Final Report

Distribution occupancy, potential suitable habitat and conservation of recolonized wolf in Annapurna Conservation Area, Nepal

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1. Introduction

Nepal is one of the richest countries in biodiversity owing to its greatly varied and unique geographical, geo-morphological, ecological, climatic condition and altitudinal variation with distinct flora and fauna (Bhattarai & Vetaas, 2003). It occupies the most diverse ecosystem in the world indicating the unique habitat of wild flora and fauna. Wolves are once most widely distributed terrestrial mammals (carnivore) in the Northern hemisphere. Worldwide approximately 13 subspecies of Grey-wolf (*Canis lupus*) are recognized (Habib *et al.,* 2013). Among them, Himalayan wolf (*Canis lupus chanco)* is the most ancestral originally inhabiting in upper mustang was found to be distributed from the central Asia across the Himalaya and Trans-Himalaya region of India, Tibet and Nepal to the Northern part of Mongolia and Korean peninsula (Subba *et al.,* 2017; Sharma *et al.,* 2004; Chetri *et al.,* 2016). Himalayan wolf *(Canis lupus chanco)* is one of the least known mammals and studies have confirmed that it is a genetically unique population drifted from the general wolf clade for quite some time ago (Chetri *et al.,* 2016). The wolf is listed as the "Critically endangered" mammal species in Red list of mammal species in Nepal (Jnawali *et al*., 2011), whereas it is least concern category in the world scenario. The wolf that are found in India, Tibet, Nepal, Bhutan and Pakistan are enlisted in the CITES (The Convention on International Trade in Endangered Species of Wild Fauna and Flora) as Appendix I species (Shrotriya *et al.,* 2012). In Nepal wolves are under protection by National Parks and Wildlife Conservation Act 1993 as priority protected species.

Annapurna conservation area (28^0 33'51" N, $83^0$19'52" E) IUCN category: VI is the largest protected areas in Nepal with an area 7,629 km^2 situated at western development region, established in 1992 AD and managed by National Trust for Nature Conservation (NTNC) practiced with peoples' participation. It ranges in altitude from 790m to Annapurna I at 8,091m above mean sea level. It bonded by the dry alpine desert of Mustang and Tibet (China) in the north with world's deepest river gorge (KaliGandaki Gorge) and a valley with fossils from the Tethys Sea dating 60 million years ago. The region holds world's largest rhododendron forest, Ghorepani; Tilicho Lake located in Manang north of Annapurna Massif, is the world's highest altitude fresh water lake (GoN/UNDP, 2016).

Climate

The areas are rich in trans-Himalayan cool and semi-arid with an average precipitation 250-400mm and fall under the rain shadow area of Annapurna and Dhaulagiri ranges. It experiences sharp seasonal differences in temperature and rainfall. Since the area lies in the rain shadow region it receives very little rainfall estimated less than 200 mm and known as the cool desert of the country. The climate of upper mustang is generally dry with strong winds and intense sunlight. As recorded by National Trust for Nature Conservation in 2008, the maximum temperature in the region was recorded in summer 26^0c whereas winter is very cold and the temperature freezes to as low as -20^0c. The region has three important bio-climatic zone i.e. cold temperature, alpine climate and tundra climate are categorized with respect to the elevation of <3000m, 3000m-4500m and >4500m respectively.

Soil characteristics

The district has four different soil characteristic and soil type zones according to the soil texture based on Land System Map prepared by Land Resource Management Plan (LRMP). The area is highly dominated with the past glaciated mountainous terrain followed by the alluvial plains.

Major soil types distribution comprises fragmental loamy, loamy skeletal, river and loamy whereas the fragmental loamy soil is highly unearthed throughout the area.

Land use land cover type

The status of land use land cover (LULC) in Upper Mustang is highly occupied by barren areas followed with grassland. Most of the western part of the region is covered with the snow/ice. The studies carried on Land Use Land Cover Change shows that the area has remarkable decrease in snow/ice and sandy/sediments covers are owing to occasional flood havoc and landslide events. Since the area is dominated with the fragile soil structure there is high susceptible to soil erosion and rapid change in the land use land cover.

