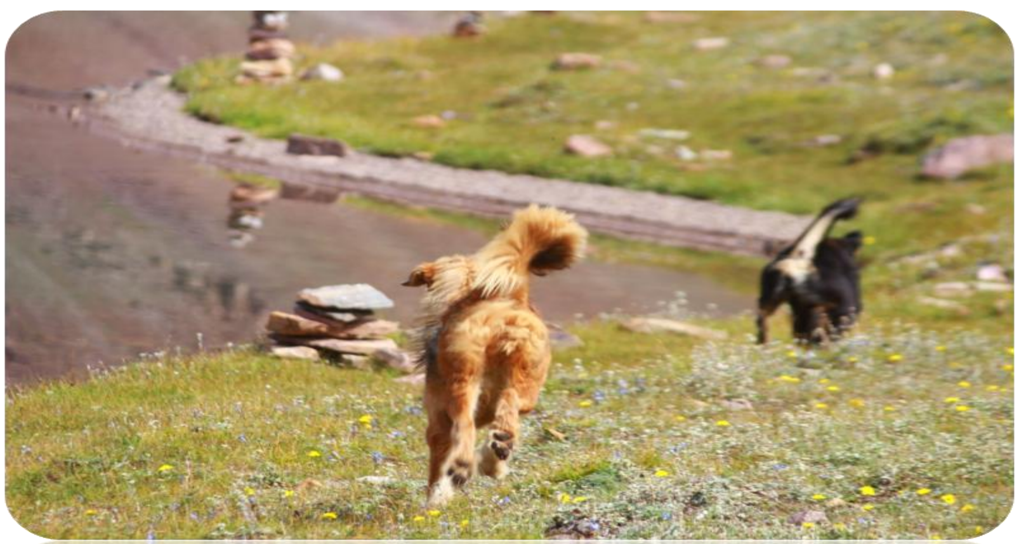
Final Project Report
of the project

"Assessment of population and impacts of feral dogs on wildlife livestock and humans to design a feral dog management strategy in the Lahaul-Pangi landscape of Himachal Pradesh"



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Executive summary

Human associated threats to the wildlife have now brought out another dimension which is related to domesticated dogs which become feral in wilderness areas. The feral dogs are leading to biodiversity loss, and they are depredating on wildlife species and also competing with large carnivores. Globally, very less but noticeable studies are available documented the impact of feral dogs on wildlife either through direct predation, changing their natural behaviour and disease transmission. In the present study, we aimed to understand the distribution pattern, population status and feeding resources of feral dogs in the Lahaul and Pangi landscape valley. We used camera trapping, trail sampling, non-invasive genetics and questionnaire survey to gather information on the feral dogs. Ensemble species distribution modelling was used to identify the areas prone to high risk with available patches for the feral dog occurrence. Through camera trapping, we got a total of5 independent captures of feral dogs in both Lahaul and Pangi valley. Whereas in trail sampling, 117 trail walked in Lahaul and Spiti valley of 634.5 km resulted in total 15 direct sightings of feral dogs (a group of 2-4 individuals). Through DNA based techniques, we identified 48 samples of feral dogs from the wildlife habitat in Lahaul and Pangi valley region and the non-invasive genetics analysis of these scats resulted in the identification of 11 individuals of dogs. Total 570 questionnaire surveys were conducted in the Lahaul and Pangi valley out of which 170 were conducted in the Pangi valley, and 400 were Lahaul valley and found substantial evidence of feral dogs presence in Pangi valley than the Lahaul valley. The food resources of dogs in the form of garbage sites (20 major) have been mapped, and a hot spot analysis has been conducted. Whereas, as micro-histological analysis of the scats suggest some of the wildlife species such as Marmot, Blue sheep and rodents species are present in the diet of dogs, but the diet is dominated by domestic livestock. The response of cattle abundance was found to be positively correlated with the distribution probabilities of a feral dog, indicating its importance in sustaining the feral dog's population in the study landscape. The negative relation of elevation with the distribution suggesting that the feral dogs prefer lower elevation areas, mostly the valley region in the Lahaul and Pangi. The comparative analysis of two valleys indicates that the Pangi valley posses more suitable areas for the distribution of feral dogs than the Lahaul valley. Therefore, we recommend these areas need long term monitoring, and more intensive study is needed to understand possible impact by feral dogs

to wildlife using the different monitoring protocols. Based on the SCER model, feral dog posterior density found to be 2.78 individuals/ 100 Km^2 (95% highest posterior density intervals (HPD) = 2.75–3.00) in the Lahaul and Pangi landscape. The density ranged from 1.4 to 5.5 individuals/ 100 km^2 and found high in few areas even four times that of the lowest density areas.

Threats abetment plan of feral dogs in the Lahaul and Pangi valley is crucial as it hold populations of several globally threatened species including Snow Leopard, Himalayan brown bear, Mush deer which are ecologically low in densities. Further other species apart from the mammals, birds including wetland migratory birds and pheasants also threatened by the dogs in the Lahaul and Pangi landscape. Through the present study we have assessed the current distribution, population density estimation, food habits, mapping of potential food resources in the landscape of the feral dogs for management of threats posed by the feral dogs to wildlife as well as human population of the landscape. Hence based on the findings of the present study to address the threats and management the feral dog infestation a logical framework has been developed. The recommended strategies along with the outcomes and responsibilities are provided to control feral dog population in the study landscape.

1.0. Introduction

History dog domestication is long, and dogs were initially domesticated by the humans when they were nomadic hunter-gatherers (Peters et al. 2005).With the expansion of human population, the formation of agriculture lands was increased which leads to various conflicts at various stages ranging from livestock and human life loss to the crop damage (Matseketsa et al. 2019). Defensively, to protect or reduce these conflict dogs have been preferred by the resident community of forest fringes as or rotational farmers in the crucial wildlife habitat (Feldmann 1974; Khan 2009). However, no accurate records are available on the population size of feral dogs, but the massive number of feral dogs is being evolved rapidly having a wide range of negative impact both on humans(disease transmission & direct attack: Knobel et al. 2005) as well as on wildlife(Young et al., 2011).Based on previous reports, it is estimated that around 500-900 million dogs occur sympatrically with humans and considered as most abundant carnivore worldwide (WHO-WSPA 1990; Gompper, 2014b; Hughes and Macdonald, 2013). When the domestic dogs have no longer use, they become stray and later feral or free-ranging and significantly disrupt ecosystems by changing the species composition (Feldmann 1974, Gompper, 2014b; Hughes and Macdonald, 2013). As the number of these dogs' increases, they expanded their ranges to wildlife habitat due to scarcity of food and other resources in human habitation. Their access to wildlife habitat results in direct killing of wildlife. Studies have highlighted they harass or chase wildlife species, which results in increased stress, and also leads to energetically costly behaviour change among the local wildlife species (Lenth et al., 2014).

Feral dogs now become the serious threat to wildlife as they depredate on a variety of native fauna, mammals but also birds, reptiles, amphibians, and invertebrates, and also prey on domestic livestock (Hughes and Macdonald, 2013; Ritchie et al., 2014; Vanak & Gompper, 2009; Young et al., 2011). The feral dogs also reported to be hybridized with concentric species such as wolf (Laurenson et al. 1998) and are also reported to mate with a female wolf in the Lahaul and Spiti district of Himachal Pradesh (Hennelly et al. 2015).They are also the potential carrier of transmissible pathogens such as rabies, parvovirus, and canine distemper virus (CDV), hence they can cause significant population decline to native species which are often endangered wildlife (Woodroffe, 1999). It is well established that feral dogs if come in contact with both humans and wildlife, may result in the transmission of zoonotic diseases (Salb et al., 2008). Reports also suggest that the feral dogs increases intra guild competition, and many intra guild species avoid the habitat where the feral dogs freely roam such as Indian foxes, *Vulpes bengalensis* (Vanak & Gompper, 2009).The presence of feral dogs in wildlife habitat also has non-lethal interactions which lead to disruption of physiology and normal behaviour such as foraging, vigilance, and bedding of wildlife species (Weston and Stankowich, 2014). However, limited records are available on the influential impact, intensity and abundance of feral dog presence on the wildlife (Ritchie et al., 2014). Especially in high altitude areas information is lacking on feral dogs largely because of recent expansion/increase in the population of the feral dogs to these wildlife habitats. In India, expansion of free-ranging dogs also has been reported from many wildlife habitats ranging from the mainland to the high altitude areas (Home et al., 2017). The range of feral dogs and their access is defined by the available space and their accessibility to nearby wildlife habitat. In India the majority of the Protected Areas are relatively small and may not meet the space requirements of existing species (Chundawat et al., 2016), so expansion of feral dogs in these areas becomes a major threat to the local biodiversity. The human population expanded to remote areas where the infrastructure development links these areas to main city has changed their life styles and also in the land use utilization pattern of the region (Chaudhary 1998; Jaglan & Thakur 2005). In the high altitude areas feral dogs are now becoming one of major threats to wildlife especially in the Trans-Himalayan region. Among the Trans-Himalayan range, the Lahaul & Spiti (L&S), which is a rain shadow area of Himachal Pradesh and it has been least explored in terms of biodiversity assessment hence, scanty information is available on the faunal diversity and distribution. A recent study using the different surveying methods reported that a total of 23 species of mammals are presented in Lahaul and Spiti valley using camera trapping (Joshi et al., 2019).

A number of strategies are now available for documenting and monitoring wildlife species in landscapes. The camera trap has been used most extensively for studying ecology, surveying species richness (Rovero et al., 2014), exploring community dynamics (Lesmeister et al., 2015), population estimation (Ramsey et al., 2015) and also for understanding the habitat utilization and occupancy (MacKenzie et al., 2002; Rovero et al., 2014). Apart from that camera trapping and other surveying methods also provide the information on the habitat utilization by the domestic livestock, feral dogs and other non-native species (Triguero-Ocaña et al., 2019). Whereas, generating information through questionnaire survey on Local Ecological Knowledge (LEK) has now become one of the important tools for gathering information about the human-wildlife conflict and other critical information on the different aspects of conservation biology (Jones et al., 2008; Turvey et al., 2014; Williams et al., 2017). The camera traps and other conventional methods are effective in documenting species presence and habitat utilization. They are also used prominently in population assessment studies, especially species which possess individual-specific patterns on the body such as Tigers, Leopards, Snow Leopards, etc. However, for population monitoring of species which does not have individual-specific patterns on their body, non-invasive DNA based sampling found to be most effective and provides very precise estimates.

The present study has been entrusted to the Zoological Survey of India, Kolkata considering the expertise of ZSI in the faunal assessment of the country. The study aimed to understand the distribution and population assessment of feral dogs in the Lahaul and Pangi valley using camera trapping, sign survey, non-invasive genetics and interaction with the locals.

Objectives/ deliverables

1. To assess distribution, population and density of feral/free-ranging dogs in the Lahaul-Pangi landscape of Himachal Pradesh.
2. To assess interactions and impacts of feral dogs on wildlife, livestock and humans in the Lahaul-Pangi landscape.
3. To assess main food sources and quantify the availability of main food sources of feral dogs in human-dominated and wilderness areas.
4. To design a comprehensive strategy for feral dog management.

Deliverables: The present deliverable report provides information on all four deliverable of the project.

2.0. Study Area

The present study was implemented in two valleys, i.e. Pangi of Chamba and Lahaul valley of Lahaul & Spiti districts of Himachal Pradesh. These two valleys are located adjacent to each other with Great Himalayan and Tran-Himalayan features. Much of the tribal population of Himachal Pradesh resides in these two areas. The local communities in the landscape are largely agrarian, and much of their livelihood comes from horticulture and animal-based agriculture. In the recent past Government has taken several initiatives for the socio-economic improvement of the local communities by way of increasing road network, infrastructure development and new livelihood opportunities. The Lahaul valley comes under the Lahaul and Spiti, district of Himachal Pradesh, extends from 31°44'57" to 32°59'57"N latitudes and 76°46'29" to 78°41'34"E longitudes between the Pir Panjal Mountain chains of the Greater Himalaya and Trans Himalaya (Aswal and Mehrotra 1994; Fig. 1). The temperature varies from a maximum of 27°C in July and a minimum of –13°C in February. Due to the climatic umbrella, the regions experiences spring, summer, autumn and very cold winter (Wagnon et al., 2007). The physiographic structure is peculiar with usual perpetual snow covered peaks and valleys with high steep and undulating terrain covered with diverse land cover types such as coniferous forests, alpine and subalpine vegetation, grassland, agricultural land (Joshi et al., 2006). The study landscape is also home to some of the top conservation priority species including Snow Leopard, Himalayan Brown bear, Musk deer, Ibex, Himalayan Wolf, Asiatic black bear, etc. Whereas, the Pangi region a safe adobe with diverse and rich habitat for several faunal species. The Pangi valley is also posses habitat for most of the species which are reported to be present in adjacent Lahaul valley. The Pangi valley is relatively scientifically least explored area in Himachal Pradesh.

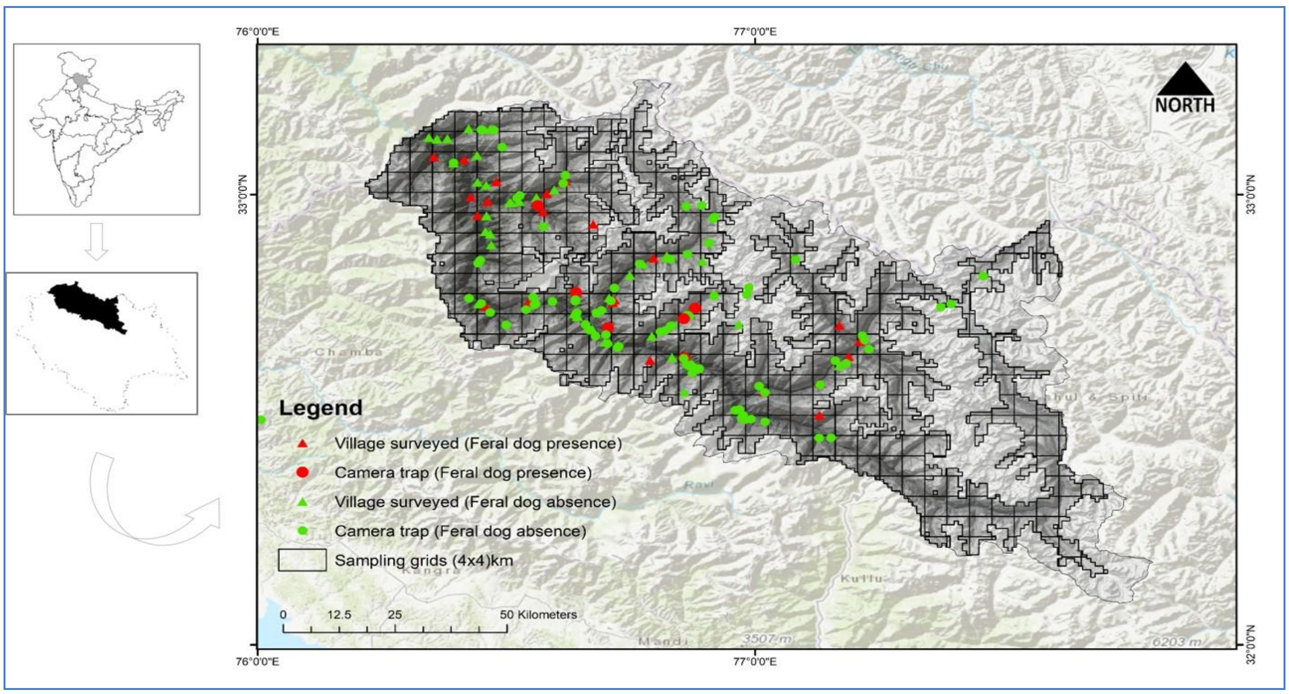

Figure 1. Study area map showing surveyed grids in Lahaul & Pangi valley using the camera trapping, village surveyed and with feral dog presence/absence.

3.0. Methodology

Deliverable 1: Distribution and Population assessment of feral dogs

3.1. Data collection

a. Sign Survey

The study landscape was divided into 4 km × 4 Km grid. We have covered four ranges of Lahaul, i.e., 1-Keylong, 2-Tindi, 3-Pattan valley, 4-Udaipur. Whereas, in the Pangi valley conducted surveys in three forest ranges: 1-Killar, 2-Sach, and 3-Purthi (Fig. 1). During the study period from March to September 2020, we walked a total of 117 trail covering 634.5 km approx. together in Lahaul and Pangi valley. In every trail, direct or indirect signs (direct sighting, faecal matter) of the feral dog were recorded. For every sighting, location name, GPS coordinates, altitude, sign type, terrain, forest type along with photographs were recorded. Indirect evidence of feral dogs (scats) collected was also identified through DNA based techniques (Joshi et al., 2019). Furthermore, efforts were made to cover grids which were logistically possible.

b. Camera trapping

Camera traps were deployed along with the active natural trails, near to forested areas, water sources and valley. A total of 34 grid cells were selected systematically and deployed total of 86 cameras in the Lahaul valley and 16 cameras in the Pangi valley in the different elevation ranges from 2,478 m to 4,100 m. The camera traps were placed at about 2.5 feet height from the ground on animal trails and paths and mostly kept 2-3 m apart from the trails. We used ultra-compact SPYPOINT FORCE-11D trail cameras (SPYPOINT, GG Telecom, Canada, QC) during the study. Sampling was conducted in all these forest ranges for mammalian fauna mainly focusing on a feral dog from March 2020–September 2020. Camera No, SD- card No, location name, GPS coordinates, altitude were noted and Camera traps were left active for 24 hrs for 15-35 days.

c. Questionnaire survey

The questionnaire surveys were conducted in Lahaul and Pangi Valley through informal discussions with locals to gather information about the presence of feral dogs in the area (Fig. 2).

A total of 570 (170 in Pangi valley and 400 in Lahaul valley) responses were noted, and about 30% of households representing different affluent classes were interviewed from each village following NSSO survey strategy. Along with feral dogs, we also gathered information on wildlife presence, human-wildlife interaction and associated impacts. The wildlife presence was confirmed by showing them several pictures of the known species from these areas. Their local names and other indicators (predation behaviours; people can differentiate livestock depredation by the Snow leopard and Brown bear, wolf howls, pugmark of snow leopard) were collected to get inferences about their knowledge for the species presence.

Figure 2. Interaction with the locals during the questionnaire survey in the Lahaul and Pangi Landscape.

d. Non-invasive DNA based identification

A total of 139 scatswere collected from Lahaul and Pangi valley. All faecal samples were first air-dried under Sunlight in field conditions and then transferred to the 100ml sterilized vials containing silica gel and brought to the lab for further analysis. All the samples were processed in the dedicated room available for the faecal DNA isolation. DNA was extracted using the Qiagen Stool DNA extraction Kit (Qiagen, Germany). All DNA extracts of carnivores (139) were PCR amplified with the ATPase 6 to confirm the species following Chaves et al. (2012). The PCR was performed in a 20 µl reaction volume containing 2.0 µl DNA template, 1.6 mM $MgCl_2$, 2x Buffer, 0.5-unit Tag DNA polymerase, 200µl dNTPs and 1.0µM each primer. The PCR cycling conditions were an initial denaturation for 5 minutes at 94˚ C, followed by 40 cycles of denaturation for 45 Sec at 94˚ C, annealing for 50 Sec at 55˚ C and 1 min extension at

72˚ C with a final extension of 72˚ C for 10 min. The cycle sequencing was done using the BigDye Terminator kit (Applied Biosystems, USA) and purified products were subjected to DNA sequencing on the ABI 3730 Genetic Analyzer (Applied Biosystems, USA).

PCR amplification of microsatellite markers

A set of 10 microsatellite loci were used for individual identification following previous studies (Janssonet al. 2014; Flagstad et al., 2003; Boitani, 2003; Table 1). Each loci was individually amplified using the PCR master mix in a 10 µl volumes with the following PCR mix: 4 µl Multiplex master mix (Qiagen, Germany). The thermal conditions were used from the original protocol suggested by Boitani (2003). PCR amplification was checked on the 2 % (w/v) agarose gel by loading a mixture of 3µl PCR product and 1 µl loading dye. The bands of the amplified product were observed under the UV light. The amplified product of microsatellite markers were pooled with different dyes in a single tube and run for genotyping in the ABI 3500 Genetic Analyzer.

Table 1. List of microsatellite loci used for the Individual identification of feral dog in Lahaul and Pangi landscape.

Primer	Primer sequence
CPH12	F:GGCATTACTTGGAGGGAGGAA
	R:GTTTGATGATTCCTATGCTTCTTTGAG
CPH8	F:AGGCTCACAATCCCTCTCATA
	R:GTTTAGATTTGATACCTCCCTGAGTCC
AHT137	F:TACAGAGCTCTTAACTGGGTCC
	R:GTTTCCTTGCAAAGTGTCATTGCT
CPH2	F:TTCTGTTGTTATCGGCACCA
	R:GTTTCTTGAGAACAGTGTCCTTCG
CPH4	F:ACTGGAGATGAAAACTGAAGATTATA
	R:GTTTACAGGGGAAAGCCTCATT
C2096	F:CCGTCTAAGAGCCTCCCAG
	R:GTTTGACAAGGTTTCCTGGTTCCA
AHT121	F:TATTGCGAATGTCACTGCTT
	R:GTTTATAGATACACTCTCTCTCCG
AHTH130	F:GTTTCTCTCCCTTCGGGTTC
	R:GTTTGACGTGTGTTCACGCCAG
C09173	F:ATCCAGGTCTGGAATACCCC
	R:GTTTCCTTTGAATTAGCACTTGGC
CXX279	F:TGCTCAATGAAATAAGCCAGG
	R:GTTTGGCGACCTTCATTCTCTGAC

3.2. Data Analysis

3.2.1. Distribution and Population assessment of feral dogs

a. Species presence data collection for distribution assessment

A total of 82 presence evidence for feral dogs, including both the primary and the secondary locations (scat, pugmarks, digging, etc.) observation were recorded. Total 48 scats samples confirmed through DNA based analysis were also used as feral dog presence. The information collected through questionnaire survey was ascertained by verifying the livestock lifting instances by the carnivore species and after interviewing the experienced forest management staff in the study landscape. However, for generating the habitat models, we have used only the presence records of direct and indirect evidence collected during the sign survey.

b. Habitat variables

Considered the ecological requirement of the species only those habitat variables (Table 2) were used which may play a potential role in predicting the habitat of the species (especially Garbage sites; Wildlife abundance; Human influence index (HII), moreover that was the foremost criteria for selecting the species influence variables (Elith et al., 2006; Franklin, 2010; Peterson et al., 2011). The modelling was initiated with a set of 27 habitat variables which are potential predictors and these were grouped into four types, i.e., environmental, land cover & land use (LULC), topographic and anthropogenic. The environmental predictors were represented by 19 bioclimatic variables extracted from WorldclimVer.1.4 (https://www.worldclim.org/). For evaluating the influence of LULC type on the study species, we have used Moderate Resolution Imaging Spectroradiometer (MODIS) product (MCD12Q1), divided into 17 classes at 500-meter resolution downloaded from https://earthexplorer.usgs.gov (Friedl & Sulla-Menashe, 2019). The Global Human Footprint Dataset was used as an anthropogenic predictor, which provides information as human Influence Index (HII) in a given landscape, which helps in understanding the influence of human activity on species. The HII data was download from Socioeconomic Data and Applications Center (SEDAC), NASA (Wildlife Conservation Society, 2005). Further, the topographic variables such as elevation, slope and aspect of the landscape were generated using the 90 meter SRTM data downloaded from http://srtm.csi.cgiar.org/srtmdata/. The landscape slope was calculated following the method suggested by Riley et al. (1999). All predictors were rasterized and resampled at 30 arcsec spatial resolution (~1km) using the spatial analyst extension of ArcGIS 10.6. The spatial multicollinearity among the predictors was tested in SDM Toolbox v2.4 in ArcGIS 10.6, and the variables with r>0.8 Pearson's correlation were dropped from the analysis.

c. Habitat modelling and final ensemble building

We used the SDM package under R version 3.1 to evaluate distribution model through multiple modeling algorithms. The ensemble approach was used to build the final distribution model for feral dogs in Lahaul and Pangi Valley. A number of studies are available highlighting the robustness of the ensemble a modeling approach in predicting the probability of species presence precisely (Barve 2011; Elith et al., 2006; Franklin, 2010; Hutchinson, 1957; Pearson, 2007; Peterson et al., 2011; Phillips et al., 2006). After completing the variables selection procedure, we converted the variables for SDM supported file format to evaluate the probability of maximum suitable habitat of study species. Out of the total presence data of both the species, 70% data use for build the model and 30% of the data used for testing. We set the SDM environment with 50 replications, and SES (Sensitivity-Specificity equality) was used as an evaluation metric. A total of eight models types were used for building suitability of the species [Generalized linear model (GLM), Generalized additive model (GAM), Multivariate adaptive regression splines (MARS), Maximum entropy (MAXENT), Artificial Neural Network (ANN), Support Vector Machine (SVM), Random forests (RF) and Gradient Boosting Machine (GBM)], for selecting best-fitted model < 0.75 was kept as AUC threshold for finally building the ensemble probability surface. The logistic output format was used to calculate the Sensitivity and specificity for each variable. We verified our final ensemble model by generated ROC (Receiver Operating Characteristic) value, which directed the model evaluation poor when the value is 0.6-0.7, normal with 0.7 – 0.8, good with 0.8 – 0.9 value and best with 0.9 – 1.0 values. Individual models with ROC less than 0.6 value was rejected (Swets, 1988). Further for the evaluation of the final ensemble model we used the ENMeval software (Muscarellaet al., 2014), and the variable importance was evaluated as the percentage contribution in the final model.

Table 2. Primary selected variable used for ensemble modeling environment.

Variable	Code	Type
Topographic		
Elevation	Elevation	Continuous
Slope	Slope	Continuous
Bioclimatic		
Annual Mean Temperature	Bio_1	Continuous

Mean Diurnal Range (Mean of monthly (max temp - min temp))	Bio_2	Continuous
Isothermality (BIO2/BIO7) (×100)	Bio_3	Continuous
Temperature Seasonality (standard deviation ×100)	Bio_4	Continuous
Max Temperature of Warmest Month	Bio_5	Continuous
Min Temperature of Coldest Month	Bio_6	Continuous
Temperature Annual Range (BIO5-BIO6)	Bio_7	Continuous
Mean Temperature of Wettest Quarter	Bio_8	Continuous
Mean Temperature of Driest Quarter	Bio_9	Continuous
Mean Temperature of Warmest Quarter	Bio_10	Continuous
Mean Temperature of Coldest Quarter	Bio_11	Continuous
Annual Precipitation	Bio_12	Continuous
Precipitation of Wettest Month	Bio_13	Continuous
Precipitation of Driest Month	Bio_14	Continuous
Precipitation Seasonality (Coefficient of Variation)	Bio_15	Continuous
Precipitation of Wettest Quarter	Bio_16	Continuous
Precipitation of Driest Quarter	Bio_17	Continuous
Precipitation of Warmest Quarter	Bio_18	Continuous
Precipitation of Coldest Quarter	Bio_19	Continuous
Landuse and Anthropogenic		
	HII	Continuous
	LULC	Categorical
	Human Footprint	Continuous
Habitat specific		
	Cattle abundance	Continuous
	Garbage Site distributions	Continuous
	Wildlife abundance index	Continuous

3.2.2. Population estimation of feral dogs

a. DNA based analysis

Generated sequences were examined and validated using Sequencher 4.7 (Gene Codes Corporation, USA). During data analysis, each mutation was considered that have only sharp and clear peak to resolve any ambiguity in the species identification. Those have sequence quality of low Q values were not used for the identification purpose. A 126 bp of ATPase 6 were used for further analysis. The sequence generated in the present study were validated using reference data through the BLAST tool of GenBank(http://www.ncbi.nlm.nih.gov) as well as with the reference database of Zoological Survey of India.

b. Microsatellite analysis

The electropherograms produced by the genetic analyser were scored using GENEMAPPER v. 5.0 after the manual calling of each allele. We used MICRO-CHECKER v.

2.2.3 (Van Oosterhout et al., 2004) to examine the presence of null alleles, GENEPOP v. 4.2 (Rousset, 2008) was used to detect the presence of linkage disequilibrium. The diversity indices and probabilities of identities were calculated using GenAlEx v. 6.5 (Peakall & Smouse, 2006, 2012).

c. Spatially explicit capture-recapture method for density estimation of feral dog

A spatially explicit capture-recapture (SECR) method for density estimation is considered a more comprehensive and reliable approach in comparison to the traditional capture-recapture method (Brochers & Efford, 2008; Gopalaswamy et al., 2012; Chase & Grey et al., 2013), it results in a lower density estimate when compared to non-spatial methods (Obbard et al., 2010; Gopalaswamy et al., 2012; Braczkowski et al., 2016). We used individual identified through the microsatellite loci from the scats samples collected from Lahaul and Pangi landscape for the density estimation. We used the 4 × 4 Km grids based on the home range of wolves because feral dogs home range information is not available (Fig. 3). Hence considered the cell size as it is well below the average home range size for sub adult/adult wolves (122.1 ± 93.6 km^2; Llaneza, 2016). Moreover, the cell size was selected to avoid an excessive loss of resolution in the spatial scale of animal movement (σ; a parameter that determines the decline of detection frequency of individuals in detectors with increasing distance from their activity centres), which resulted in 400 cells of 4 × 4 km in Lahaul and Pangi valley. Here, we defined the detector as the centroids of the cells within the sample grid, and "detector level" covariate consider the effort invested in searching samples (López-Bao et al., 2018). We added "state-space (*S*) adding a 10-km buffer to the detector grid of>2.5 × σ (Royle et al., 2014; Fig.3). All the analysis were performed using *secr* (Efford, 2014) package of program R 3.6.3 (R Development Core Team, 2017) and uses a maximum likelihood approach to estimate model parameters (Borchers et al., 2008; Efford et al., 2009).

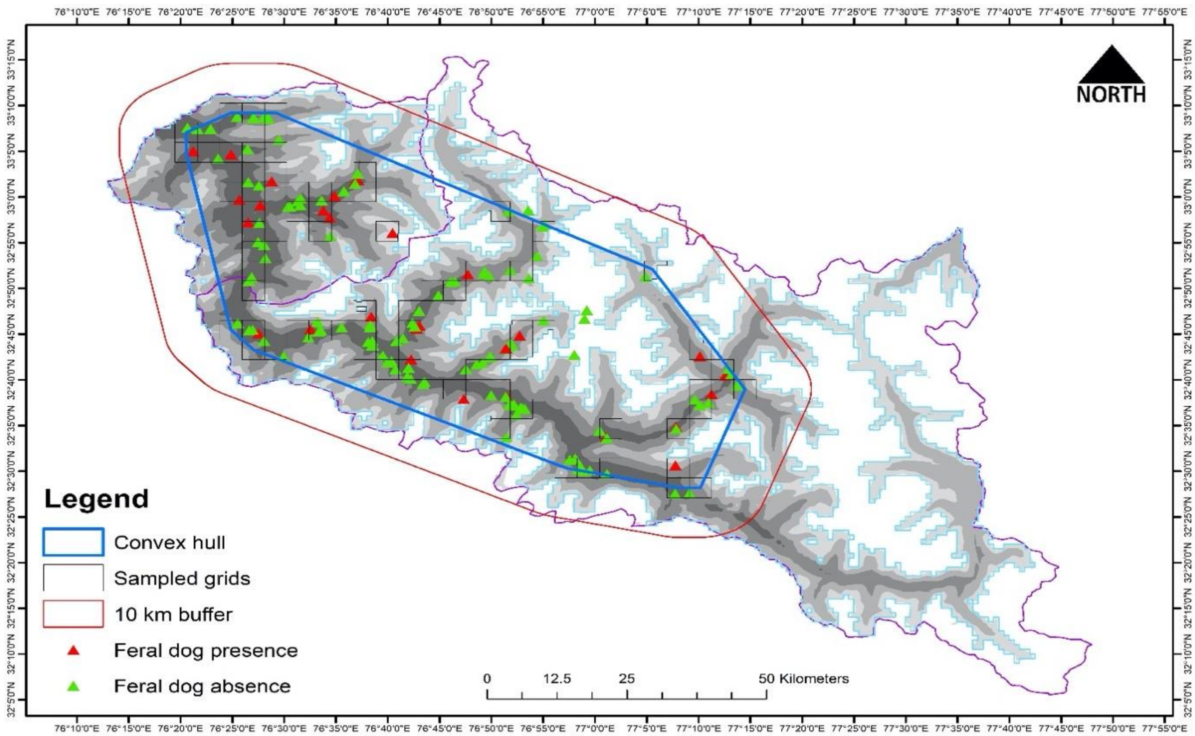

Figure 3. Study design for the density estimation in the Lahaul and Pangi Landscape of feral dogs.