Biodiversity

Mustang is rich in both temperate and trans-Himalayan biodiversity. The region is home of many rare and endangered flora and fauna. The biodiversity of the mustang encompasses five species of zooplankton, seven nematode species, two Mollusca species, one Annelida species, 25 insects' species (7 aquatic and 18 butterfly species), one spider species, 11 amphibian species, eight lizards, 105 birds and 29 mammals. Mustang holds the most elusive mountain mammals like Himalayan wolf *(Canis lupus chanco)*, snow leopard *(Uncia uncia)*, and birds like Tibetan Sand Grouse *(Syrrrhaptes tibetanus)*, Bearded vulture *(Gypaetus barbatus)* and Eurasian Eagle Owl *(Bubo bubo)*. Among the list of protected species as per the National Parks and Wildlife Cconservation Act, 1973 (2029 BS) six of the species from the Upper Mustang are included in different threat categories of the IUCN Red Data Book (GoN/UNDP, 2016) such as Himalayan wolf is one of them.

Mustang is also recognized as the region of medicinal and aromatic plants with very high economic and ethno medicinal value. Local people use those number of plants for food, spices, fiber, medicine, fuel, dye, tannin, gum, resin, religious purpose, roofing materials, handicrafts and so on. Studies have revealed that the region holds over 200 species of Non-Timber Forest Products (NTFPs)/Medicinal and Aromatic Plants (MAPs) leaving the space of more exploration and identification. Local Amchis (traditional healers) uses around 72 species of medicinal plants to treat 43 human ailments. Similarly, Cottonwood poplar *(populus deltois)* is found nearby the agricultural farm and settlement areas.

2. Study site

Study area **[Fig.1]** located in high Himalayan region with distinct of geographical structure highly occupied by fragile mountain. This area is less susceptible from the urbanization. Upper mustang covers an approximately 2076.56 Km^2 areas with two Rural Municipality Lo-Mangthang and Lo-Ghekar Damodar Kund holding 1899 and 1423 population respectively. which is extended to the southern China to the north and neighboring Dolpa district to the west. These areas have an unmated and amazing piece of land enriched by natural wonders like the breath catching views of Himalayas, river fountains, lake and diversity of wild flowers and animals. Majority of the areas are covered with dry alpine desert where there is number of grassland accessible for the livestock grazing and makes suitable habitat for the wild predators and prey ungulate counting the other small wild flora and fauna.

The biological diversity of the area equally resembled by its cultural diversity. The majority of local inhabitants of the areas are Thakali, Loba and Gurung; Tibetan origin are the most dominant in the north followed by Magar, Brahamin, Chhetri and other occupational caste comparatively smaller number in south who rely on their own rituals, speaks their own dialect and have unique culture and traditions (CBS, 2012). Majority of the People in the study site believes in Buddhim. Livestock herding is one of the key economic activities supporting agriculture, tourism and Yartsagumbu (*Ophiocordyceps sinensis*) trading in the north. The livestock grazing in the areas highly depend on high grassland with rotational grazing practice and most of the livestock are kept in open sky in the night enclosed with loose stone wall. It has been unique natural, cultural, and geographical wonders making it the most sought-after destination in Nepal.

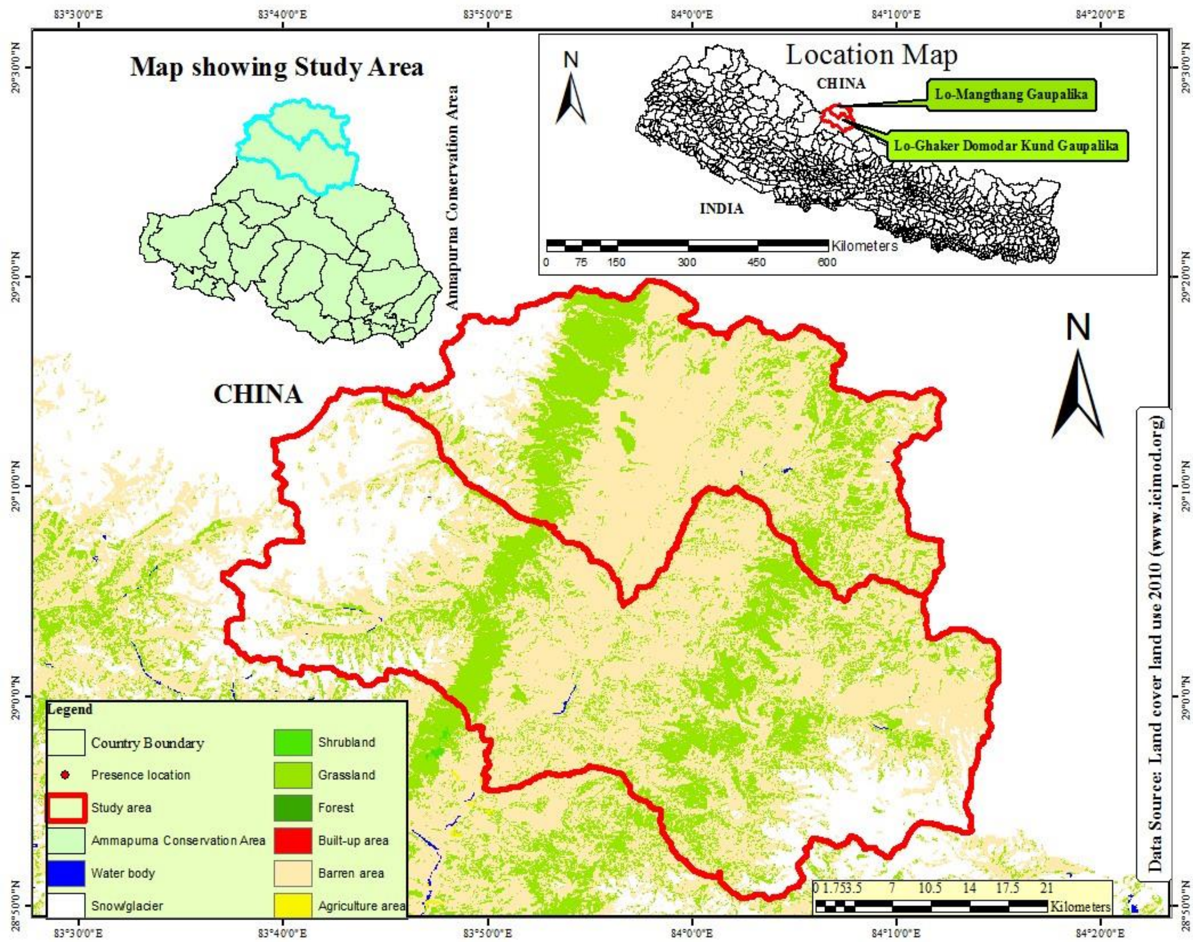

Figure 1. Map showing two rural municipality of Upper Mustang, Annapurna Conservation Area, Nepal.

3. Objectives of the project:

Interestingly, during my B.Sc. Project paper work in 2016, several people used to ask about the existence of wolves in my study area (Neshyang valley, Manang, Annapurna Conservation Areas which had driven me to this research and compelled me to read more about the species in many articles and published papers which showed that wolves are inhabiting in these areas. On the basis of that, I wanted to know the answer of the following research question since it is very new and findings of this research will be instrumental in future conservation planning being a baseline information.

Research question:

- How large the extent of potential habitat for recolonization of Himalayan Wolf in ACA?
- What are the most important factors for Himalayan wolf potential habitat in ACA?

Having said, the study will provide the baseline information on the status distribution and its maximum potential habitats in the Nepalese Himalayas. Finally, my major objectives are documented below:

1. To study occupancy distribution of recolonized Himalayan wolf in Upper Mustang, Annapurna Conservation Area, Nepal.
2. To map the potential habitat of recolonized Himalayan wolf in Upper Mustang, Annapurna Conservation Area, Nepal.
3. Conduct conservation awareness campaign in two high conflict areas.

4. Materials and Methods:

A. Reconnaissance Field Survey

The reconnaissance survey was conducted during the month of June 2018. The informal and formal group discussion with herdsmen and conservation officials of two rural municipality was conducted. During the primary survey, semi-structured questionnaire was piloted. In consultation with the herdsmen and key informant (i.e. Conservation staff, local people who have interest in wildlife conservation) and the initial analysis of the field data the participatory map was prepared indicating the availability of wolf throughout the study areas. On the basis of perceived information different strata of occurrence possibility areas were located on the prepared map.

All the mapping process was worked in ArcGIS. To map the study area, shape file (.shp) of the country was downloaded from the Survey Department official website which was compiled by the National Geographic Information Infrastructure Programme (NGIIP) then the core study areas were extracted i.e. two rural municipality of Upper Mustang (Lo-Mangthang and Lo-Ghaker Damodar Kund). A fishnet grid was developed with 2*2 square grid cells throughout the study area that account almost 589 square grids **[Fig.2]**.