Deliverable 2: To assess interactions and impacts of feral dogs on wildlife, livestock and human in the Lahaul and Pangi landscape.

a) Questionnaire Survey

We analysed the set of questionnaire data of 570 (170 in Pangi valley and 400 in Lahaul valley) respondent to understand the livestock predation by feral dogs in the Lahaul and Pangi landscape. The responses were obtained weather the livestock have been depredated by the feral dogs or not to understand the impact on the livestock.

b) Generalized linear modelling

To understand the interaction between the dogs', livestock and wildlife species we used generalized linear modeling (GLM). In which we used dogs' presence as response variable and each sites of dog presence were modelled with the wildlife species presence (species richness), cattle abundance (domestic livestock), presence of garbage sites as a covariate along with other

13 variables to understand the association of these predictor on the distribution of the feral dogs. We used the programed 'glmer' in the R package to performed the GLM analysis and includes all the 16 variables with the response variable (dog presence). Different set of models were tested by removing the non-significant variables in a backward stepwise manner to obtain the most parsimonious model (Mérő et al., 2015) and also combination of the more than one variables in model to check the combined effect of these variables on the dog distribution. From a set of different competing models, a model assigned and selected with the evidence of the lowest information loss (Kullback-Leibler information loss index; Burnham and Anderson, 2002) based on the Akaike's information criterion (AIC; Burnham and Anderson, 2002).

c) Diet Analysis

Further, we also carried out the feeding analysis of feral dog scat samples from the Lahaul and Pangi landscape to understand the impact of dogs on the livestock as well as on the wildlife. As feral dogs becoming a threats for both the livestock and wild animal, results killing of rodents to large animal like blue sheep, Siberian ibex, argali and other deer species in the different region (Young et al. 2011).

We used 48 confirmed scat samples of feral dogs using the mitochondrial DNA,i.e., ATPase 6 (Chaves et al. 2012). All the identified scat samples were soaked in water overnight and then thoroughly washed in running tap water using a sieve of 2mm and air-dried (Phillips et al. 2007). Remains recovered from the scats like skeletal materials like bones, claws, hairs, plant, feathers and seeds were air-dried for 2 days and stored. To avoid biases, we selected 20 hair samples randomly from the samples and mounted them on microscopic slides following the methodology of Mukherjee et al., (1994). Each prey species hairs were identified under the light microscope on the basis of microscopic characteristics like cuticular, medullar and cross-sectional patterns and compared with photographic reference key (Oli, 1993; Mukherjee et al. 2004 and Bahuguna et al. 2010). After identification of prey species, data was prepared in the form of presence and absence of prey species and recorded in an excel sheet. We calculated the frequency of occurrence {(no. of occurrences/total no. of samples) *100}, the relative frequency of occurrences {(No. of occurrences/No. of food items) *100} of each prey species in the scat samples. Plant materials like grasses, seeds and twigs and unidentified prey species hair were recorded but not included in the statistical analysis (Kojola et al. 2004; Breuer 2005). Though the frequency of occurrence is a widely used technique to quantify carnivore's diet this can underestimate the relative number of small mammalian prey consumed and overestimate their relative biomass due to their higher surface to volume ratio than larger mammals (Breuer 2005). Then we calculated the relative biomass and relative number of prey species consumed using the formula $D = \{(A\times Y)/\Sigma(A\times Y)\}\times 100$ and $E = \{(D+x)/\Sigma(D+x)\}\times 100$ respectively, where D denotes relative biomass, A frequency of occurrence, Y is the correction factor, E represents a relative number of prey species consumed and x is the live body weight of different prey species (Atkinson et al. 2002).

Deliverable 3. To assess main food sources and quantify the availability of main food sources of feral dogs in human-dominated and wilderness areas.

3.2.3. Food resources mapping and feeding habitats of feral dogs

For assessing the food sources, identifying the hot spots of food resources, we used GIS-based strategy. The food is largely available in the form of garbage in dumping sites located in outskirts or fringe areas of human habitation in villages and towns in the study landscape. Moreover, few wilderness areas located in both the valleys possess a good abundance of wildlife which is vulnerable to feral dogs.

Methodology

To understand the food resources of the feral dogs, we adopted the IDW interpolation techniques in ArcGIS 10.6. During the study, duration efforts were made to located and map the food resources of feral dogs based on the field survey as well as questionnaire surveys. Furthermore, to understand the diet composition of feral dogs, micro-histological analysis of collected scats was carried out during the study duration.

a. Feeding analysis

We also understand feeding availability of species through diet analysis and how the feral dogs dependent on livestock and wildlife species for the dietary requirement. The detailed methodology described above.

4.0. Results

Deliverable 1: Distribution and Population assessment of feral dogs

A total of 98 cameras placed in the Lahaul and Pangi valley in which 5 cameras (6 captures) detected the presence of feral dogs near to the wildlife habitat (Fig. 4).Among these different localities, one captures were detected in the Pangi valley and 5 in the Lahaul valley. Whereas, different dogs were capture on different occasion. Out of the total117 trails walked (634.5 km)nine trails resulted in the direct sighting of feral dogs in groups of two to four individuals were encounter (Fig. 5&6). Based on the 570questionnaires conducted from both the valleys (170 from Pangi valley and 400 from Lahaul valley) only 29% responded from the Pangi valley and 12% respondents from the Lahaul valley admitted the presence of feral dogs in their locality. Furthermore, a total of 139fecal samples collected from Lahaul and Pangi valleys processed for the DNA extraction and shown the degraded quality of DNA ranges from 100bp to 1Kb (Fig. 7).All of these samples processed for the PCR amplification using ATPase 6 primer and 48 samples were confirmed as the Feral dog with the good quality of sequences (Fig. 9).

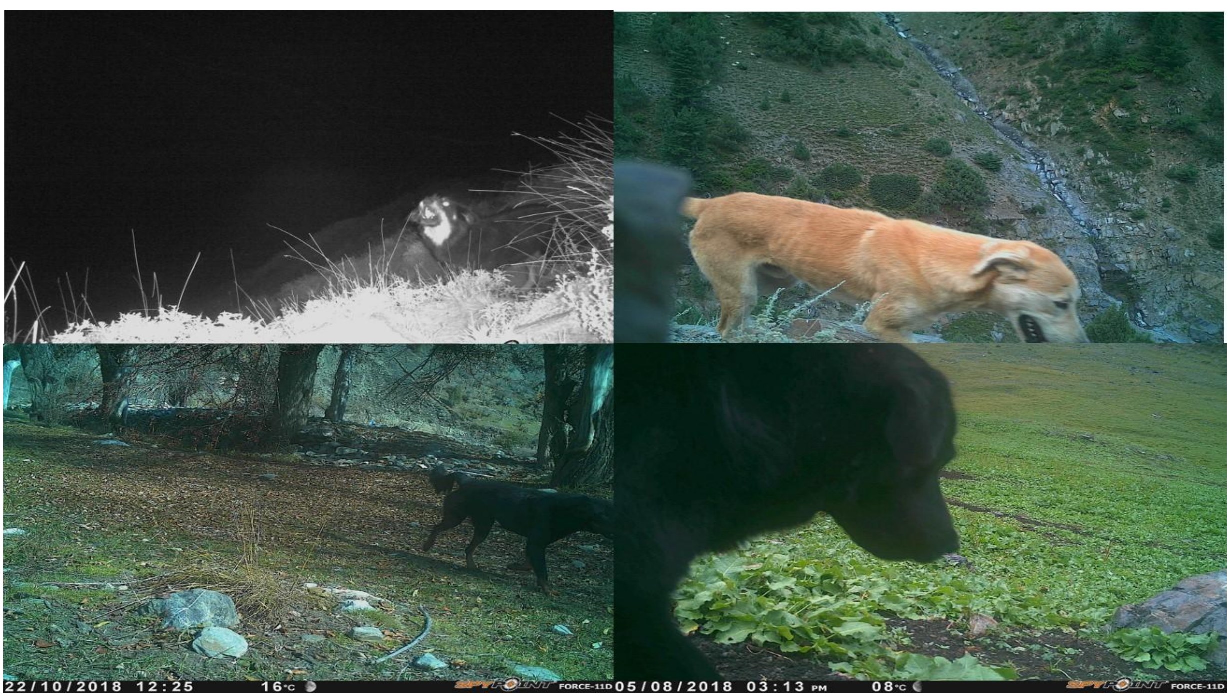

Figure 4. Feral dog presence captured through camera traps in the Lahaul-Pangi Landscapes in wildlife habitat.

Figure 5. Feral dog presence captured direct sighting in the Lahaul-Pangi Landscapes in wildlife habitats and roads.

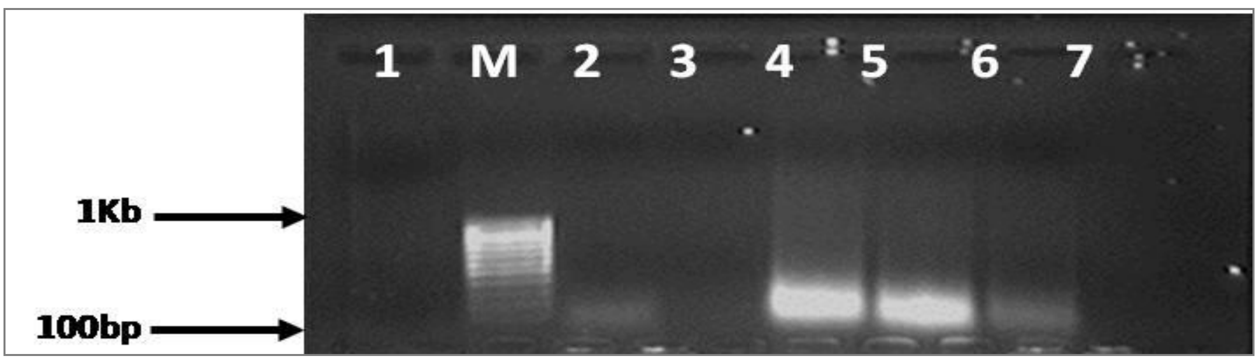

Figure 6. DNA extracted from scat samples of carnivores using Qiagen kit on 0.8 % agarose gel. M, MW marker 100bp ladder.

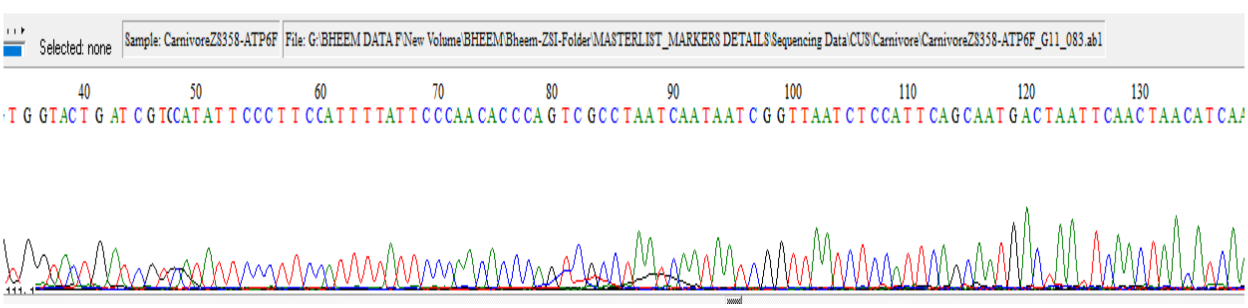

Figure 7. DNA sequences chromatogram of *Canis lupus familiaris* using the ATPase6 of samples collected from the Lahaul–Pangi landscapes.

4.1. Distribution of feral dogs in Lahaul & Pangi valley

The final ensemble model predicts the potential distribution of feral dog in Lahaul and Pangi valley in the state of Himachal Pradesh (Fig. 8) using the presence locations. Out of nine participating models for the species, a total of six models have been qualified for the final ensemble building for the feral dog (GLM; MARS; GBM; RF; ANN; SVM) on the basis of AUC based selection threshold of (AUC > 0.75) (Fig. 9 & 10). The AUC ranged from 0.92 for the RF model followed by GLM, ANN and SVM model with AUC=0.91 (Figure 10).

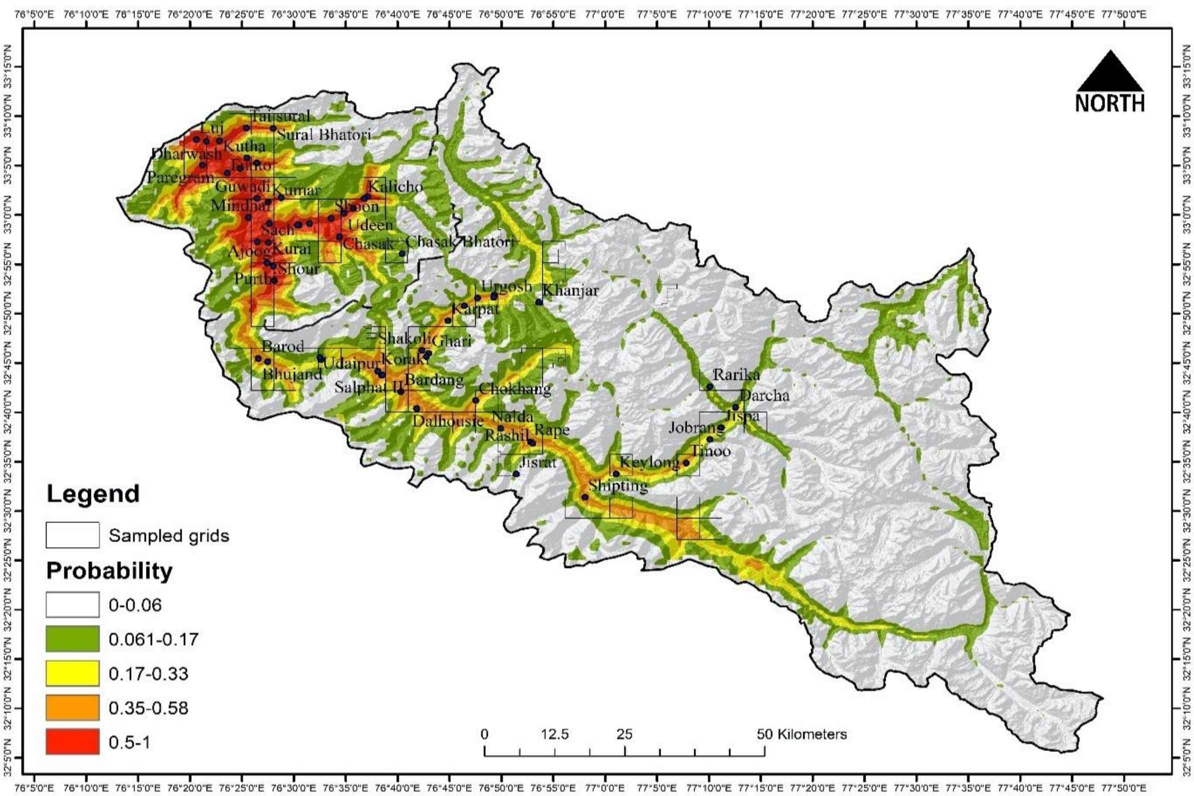

Figure 8. Final ensemble distribution map of the feral dog in Lahaul and Pangi Valley. The probability of presence has been categories into three groups, i.e. 10% to 30% (Yellow), suggesting the low suitability; 30% to 50% (Orange) suggesting medium suitability and 50%-100% (Red) suggesting the high probability of the presence of a feral dog in the study landscape.

The lowest scores of AUC was observed for the MARS model with a score of 0.81. Apart from AUC based evaluation, the resulted in scores of other evaluation metrics, i.e. PCC (varied between 0.92-0.89), Kappa (varied between 0.84-0.35) sensitivity (varied between 0.92-0.71) and specificity (varied between 0.92-0.89) (Fig. 11).

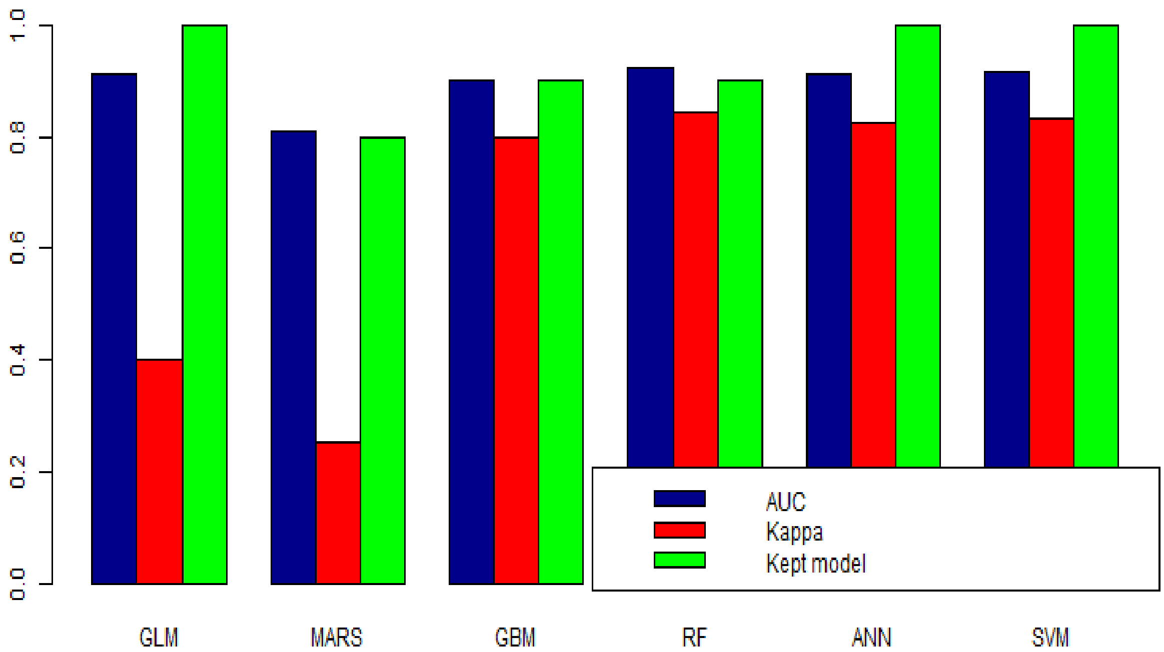

Figure 9. Model evaluation matrices for the final selected model. Representing the values of AUC, Kappa and no. of the Kept model in total model runs (n=50).

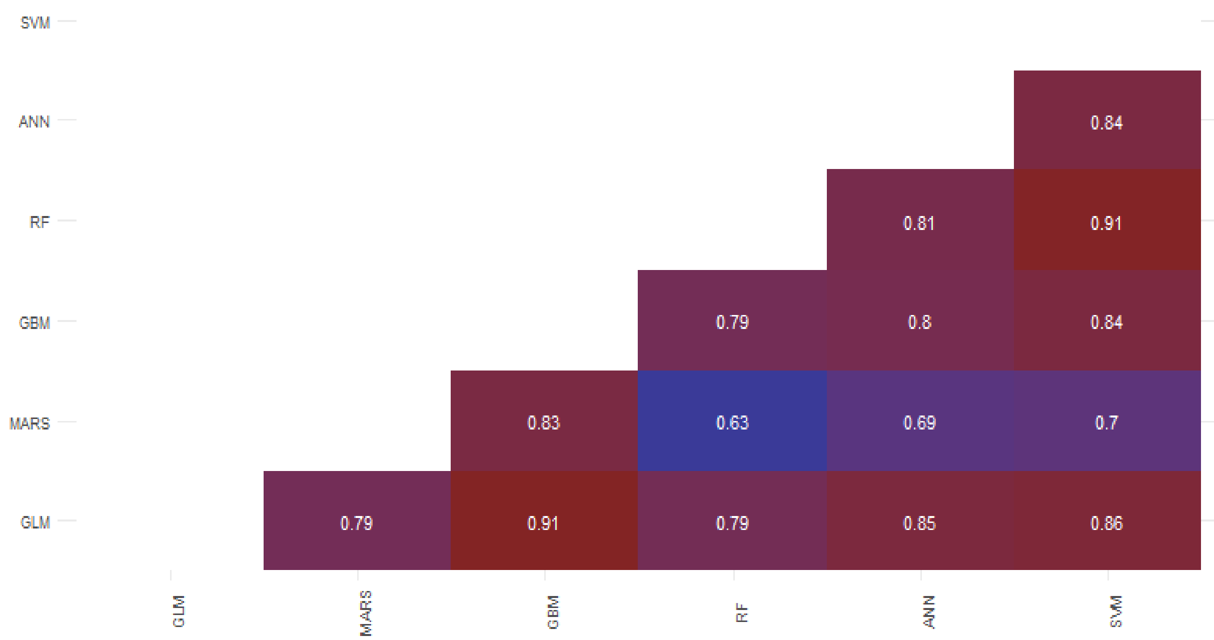

Figure 10. Model correlation plot for the selected model for ensemble building. Where Generalized linear model (GLM), Generalized additive model (GAM), Multivariate adaptive regression splines (MARS), Maximum entropy (MAXENT), Artificial Neural Network (ANN), Support Vector Machine (SVM), Random forests (RF) and Gradient Boosting Machine (GBM).

All the participating models have selected all the final selected predictors. Among all the predictor's cattle abundance was found to be the most contributing factor, which contributed 17.09% in the final selected model (Fig.11). The response of cattle abundance was found to be positively correlated with the distribution probabilities of the feral dog (Fig.11). Following, the contribution from bio_19 (Precipitation of Coldest Quarter) and slope by 14.44% and 12.14% respectively. The relative abundance of the wildlife species and the distance from garbage sites have also been contributed by 10.15% and 9.32% respectively. Thus, it evident that the feral dogs distribution in the study landscape is influenced by the density of cattle as well as the abundance of wildlife species. Furthermore, the positive relationship of garbage sites hot spots with the distribution indicates the role of garbage sites on the distribution of feral dogs in the study landscape (Fig. 11). The negative relation of elevation with the distribution suggesting that the feral dogs prefer lower elevation areas, mostly the valley region in the Lahaul and Pangi (Fig. 12). The comparative analysis of two valleys indicates that the Pangi valley posses more suitable areas for the distribution of feral dogs than the Lahaul valley.

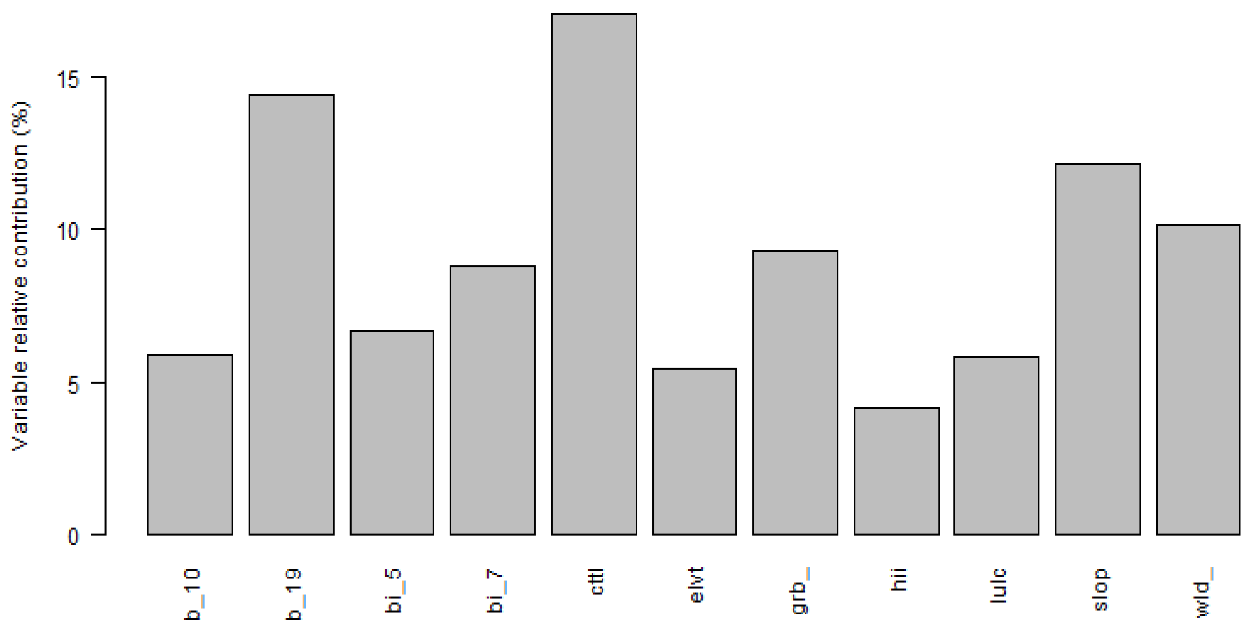

Figure 11.The relative contribution of the predictor variable evaluated through the Pearson method.

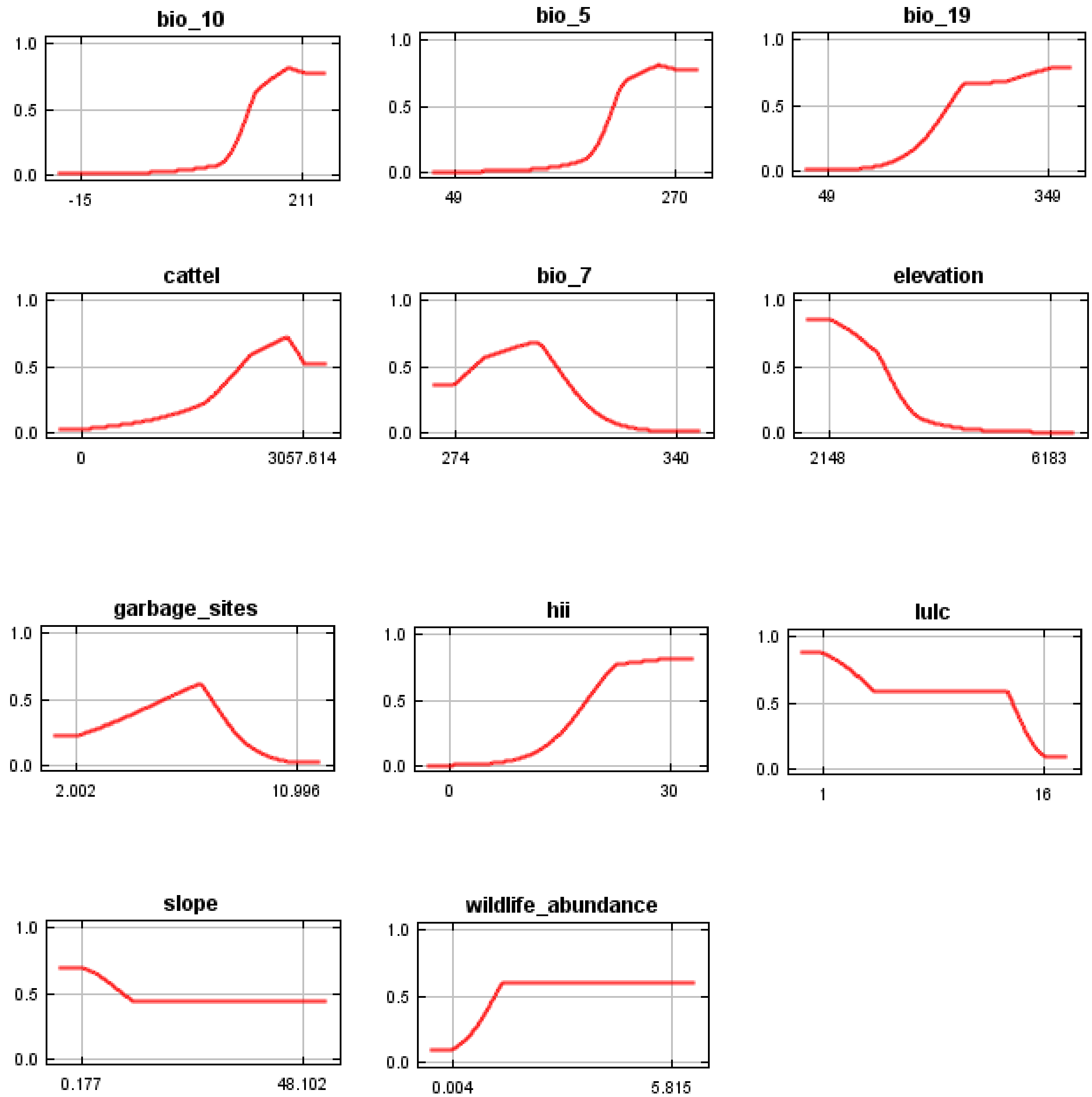

Figure 12. These curves show how each environmental variable affects the ensemble prediction. the curves show how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. The curves can be hard to interpret if you have strongly correlated variables, as the model may depend on the correlations in ways that are not evident in the curves. In other words, the curves show the marginal effect of changing exactly one variable, whereas the model may take advantage of sets of variables changing together.

4.2. Population density estimates of feral dogs in Lahaul & Pangi valley

a. Individual identification and use in molecular tracking

The confirmed feral dog samples were further process for the individual identification as in the absence of invasive physical tags, establishing molecular identities through microsatellite genotyping of individuals can be used for tracking the movement patterns of individuals. However, to effectively use molecular tracking, a panel of suitable microsatellite markers require to be established to avoid the wrong identity of feral dog individuals. Hence, we used a total of 10 microsatellite loci out of 9 loci provided consistent results (Table 3). Our analyses showed that there was the probability of misidentifying two unrelated individuals as a single individual (P_{ID}) with the combination of four and nine loci were 5.8E-07% and 4.1E-14% respectively. However, we found that the probability of misidentifying two full siblings as a single individual (P_{ID}sib) reach an acceptable value of 0.3% only if we used the combination 5 loci and 0.0045% when we used all 9 loci (Fig. 13).

Table 3. List of microsatellite loci used for individual identification.