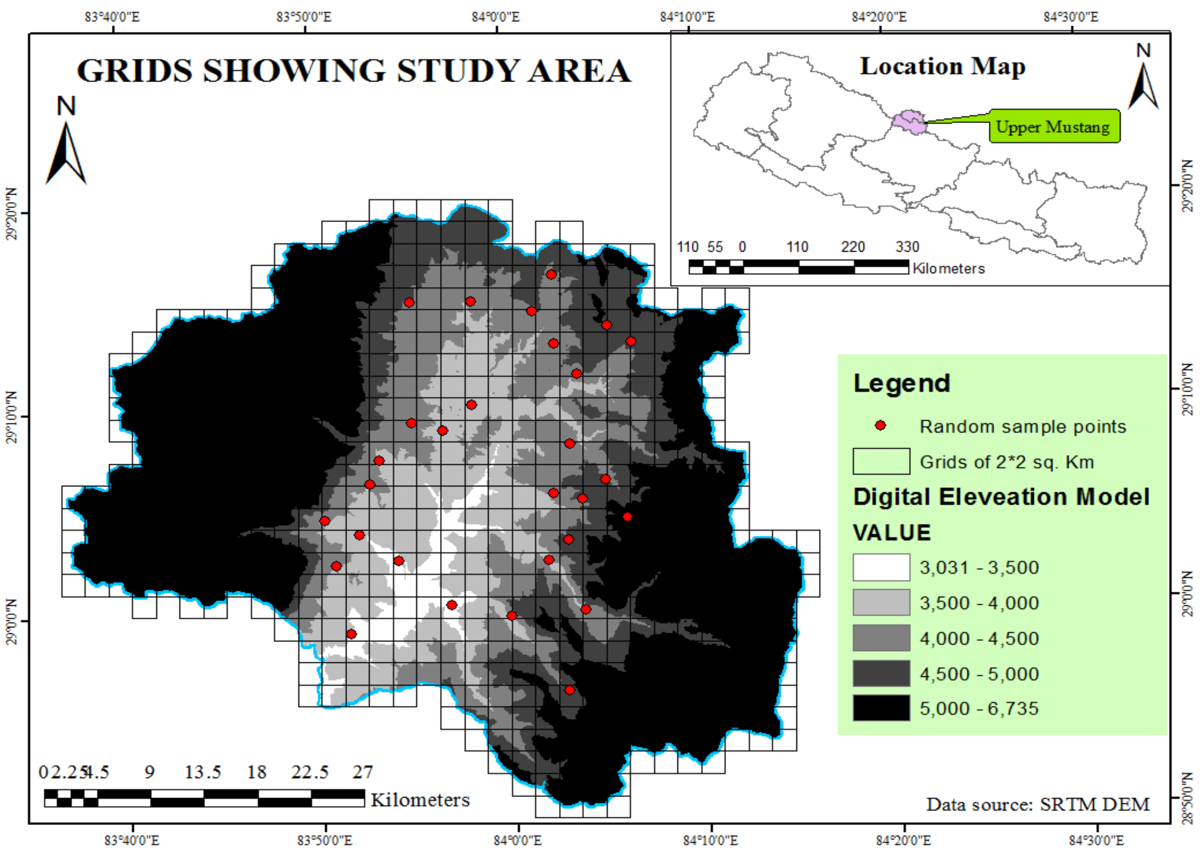

Figure 2. Study grids of 2*2 square cells and the random sample with Himalayan wolf occurrence location.

The Digital Elevation Model (DEM) was extracted from the Shuttle Radar Topographic Mission with a resolution of 1km. Then, the prepared gridded map was corresponded with DEM with an initial categorization based on elevation. The grids corresponded with the elevation approximately 3000m to 6800m where the area between >3500m to <5500m found to be more suitable then the area was calculated. Along with the feasible study area the random sample plot was established based on which the detailed field survey was further conducted. The detailed survey was planned to cover most of the areas addressing different geographical and ecological habitat which are susceptible to be potential perceived from the primary database.

The occupancy estimation is one of the important concepts in ecology. Obtaining an unbiased estimator of occupancy, it is necessary to address the issue of imperfect detection, which requires conducting replicate survey at the site being sampled. In the established sampled grids stratified random sampling method was used under the predefined study areas.

During the visit direct sighting information by herdsmen, local people and the researcher were taken as high consideration for the field validation of the sample observed and collected. This information provides the strong evidence in validating the empirical record. Occupancy methods are especially useful in sign-based surveys of wolf (elusive and occurring at relatively low densities) at the landscape scale (Linkie *et al.*, 2006; Wibisono *et al.*, 2011) because they explicitly address the issue of false absences (e.g. wolf tracks may be harder to detect in a sandy area) (MacKenzie *et al.*, 2003).