Locus	Na	Ne	I	Ho	He	F
CPH12	13.000	10.522	2.453	0.909	0.905	-0.005
CPH8	9.000	7.333	2.087	0.909	0.864	-0.053
AHT121	11.000	6.914	2.147	0.909	0.855	-0.063
C09173	12.000	7.806	2.260	0.727	0.872	0.166
CXX279	10.000	7.563	2.138	0.818	0.868	0.057
AHTH130	10.000	6.050	2.046	0.909	0.835	-0.089
CPH2	7.000	4.321	1.654	0.909	0.769	-0.183
CPH4	11.000	7.563	2.224	0.818	0.868	0.057
C2096	12.000	9.308	2.350	0.818	0.893	0.083
Mean	**10.556**	**7.487**	**2.151**	**0.859**	**0.859**	**-0.003**
SE	**0.603**	**0.590**	**0.075**	**0.022**	**0.013**	**0.035**

No. alleles (Na), No. effective alleles (Ne), Information index (I), Observed (Ho) and Expected Heterozygosity (He) of F, FIS value

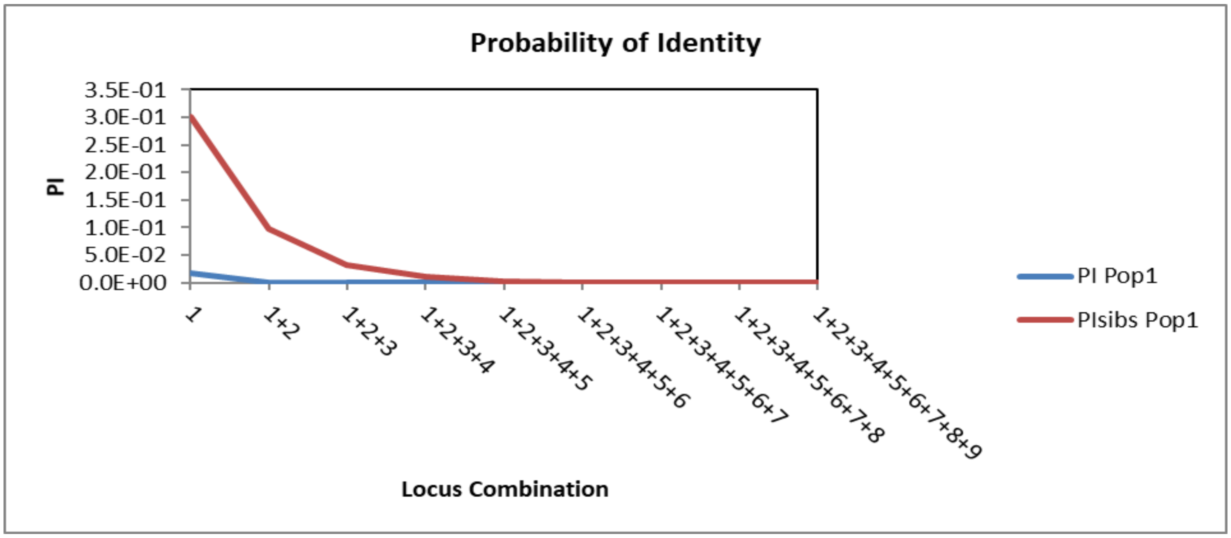

Figure 13. Probability of identities of feral dogs individuals understudy with increasing locus combinations.

b. Population density estimation of feral dogs in the Lahaul–Pangi Landscape.

Out of 196 scats of carnivores collected from Pangi and Lahaul landscape, of which 48 scats were identified as of the feral dogs. These 48 scats resulted in the identification of 11 individuals in the study landscape. Hence, using the SCER model feral dog,posterior density found to be 2.78 individuals/ 100 Km^2(95% highest posterior density intervals (HPD) = 2.75–3.00) in the Lahaul and Pangi landscape (Table 4). We found 1.4-5.5 individuals/ 100 km^2 and found high-density areas have four times that of the lowest density areas. The abundance of feral dog was found to be higher in Pangi valley than the Lahaul valley.

Table 4. Posterior summaries of parameters estimated from the SCR model to estimate the feral dog density in the Lahaul and Pangi landscape.

	Posterior Mean	SD	95% Lower HPD	95% Upper HPD
D/100 Km^2	2.78	0.10	2.75	3.00
σ	69.54	47.50	5.78	159.10
Ψ	9.88	2.70	4.89	15.29
N	11.00	0.39	11.00	12.00
p1	0.06	0.01	0.04	0.07
p2	0.58	0.07	0.45	0.71

D, density/100 Km^2, sigma (σ) movement parameter, psi (ψ) is a parameter of the augmented data, N number of individuals; p1 encounter probability of individuals those were not previously encountered; p2, the encounter probability for individuals captured in subsequent to their initial encounter.

Deliverable 2: To assess interactions and impacts of feral dogs on wildlife, livestock and human in the Lahaul and Pangi landscape.

4.3. Feral dogs interactions

For understanding the interaction and impact of feral dogs in the wildlife, livestock and humans questionnaire survey were carried out in Lahaul and Pangi valley. A total of 570 questionnaire surveys were conducted in the Lahaul and Pangi valley. In which 170 were conducted in the Pangi valley and 400 were Lahaul valley. Out of 170 respondents, 29% respondent admitted the presence of feral dogs in the Pangi valley (Fig. 14). Out of those, 22% responded believed that these feral dogs are the threats to their livestock as well as wildlife and 12% among them claimed their livestock have been killed by the feral dogs (Fig. 14).

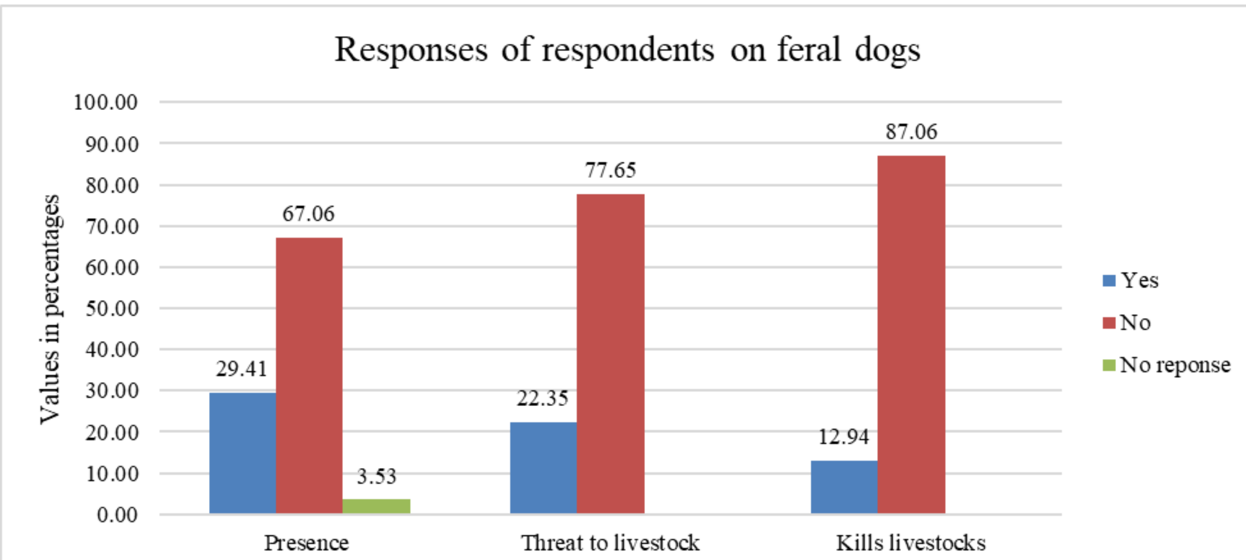

Figure 54. Percentage of respondent who admitted presence, threats to livestock and depredation on their livestock in the Pangi valley.

Whereas in Lahaul valley, out of 400 respondents, only 12% respondents confirmed the feral dog presence. Among those, only 11% believed that feral dogs are the threats to livestock and only 6.7% respondent claimed their livestock have been killed by the feral dogs in the Lahual Valley (Fig. 15).

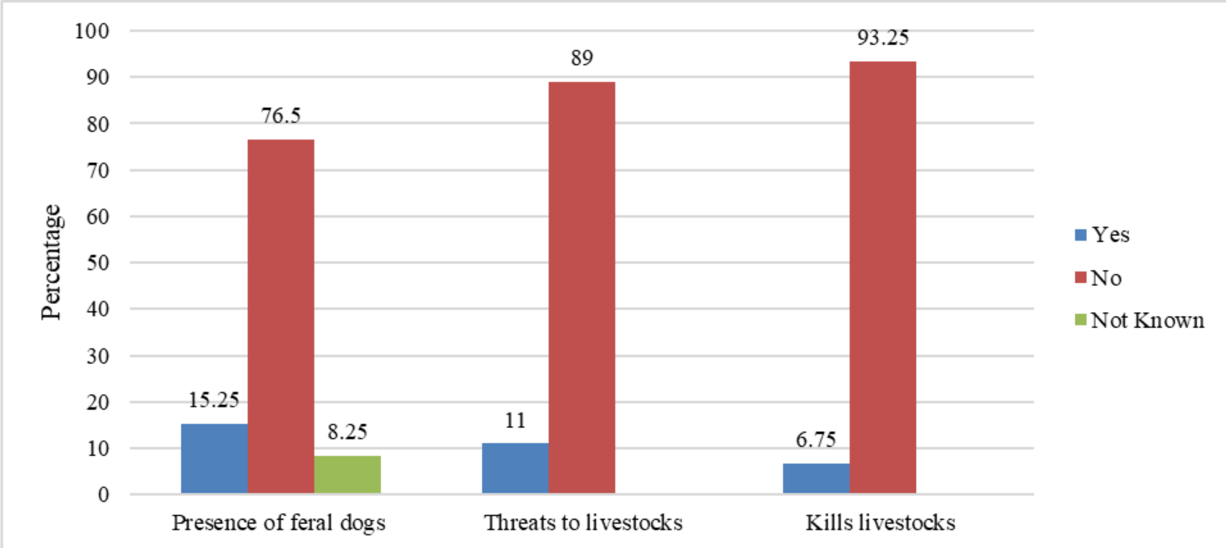

Figure 15. Percentage of respondent who admitted presence, threats to livestock and depredation on their livestock in the Lahaul valley.

Generalized Liner modeling for modeling interaction

We used the generalized liner modeling to understand the interaction of feral dogs in response to different parameters used and the top five models were depicted in Table 5. We used 27 variables, as per the ecological requirements of the species and run models with different combination of the variables. Based on the AIC criteria, the top model suggests that the cattle presence and wildlife abundance significantly (P=<0.01) influencing the distribution of feral dogs which indicates higher association with these two variables (Table 6 and Fig. 16). In the top models cattle's number has positively influenced the feral dogs' presence (β=0.0001; SD=0.0000) suggesting that feral dogs are involved in depredating livestock in the study region. Whereas, the wildlife abundance was negatively associated with feral dogs distribution in the landscape. At present the feral dogs might not be a serious conservation and management issue however further increase in its population will greatly impact the wildlife populations in the landscape. Further, the distribution of garbage dumping sites were showing the positive relationship with the dog presence though it is not the statistically significant but these sites we believed have substantial role in increasing the feral dogs' population in the study landscape.

Table 5. The three most parsimonious generalized linear models representing the most influencing predictor variables according to AIC

Model	Variables	K	AIC	ΔAICc	*w*AICc
Model –1	bio_5 + bio_7 + bio_19 + cattle + elevation + garbage + hii + lulc + slope + wildlife_abundance	1	14.29	0	0.7009
Model –2	response ~ I(elevation^2) + wildlife_abundance + cattle + garbage + lulc + slope + cattle:lulc	1	16	1.71	0.2981
Model –3	elevation + wildlife_abundance + cattle + I(cattel^2) + elevation:cattle	1	28.72	14.43	0.0005
Model–4	elevation + wildlifeabundance + cattle + I(cattel^2) + elevation:cattle	1	29.07	14.78	0.0004
Model–5	elevation + wildlife_abundance + cattle + elevation:cattle	1	31.66	17.37	0.0001

Table 6. Influence of the predictor variables selected based on top models on mammalian species richness as tested by generalized linear mixed-effects models in the study area.

	Estimate	Std. Error	t value	Pr(>|t|)	Significance
(Intercept)	-0.7512	2.2268	-0.337	0.737	
bio_5	-0.0043	0.0041	-1.068	0.289	
bio_7	0.0090	0.0064	1.399	0.166	
bio_19	0.0031	0.0018	1.723	0.089	.
cattle	0.0002	0.0001	3.202	0.002	**
elevation	-0.0004	0.0002	-1.95	0.055	.
garbage	0.0258	0.0272	0.947	0.347	
hii	-0.0046	0.0084	-0.554	0.581	
lulc	0.0193	0.0155	1.246	0.216	
slope	-0.0082	0.0042	-1.929	0.057	.
Wildlife abundance	-0.1963	0.0378	-5.187	0.000	***

Note: level of significance: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

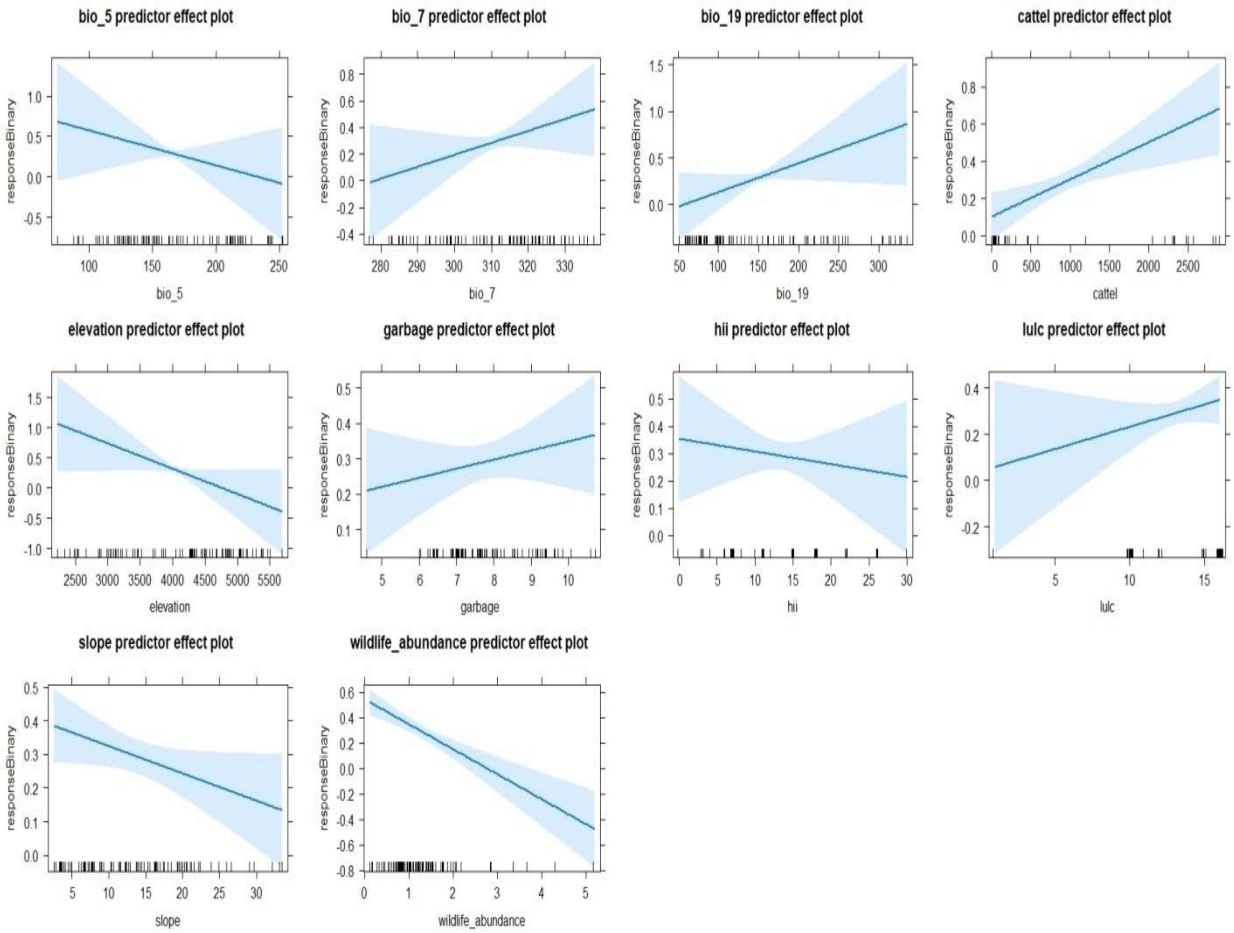

Figure 16. Influence plot of the different variables on the dog presence in the Lahaul and Pangi landscape.

Feral dog conflict hotspots in Lahaul and Pangi valley.

In the Lahaul and Pangi landscape based on the questionnaire survey number of incidences were recorded where locals admitted that feral dogs are resulting with negative interactions by way of livestock depredation in their locality. We observed the 13 villages in the Lahaul valley and 18 villages in Pangi valley where the different number of respondent admitted the conflict incidences (Table 7). The number of feral dog conflict instances were more in Pangi than the Lahaul valley. Whereas in the Lahaul valley the majority of instances were reported from Miyar valley (Fig 17).

Table 7. Number of respondent admitted conflict in the Lahaul and Pangi valley with the feral dogs.

S.No		Name of the village	Latitude	Longitude	Feral Dog Conflict
1	Lahaul Valley	Ghari	32.766	76.71708	6
2	Lahaul Valley	Bhujand	32.7516	76.4586	2
3	Lahaul Valley	Upper Shakoli	32.7604	76.7133	1
4	Lahaul Valley	Salangra	32.759	76.5425	1
5	Lahaul Valley	Jispa	32.64049	77.1872	3
6	Lahaul Valley	Khanjar	32.8522	76.89396	7
7	Lahaul Valley	Kardang	32.56214	77.01784	4
8	Lahaul Valley	Chika	32.56214	78.56936	3
9	Lahaul Valley	Tinoo	32.5808	77.13056	3
10	Lahaul Valley	Darcha	32.67462	77.20956	4
11	Lahaul Valley	Lindoor	32.37474	76.52435	5
12	Lahaul Valley	Rarika	32.70975	77.16869	3
13	Lahaul Valley	Urgosh	32.8590	76.7955	5
14	Pangi Valley	Hilutuwan	33.0309	76.61911	4
15	Pangi Valley	Kalicho	33.02691	76.61342	2
16	Pangi Valley	Udeen	33.00236	76.58134	1
17	Pangi Valley	Shoon	32.99382	76.56025	3
18	Pangi Valley	Sindhari	33.01078	76.59616	1
19	Pangi Valley	Dhanela	32.98231	76.5092	3
20	Pangi Valley	Hillor	32.98238	76.5061	3
21	Pangi Valley	Kumar	33.02117	76.45912	4
22	Pangi Valley	kutthal	32.98495	76.46149	2
23	Pangi Valley	ParmarBhatori	33.02889	76.47983	5
24	Pangi Valley	Chasak	32.9626	76.57374	5
25	Pangi Valley	ChasakBhatori	32.93417	76.67439	4
26	Pangi Valley	Sach	32.95402	76.44193	2
27	Pangi Valley	Mindhal	32.99508	76.42783	1
28	Pangi Valley	HuddanBhatori	32.02889	76.47983	1
29	Pangi Valley	Takwas	33.08728	76.44075	5
30	Pangi Valley	Paregram	33.08382	76.35384	3
31	Pangi Valley	Sural (Lower bhatori)	33.07799	76.41437	1

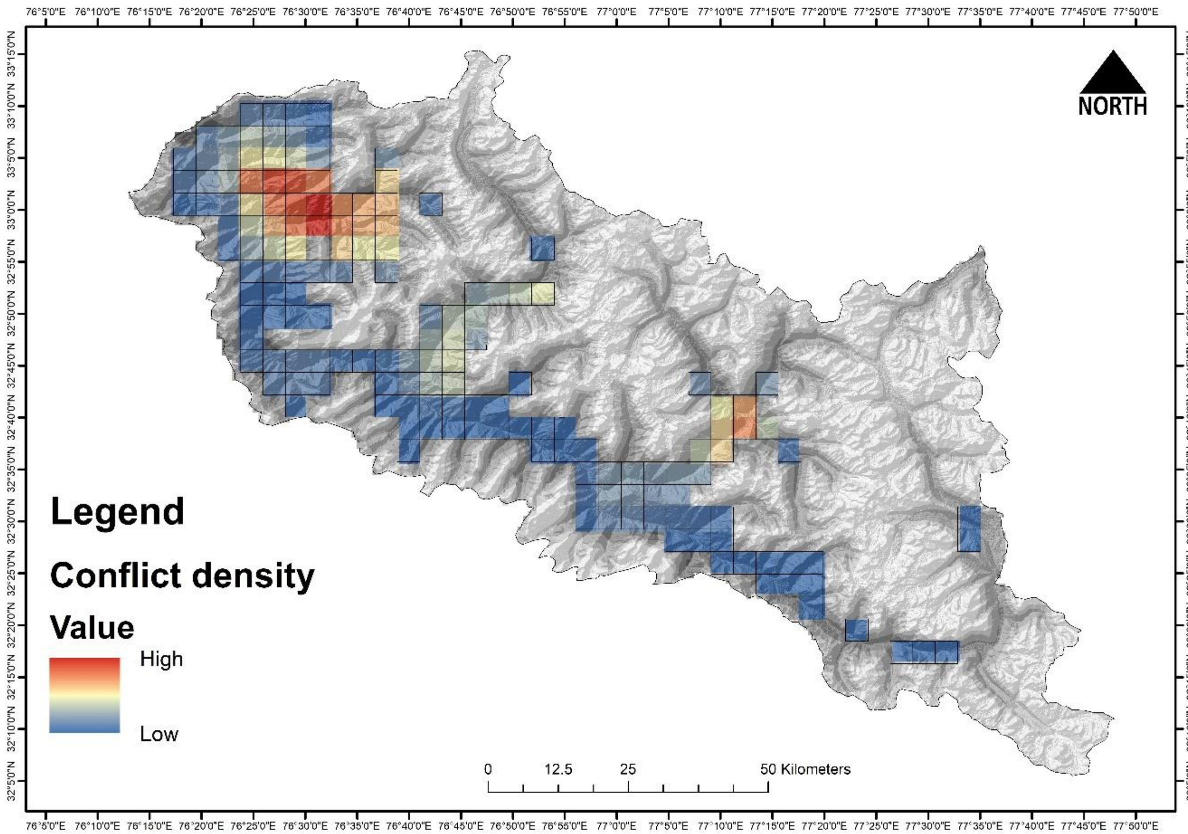

Figure 17. Feral dog conflict hot-spot maps

Food habitat of feral dogs in Lahaul and Pangi Valley

However, we have not found any direct sighting of feral dog attacks on the wild or either on the livestock. But indirect evidences indicated by locals were observed. Further, 12% locals in Pangi valley and 6.7% respondent admitted their livestock have been killed by the free ranging dogs. To ensure these we undertaken the feeding analysis and to validate the prey items present in the diet of feral dogs in the Lahaul and Pangi valley.

Feeding analysis

Upon processing 48 feral dog scat samples, three wild prey species and four domestic prey species were identified (Fig. 18). Most of the scat samples contained 2 food items with a proportion of 44.4%. Whereas, 22.2% of the total scat contained one to two food items each and four food items occurred in 33.3% of scat samples. In the relative biomass models, domestic prey species hold an important place in the diet of a feral dog. The livestock such as cattle and

Pony/horse were the most consumed with a higher frequency of occurrence of 81.25% and 25.00% respectively. Therefore, their relative biomass was also higher for cattle (64.14%) and Pony/horse (18.58%).

Moreover, the relative number of prey species consumed was highest for cattle (43.19) and was lowest for rodents (0.32). Among the wildlife species, the relative number of blue sheep consumed was 9.46 (Table 8). The relative biomass of blue sheep and marmot consumed constitutes only 2.86% and 1.60% respectively. Furthermore, plant material was also found to be the dominant food items with a relative frequency of occurrence of 16.16% next to cattle. Other residues such as unidentified seeds and tissues were also observed but were unquantifiable.

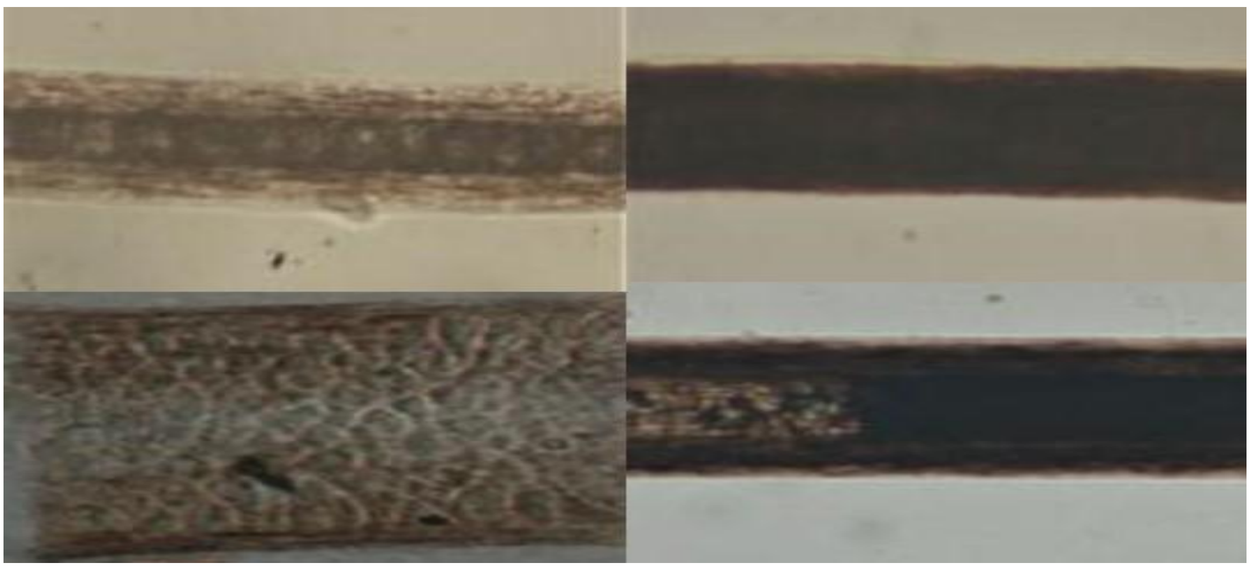

Figure 18. Some selected Microscopic structure of hair of different prey species found in feral dog samples from the Lahaul and Pangi valley.

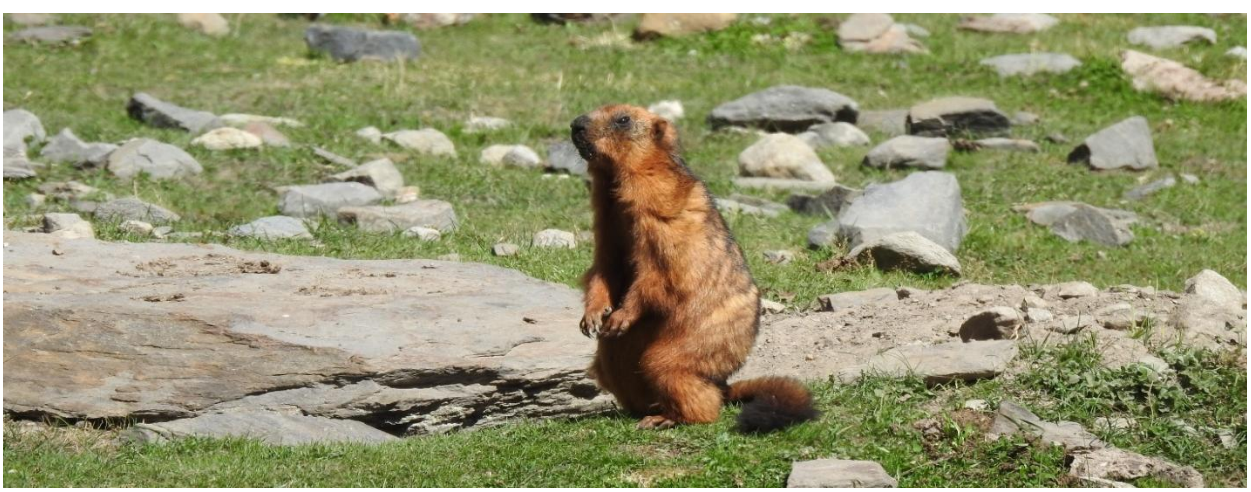

Table 8. Diet profile, the relative frequency of occurrence, biomass consumed and relative number of prey species consumed by feral dogs in the study landscape.

Prey Species	Frequency of Occurrence (%)	Relative Frequency of Occurrence (%)	Weight of prey consumed per scat (kg/s)	Relative biomass (%)	Relative Number of prey species consumed
Cattle	81.25	39.39	8.98	64.14	43.19
Pony/Horse	25.00	12.12	8.46	18.58	33.29
Domestic Goat	16.67	8.08	3.21	4.70	6.49
Domestic Sheep	25.00	12.12	3.03	6.66	5.99
Rodent species	8.33	4.04	2.00	1.46	0.32
Blue Sheep	8.33	4.04	3.91	2.86	9.46
Marmot	8.33	4.04	2.19	1.60	1.24
Plant Materials	33.33	16.16	-	-	-

Based on the interview conducted, we found that, there negative interaction of feral dogs with the human though the direct attacks, disease transmission and economic losses through livestock depredation. Further, through feral dogs'–livestock have the negative interaction results livestock killing that 12% people admitted livestock killing in the Pangi valley and 6.7% in the Lahaul valley (Fig. 14 & 15). Further diet analysis also shown high rate of livestock–feral dog interaction by consuming about 80% of livestock. Diet analysis also reveals feral dogs also feed on the wildlife species and also regions overlap the habitat with wild species which may leads to disease transmission, wild life species harassment and killing hybridization with the other canids species.

Deliverable 3: Food sources and quantify availability of main food sources of feral dogs in human–dominated and wilderness areas.

4.4. Food resource hot spot sites

Based on the primary observation, we observed a total of 20 dumping sites nearby town and villages maybe immediate possible food sources in Pangi and Lahaul valley (Fig. 19; Table 9). In the Lahaul valley, we observed a total of 14 dumping sites and six were observed the Pangi valley (Fig. 20; Table 9). These dumping sites were near to human habitation and confined to major towns and villages.

Figure 19. Dumping sites in the Lahaul and Pangi landscape.

Table 9. List of dumping sites in the Lahaul and Pangi valley.

Area	S.No	Location	Latitude	Longitude	Altitude
Lahaul Valley	1	Udaipur	32.715601	76.672406	2638
	2	Udaipur	32.72744	76.658004	2632
	3	Kukumseri	32.69814	76.687131	2672
	4	Thirot	32.660637	76.778813	2718
	5	Jhalman	32.635572	76.867772	2897
	6	Jobrang	32.62488	76.870469	2804
	7	Goushal	32.553325	76.971619	2868
	8	Goushal	32.547271	76.973134	2882
	9	Keylong	32.571993	76.035859	3113
	10	Koksar	32.414385	77.235942	3119
	11	Shipting	32.520529	76.965524	3069
	12	Tindi	32.758405	76.450088	2569
	13	Madgram	32.740353	76.631781	2678
	14	Naingar	32.728574	76.857373	3391
Pangi Valley	15	Killar	33.10774	76.36057	2447
	16	Sechu Nallah	32.9871	76.5605	2692
	17	Shali	32.985	76.5271	2591
	18	Mindhal	32.9962	76.4274	2473
	19	Sural Bhatori	33.1451	76.4669	3376
	20	Paregram	33.0849	76.3564	2887

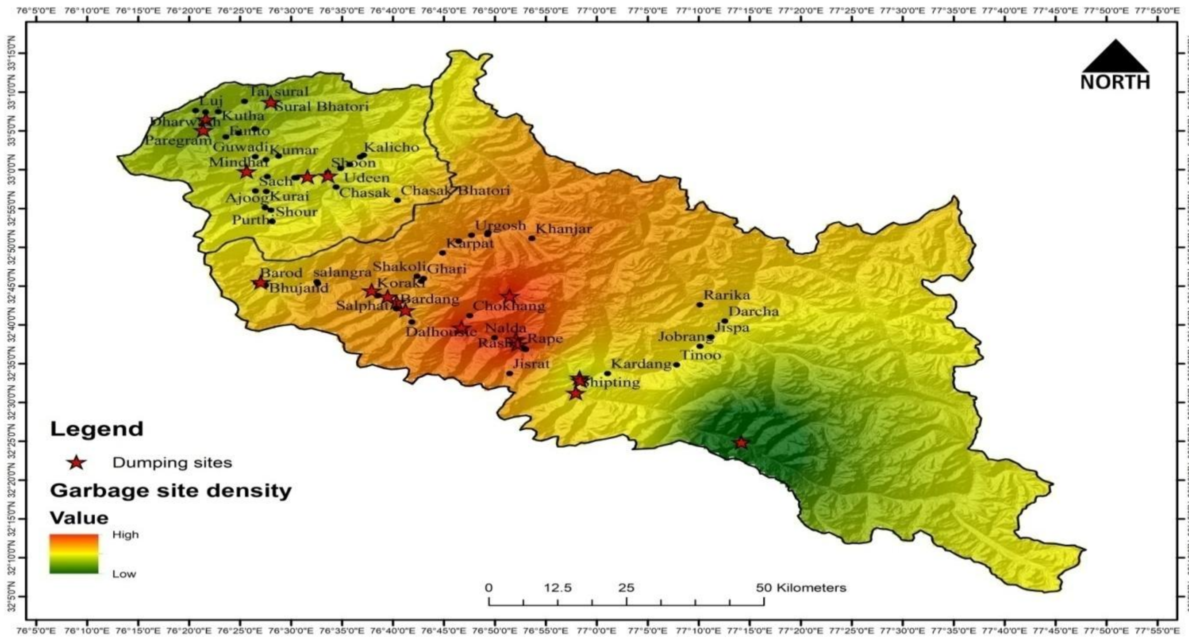

Figure 20. Garbage sites hot spots in the Lahaul and Pangi landscape.

Both Lahaul and Pangi valleys are rich in the wildlife species, and their abundance distribution is significantly high in many areas (Fig. 21). Such areas are vulnerable to feral dogs infestation because of the availability of potential wild food resources.

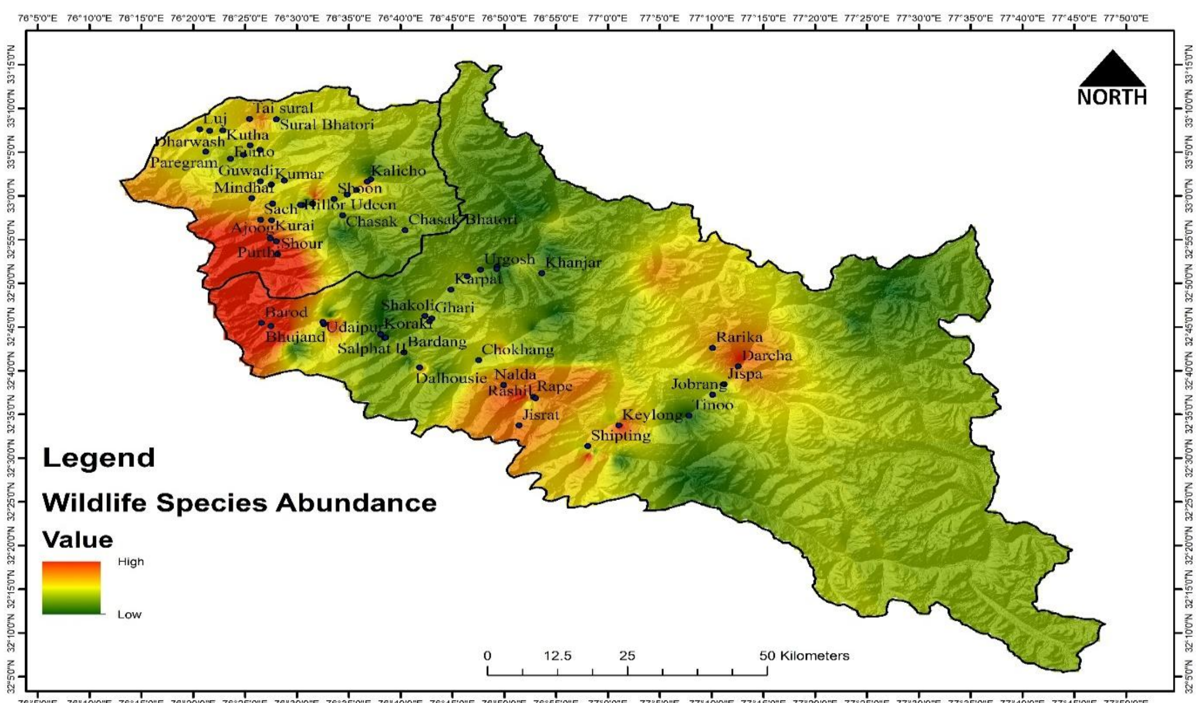

Figure 21. Region with wildlife abundance in the Lahaul and Pangi landscape.

Feeding analysis

Based on the feeding preferences, domestic animals are constituted the higher proportion of feral dogs diet in the Lahaul and Pangi valley (Fig. 22). In which the cattle (82.6%; Cow/pony/yak) form a larger proportion of diet of feral dogs followed by the domestic sheep and goat (9.1%). However, some of the studied highlighted that dog packs that are primarily dependent on garbage and restricted range to vicinity of these dumping sites as we have noticed in our study. Further, the species those dogs depend on livestock or wild species may extended their ranges to over an area of 130 km² or more (Green and Gipson, 1994; Young et al. 2011). Whereas, feral dog also feed on the wild species and we found the blue sheep and marmot in feral dogs (Fig. 22).

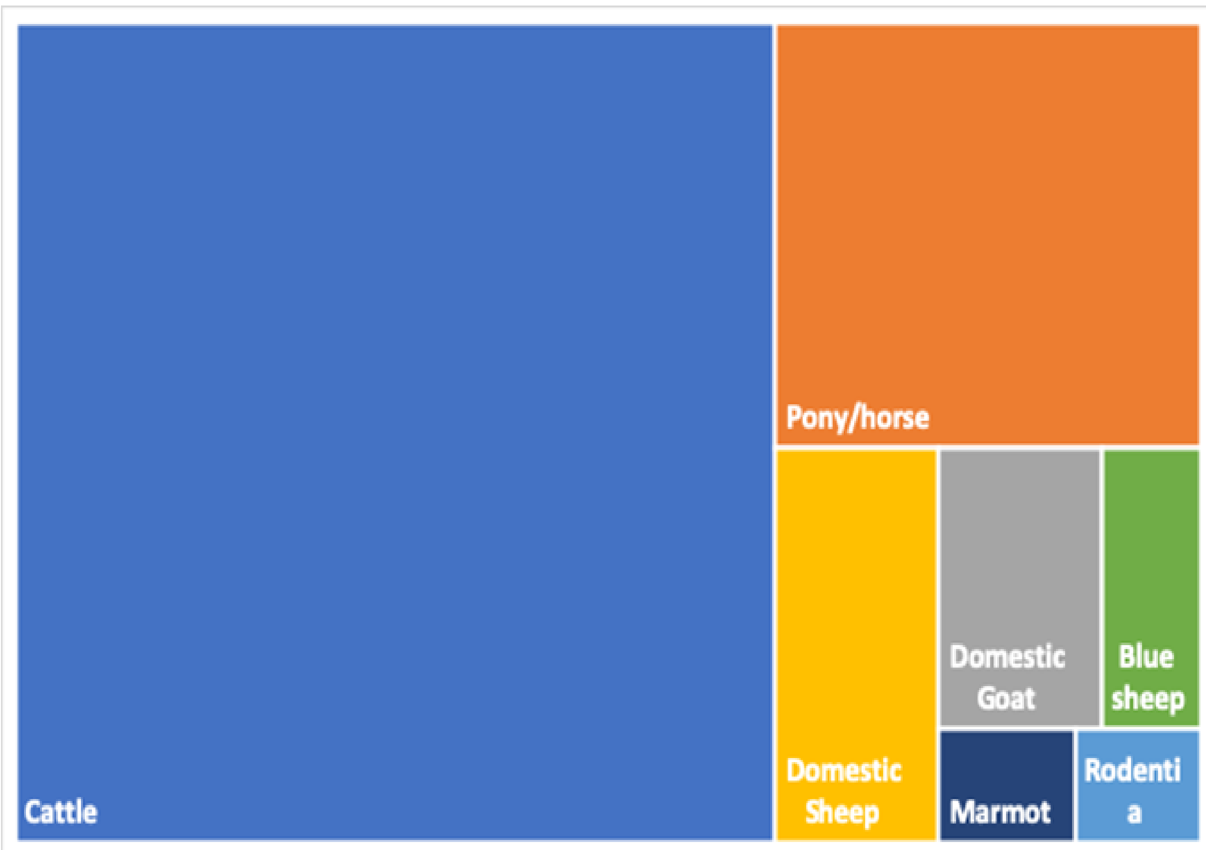

Figure 22. Treemap representation of relative biomass of prey species consumed

Deliverable 4: Comprehensive strategy for feral dog management in Lahaul and Pangi landscape.

4.5. Threats abatement plan for the feral dogs in Lahaul and Pangi landscape

4.5.1. The Threats

The nomadic hunter-gatherers first domesticated dogs for various purposes such as protectors for the property, as a pet and to control the population of pest species (Peters et al. 2005). The domesticated dogs became integral part of the communities throughout the world especially among the remote communities. The nomadic grazers in mountain ecosystems keep dogs for guarding their livestock from predators such as leopard, bears and wolf. Even dogs have been used in wildlife conservation research for locating wildlife indirect evidences. The growing human population has resulted in the expansion of agriculture land, human colonization by converting forested habitat which has resulted in increasing human–wildlife conflicts. These conflicts are largely in the form of livestock depredation by large carnivores, hence to minimize and to protect their livestock the forest fringes communities started keeping dogs with their livestock herds (Feldmann 1974; Khan 2009; Matseketsa et al. 2019). The nomadic grazers take these dogs along with livestock for grazing in higher mountains of Himalayas. But because of old age and non effectiveness of these trained dogs in minimizing livestock depredation by large carnivores the herders many a times disown them and left them in wilderness areas. During our field surveys the local communities informed us that the disowner-ship rates of these dogs have been increase. The dogs which are classified as feral dogs are the outcomes of the disowner-ship by the herders in study landscape. Over few years these dogs become habituated to the wilderness conditions. The high breeding success as a feral population and availability of sufficient food (exposed garbage) are the primary cause for the increasing population of feral dogs in study landscape as well as other regions especially in Himalayas. Globally, it is estimated that around 500-900 million dogs occur sympatrically in wilderness areas (WHO-WSPA 1990; Gompper, 2014b; Hughesand Macdonald, 2013). However, there are no accurate population estimate is available for the feral dogs. But the significant rate of invasion by feral dogs in the wildlife habitats is impacting the wildlife population through direct killing, disease transmission, hybridization, and resource competition

(Knobel et al. 2005; Lenth et al., 2014; Hughes and Macdonald, 2013; Ritchie et al., 2014; Vanak & Gompper, 2009; Young et al., 2011).

4.5.2. The impacts

While considering the impact of Anthropocene on biodiversity, nature and environment has led to many management complications for both implementing the management and conservation programmes. Along with the expansion of human population and colonization the dogs proportionately become the largest distributed carnivores throughout the globe. This has resulted in wide range of negative impact both on humans as well as wildlife species (Knobel et al. 2005; Young et al., 2011). The disowned domestic dogs become feral or free-ranging and they can significantly disrupt ecosystems functions by changing the species composition and food web (Feldmann 1974, Gompper, 2014b; Hughes and Macdonald, 2013). In a given area as the number of these dogs' increases, they tend to expand their range or territories into wildlife habitat due to scarcity of food and other resources in human habitation. Their access to wildlife habitat results in direct killing of wildlife species and several other negative impacts including transmission of disease, competition for resources with wildlife species. Moreover, studies have highlighted that they harass or chase wildlife species, which results in increased stress, and also leads to energetically costly behavioural changes among the local wildlife species (Lenth et al., 2014). In the Lahaul valley, feral dogs are potential treats to several species including Ibex, Musk deer, small mammals, pheasants and reptile species. Further, this landscape also holds the population of wolf and evidences suggest these feral dogs can also interbreed with the wolf in the landscape. The genetic contamination or hybridization with concentric species such as wolf is a serious threat to the native wolf population in the landscape and elsewhere in Trans-Himalayan region (Laurenson et al. 1998).

In the study landscape feral dogs are becoming serious threat to wildlife as they are depredating upon a variety of native fauna. A number of studies have highlighted that they primarily impacts mammalian species but they can greatly impact the other taxons including birds, reptiles, amphibians, invertebrates, and also prey on domestic livestock (Hughes and Macdonald, 2013; Ritchie et al., 2014; Vanak & Gompper, 2009; Young et al., 2011).

4.5.3. Threat abatement plan

Threats abetment plan of feral dogs in the Lahaul and Pangi valley is crucial as it hold populations of several globally threatened species including Snow Leopard, Himalayan brown bear, Mush deer which are ecologically low in densities. Further other species apart from the mammals, birds including wetland migratory birds and pheasants also threatened by the dogs in the Lahaul and Pangi landscape. Through the present study we have assessed the current distribution, population density estimation, food habits, mapping of potential food resources in the landscape of the feral dogs for management of threats possed by the feral dogs to wildlife as well as human population of the landscape. The analysis indicates that the numbers of feral dogs are more in Pangi in comparison to Lahaul valley. Moreover their probability of distribution was higher in the Pangi valley than the Lahaul (Fig. 8). Their distribution in the landscape is influenced with the density of cattle as well as the abundance of wildlife species (Fig. 9 & 10). Furthermore, the positive relationship of garbage sites with the distribution indicates the role of garbage sites on the distribution of feral dogs (Fig. 11). The micro-histological analysis of feral dog's scats indicates that the cattle and other livestock species constitute the majority of its diet (Fig 18 & 19). However, species belonging to Rodentia order of mammals, marmots, and blue sheep are also present in the diet of feral dogs (Fig. 18). The dominance of cattle and other livestock in feral dog diet indicates that dogs are predominantly dependent on livestock population in the area. This can be attributed to grazing practices by local communities in wilderness areas, most profoundly in Pangi valley. The detection of blue sheep in dog scat indicates that the feral dogs in Lahaul are also moving into Spiti valley through Jispa and Darcha area.

Hence based on the findings of the present study to address the threats and management the feral dog infestation a logical framework has been developed. The below chart provides a overview of the feral dog management in the study landscape (Figure 23).

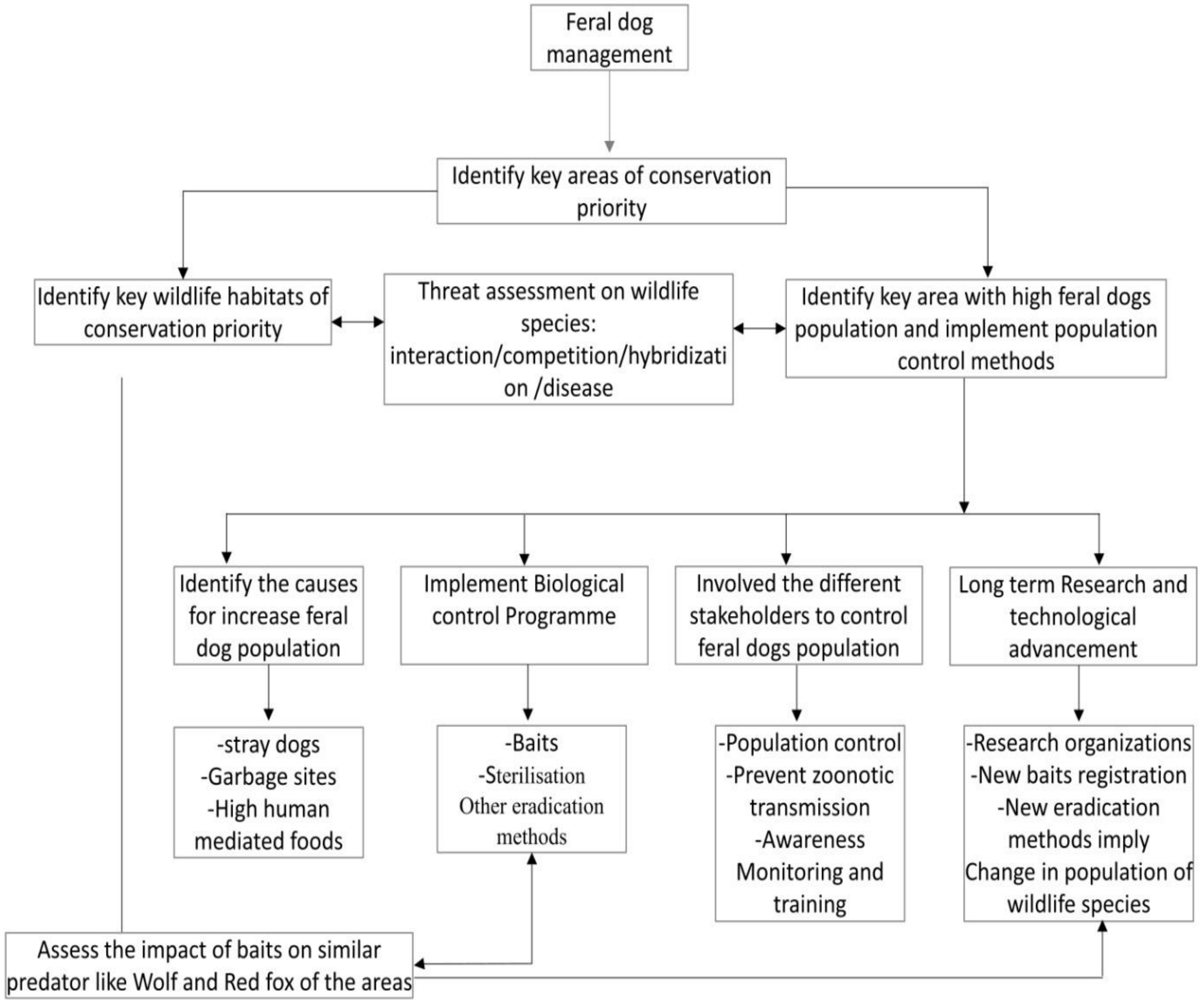

Figure 23. Feral dog management framework overview in Lahaul and Pangi Landscape, Himachal Pradesh.

To mitigate the wildlife conservation issues and the threats to livestock and humans in the study landscape a set of recommendation are provided below:-

1. **Regular monitoring of feral dogs in the landscape**

Identification of key habitats which are infested by feral dogs, mapping resource availability and regular monitoring for documenting the change in population should be integral part of the working plans of the region. The forest working plan of the territorial forest ranges and the action plan of the Protected Areas should have enough component and financial allocation for monitoring the population of feral dogs. The present study provides map indicating areas which are hot spots of the feral dog distribution. These areas can be earmarked for monitoring activities under the working plans and other scheme such as SECURE Himalaya.

2. Prevent the feral dogs occupying the new habitats

The feral dogs have the capabilities to adapt and occupy diverse kind of habitats and significantly impact the regional populations of mammals, pheasants, amphibian and reptiles species. Therefore, it is required to prevent these feral dogs occupying the new habitats. Therefore, the present study provides map showing areas with high abundance of feral dogs and also identified in the areas with high wildlife abundance for prioritization of activities to control population so to prevent further infestation in new areas. Especially, the areas with good populations of small mammals, Ibex and Musk deer as these species are easy targets for feral dogs. The feeding analysis of feral dogs in the present study suggests that feral dogs also feed upon species such as marmot, pika, blue sheep, flying squirrels and cattles grazing in wilderness areas. Hence, prevention for feral dog infestation can be achieved by controlling the population of dogs in high abundance areas as it will stop spill over from already occupied areas. Affective strategy including chemical fertility control can be used through contraceptives which can prevent the birth of offspring by sterilization which renders animal infertile. Three major types of contraceptives including viz., hormonal, immune-contraceptives and chemosterilants are available which can be administered through injection after catching dogs in field.

3. Biological control programme for feral dogs and controlling the population of stray dogs.

As a biological control strategy of feral dogs and other stray dogs sterilization programme is one effective and one of the best tool to curtail their population. The other biological control methods including eradicating the species such as feral dogs by using species specific baits (Mifsud, 2016). The poison baits including the locally available rodenticides found effective in control the stray dogs could be used for controlling the population of feral dogs. These baits are found to be economic, humane and effective in inaccessible areas. However, the use of these baits is not suggestive in areas with Himalayan wolf presence are reported. In such areas dog attractants should be used for trapping feral dogs. For trapping country made dog traps can be used which are normally used in urban areas for catching dogs.

4. To understand the proportion of domestic dogs, stray dogs and feral dog population

The identification of dogs is central to implement identify and differentiate among domestic dogs, stray dogs and feral dogs. However, it is difficult to differentiate among dogs but for implementing the mitigation strategy the definition for identifying types is provided below:

Domestic dogs **–** are those owned by an individual, a household, a business or corporation; most or all of their needs are supplied by their owners.

Stray dogs **–** are those dogs found in and around cities, towns and rural properties; they may depend on some resources provided by humans but are not owned; and

Feral dogs– are those dogs which live and reproduce in the wilderness areas (e.g. forests, woodlands, grasslands, deserts) and survive by hunting or scavenging; none of their needs are satisfied intentionally by humans.

5. Ensure the ownership of the dogs

It is important to ensure the ownerships of dogs strictly to reduce the stray dogs population in the landscape. Further, at many instances when need of these domestic becomes over, local and nomads leave these dogs as stray where the chances of these dogs become a feral are very high. Hence, the ownership of these dogs can by assured by competent authorities though registration and identification of owned dogs. This will help in responsible ownership in areas and control the birth of unwanted puppies timely. Further competent authority can trace the stray dogs and identify their owner and can also stop them to freely roam across the landscape. The population of these stray dogs can be controlled by the animal husbandry and municipally through sterilization (surgical, chemical) and even by separating the female dogs during oestrus from unsterilised male population by catching.

6. Engage the local community and other stakeholder in maintain the feral dogs' population.

For effective implementation of management strategies it is vital to take all stakeholders on board by involving them directly in strategies through participatory mechanism such as JFMCs, FDAs and other existing programmes of Forest and other line departments. The local communities can be advised to adopt the stray dogs in their locality after sterilization to control and manage the standing population of stray dogs more humanly. The panchayati raj and other community organizations should be involved and given role and responsibility for maintaining better dumb yards so that the food provisioning for stray and feral dogs can be prevented. A number of schemes and programmes are available with State Government for dealing with hygene and cleanness at public places. Hence, there is a need to dovetail such programmes for reaping multiple benefits. Schemes including Swatch bharat, MNREGA, and Intergrated watershed development should be taken under consideration for safeguarding and main streaming biodiversity. The activities such as awareness creation about the threats of feral and stray dogs to wildlife, biological control or removal of feral dogs may be takenup through these schemes and programmes of government. The local communities may be incentivised for adopting the stay dogs. The employment guarantee scheme can be used for creating awareness, removal and control activities by employing local communities. Whereas, of waste and garbage management schemes such as Swatch bharat, and integrated watershed management can be considered. The Animal Birth Control 2001 programme of Central Government shall be considered for sterilizing and vaccinating the stray dogs with an aim to control both dog population and infectious diseases. Moreover, the management of stray and feral dogs should be an imtegral part to these schemes. In addition, the activities and programmes of SECURE Himalaya may also consider feral dog management in their agenda.

The State Forest Department as main agency and few other major stakeholders which can be involved are listed below:

***Animal Husbandry Department*:** The veterinary or the animal husbandry department in the landscape is responsible for implementing of the programmers and schemes pertaining to the animal health and animal welfare, along with the other agencies and institutions in the valley. The important part of their task is to control theendemic zoonotic diseases such as rabies and parasitic infections. The animal husbandry department is will equipped with logistics and capacity to deal with initiatives such as vaccination and controlling zoonotic diseases. Hence, this department can play significant role in vaccination and sterilization of stray and feral dogs in the landscape.

Non-governmental organisations (NGOs): The NGOs can be potential partner to control the population of the stray and feral dogs in the valley. The NGOs can help in creating the public awareness and to obtain resources to contribute in apractical way to the design and successful implementation of dog control programmes. These organizations can disseminate information among the local communities more profoundly than anyone else because of their linkages at grassroots level. The Government of India implementing several programmes throughout the spatial extent of the country by engaging local NGOs and self help groups. They can significantly help in several activities such as awareness creation, population monitoring, handeling and kennelling dogs during the sterilization programme for stray and feral dogs. Moreover, the NGOs can also educate the local communities about adopting stray dogs an strategy for controlling further increase in feral dog population.

Panchayati raj institutions and public authorities: The authorities such as municipal corporation, panchayati raj and District administration can assure the upholding of activities pertaining to public health, waste management and also controlling the population of stray dogs.

Forest Department*:* The Lahaul and Pangi valley is rich in biodiversity and holds populations of several conservation priority species because of rich and relatively untouched forests. The Forest Department is responsible for maintenance of forest patches intact for conservation and management of species. The FD may implement activities in hot spot areas of feral dog infestation for controlling the problems associated with stray dogs. The FD can identify their transition phase to become a feral by better and improved monitoring surveys in forest fringe areas. This will help in controlling population of feral dogs by preventing them entering in wilderness areas (e.g. control of feral dogs in national parks; prevention of dog attacks on wildlife).

7. **Mass awareness creation among the locals about the negative impacts of stray and feral dogs on wildlife, livestock, and human populations**

Although the local communities are aware of the feral dogs in their surroundings but their knowledge pertaining to the ecological impacts of feral dogs on wildlife population is not sufficient. It is important to implement large scale or mass awareness programmes about the impacts of disowning dogs, disease transmission which is bidirectional. Focussed awareness campaigning can greatly reduce the conversion of stray dogs to feral dogs. The nomadic grazers coming in the landscape from other areas for grazing should be aware about the implications of disowning dogs, conversion of domestic disowned domestic dogs to the feral dogs.

8. **Nature based Eco-tourism**

The eco-tourism should be nature based in true sense because it has been observed in the study landscape and elsewhere that the current mode of ecotourism practices is not the correct or not implemented as it to be in correct sense of ecotourism. The tourists visiting in study landscapes should be well informed in advance about the do's and don'ts which need to be strictly followed while tracking and hiking in the wilderness areas to control throwing trash and other things which will attract dogs and other scavengers in the study landscape. Moreover there should be strict guidelines needs to be imposed so that the unwanted trash or food items should not be thrown in the wilderness areas.

For implementing the proposed recommendations Table (10) blow provides a actions, priority, time frame of action, expected output, outcomes and responsibility of different stakeholders towards effective management of feral dogs in Lahaul and Pangi valley.

Table 10. Actions priority, Output, Outcomes and Responsibilities for implementing the recommended strategies for controlling the feral dog population in Lahaul and Pangi Landscape.

Action	Priority and time frame	Output	Outcome	Responsibility
Regular monitoring of feral dogs in the landscape	High, Long term (Regular information gathering during the forest beat patrolling), Data should be analysed once in a year	Population trend of feral dogs in landscape	Help to know the what control programme need to implement	Joint implementation by Research organization, and Forest Department
Prevent the feral dogs occupying the new habitats	High, long term (Review of management activities as per the working plan/ action plan twice in a year)	To prioritize the areas of feral dogs management	Help to understand what key factors help to spreading the feral dog population in the wild.	Forest Department

Biological control programme the valley and control the population of stray dogs.	High, Periodically (twice a year)	To control feral dog population and their spread in new areas/	Help in preventing further infestation of feral dogs to new areas.	Joint implementation by Forest Department, Animal Husbandry Department, Municipal corporations, Panchayati raj.
Ensure the ownership of the dogs	Med, Long term, Twice a year campaign for understanding ownership, stray dog adoption drive round the year.	Decreasing the disowning rates of domestic dogs.	Minimizing addition of new individuals to the feral dog population in the study landscape	Joint implementation by NGOs, SHGs, Panchayati raj, Local Governing councils and other legislative as well as elected representatives
Mass awareness about the negative impacts of stray and feral dogs on wildlife, livestock and human populations	High, Long Term at least one mass awareness creation programme in a range yearly.	Better understanding of transition from domestic-to-stray-to-feral dog population.	Factors affecting the transition between domestic, stray and feral populations understood and addressed. Awareness of the communities about the linkages between domestic and feral dogs.	Joint implementation by Forest Department, NGOs, Animal Husbandry Department and District administration.
Nature based	Medium, Long	Sustainable	Control feral and stray	Forest

eco-tourism	term at every instance of such tourism activity the tourist should be made aware about the do's and don'ts.	tourism, waste management in wilderness areas	dog exposure to human food or food provisioning	Department, Tourism Department and Local trackers and tour operators

5.0. Discussion and Conclusion

Maintaining and restoring ecosystem balance is a major conservation goal, but achieving it is challenging because of several threats, including habitat loss, disease infestation and invasion of non-native species. The impacts of some threats have been well studied, while others remain less understood. Doherty et al., (2017) documented that in the human-populated landscape, dogs are the most abundant terrestrial carnivore. Despite being a major problem in many places the potential predators and competitors with a wider variety of native species (Feldmann 1974, Ritchie et al., 2014) feral dogs (*Canis familiaris*) receive less attention. Only a few studies have focused on population-level impacts to endemic species associated with wildlife-dog interactions (Wierzbowska et al. 2018). Studies suggest that feral dogs mostly depredate on goat and sheep, which also corroborated with our food habit analysis indicating high proportion of goat and sheep in the diet analysis after the cattle. The areas found suitable in the present study for feral dogs are also habitat for several wildlife species including Red fox, Wooly hare, Ibex and many more which are conservation priority species in the landscape (Kumar and Paliwal, 2015). During the present survey we collected a large number of feral dogs scat samples in wild-species habitat, identified through DNA based techniques. The presence of dogs was also documented through camera traps in the landscape. Furthermore, the questionnaire respondent's reported that the ungulate species in the wilderness area are severely threatened because of depredation by feral dogs and unsustainable grazing. Such interference and competition is likely to hamper conservation efforts to recover populations of conservation priority wildlife species. This is of significant concern, as any additive mortality of such wild species will affect their population.

The ensemble modeling in the present study indicates that the distribution of feral dogs is higher in the Pangi valley than the Lahaul valley (Fig. 8). Further the distribution feral dogs in the study landscape is influenced with the density of cattle as well as the abundance of wildlife species (Fig. 9 & 10). The positive relationship of garbage sites hot spots with the distribution indicates the role of garbage sites on the distribution of feral dogs in the study landscape (Fig. 11). These garbage dumps sites may be acting as important food sources for the feral dogs in the study landscape (Fig. 14 & 15). The local communities also highlighted the depredation of their livestock by feral dogs most prominently in Pangi valley than Lahaul valley. The micro-histological analysis of feral dogs indicated that the cattle and other livestock species constitute the majority of its diet (Fig 18 & 19). However, species belonging to Rodentia order of mammals, marmots, and blue sheep are also present in the diet of feral dogs (Fig. 18). The dominance of cattle and other livestock in feral dog diet indicates that dogs are predominantly dependent on livestock population in the area. This can be attributed to grazing practices by local communities in wilderness areas, most profoundly in Pangi valley. The detection of blue sheep in dog scat indicates that the feral dogs in Lahaul are also moving into Spiti valley through Jispa and Darcha area.

Based on the non-invasive DNA analysis, we identified 11 individuals of feral dogs in the study landscape during the study period. The capture data of these individuals were used to estimate the densities. The estimated population density of feral dogs 2.78 individuals/ 100 Km^2 (95% highest posterior density intervals (HPD) = 2.75–3.00) in the Lahaul and Pangi landscape is a baseline estimate (Table 4). However, the density ranged from 1.4 to 5.5 individuals/ 100 km^2 and it can be four times higher than of the lowest density areas. The abundance of feral dog was found to be higher in Pangi valley than the Lahaul valley. The present study is a first of its kindly where non-invasive DNA based density estimation of feral dogs have been attempted. Although the present estimates are not high in the present scenario, the feral dog's populations need to be controlled in the region for the long term viability of wildlife species such as rodents, Galliformes birds and mountain ungulates.

Traditionally the nomadic grazers/ shepherds use dogs to facilitate protection to their livestock from predators such as brown bear, wolf and snow leopard. But when these dogs are no longer needed, they abandon them in the wilderness habitat. However, in areas of conservation concern a number of control methods needs to be applied for prevention and removal of unowned dogs. As above mentioned growing evidence of the detrimental effects of feral dogs on wildlife, there is a need to prioritize and manage the feral dog infested areas in Lahaul–Pangi valley. However, a multipronged approach is required to mitigate the feral dog's impacts on wilderness species as well as domestic animals by involving different stakeholders in the landscape.

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