B. Overview of the study methods

The study was carried out on the basis of the empirical data acquired from the field and the different environmental variables for the potential habitat prediction was applied for the MAXENT model as displayed in. background data were compiled from SRTM, WorldClim, ICIMOD and topographical map database. Presence data were collected from the detailed field sampling [Fig.3].

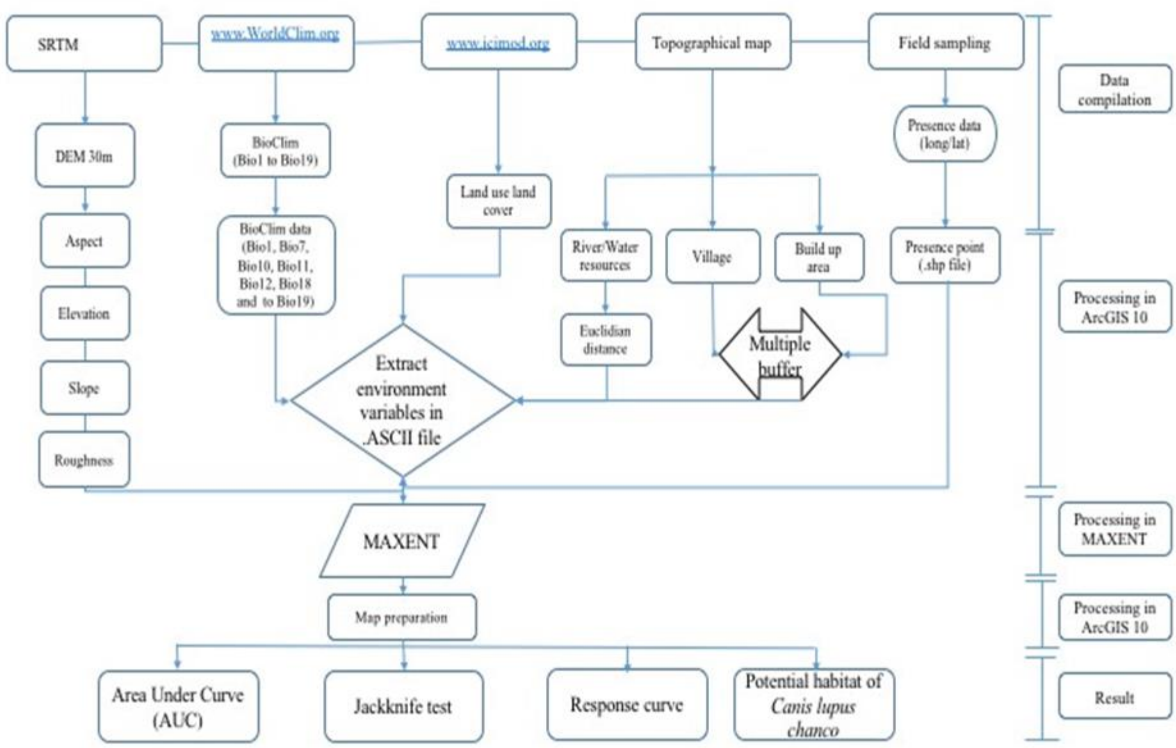

Figure 3 Flow chart of the study methods overview

B. Occupancy and potential habitat modeling

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I. Sign Survey and prey abundance

As shown in **[Fig.4]**, sign survey was the method used when there is absence of visual confirmation of the species and is a commonly used method for monitoring the large carnivores and determination of presence in the studied areas.

An underlying assumption in this study was "higher the carnivore densities, higher will be the possibility of sign in more transects." During the field visit signs of wolves **[Fig.4]** (i.e. scratches, scats, pub marks, etc.) including the kill sites and direct sighting were recorded which indicated the presence, relative distribution and indirect indices of the abundance. Direct sighting during the field visit and by herdsmen have cogitated as one of the strong evidence whereas visiting the herders who temporarily camp in the pastureland and record of their sighting the wolf, their GPS location was recorded with associated habitat features.

Figure 4. Shows the Himalayan wolf scat and pugmark assessed during the field visit in Annapurna Conservation Area

C. Background environmental Variables

I. Topographical data

To determine the best habitat of *Canis lupus chanco* in Nepalese Himalayas three topographical factors i.e. water resources/river, village/settlement and build up areas/roads were examined with Euclidean distance of 50 m interval from 50m to 500m and multiple buffer of 100m interval from 100m to 500m respectively.

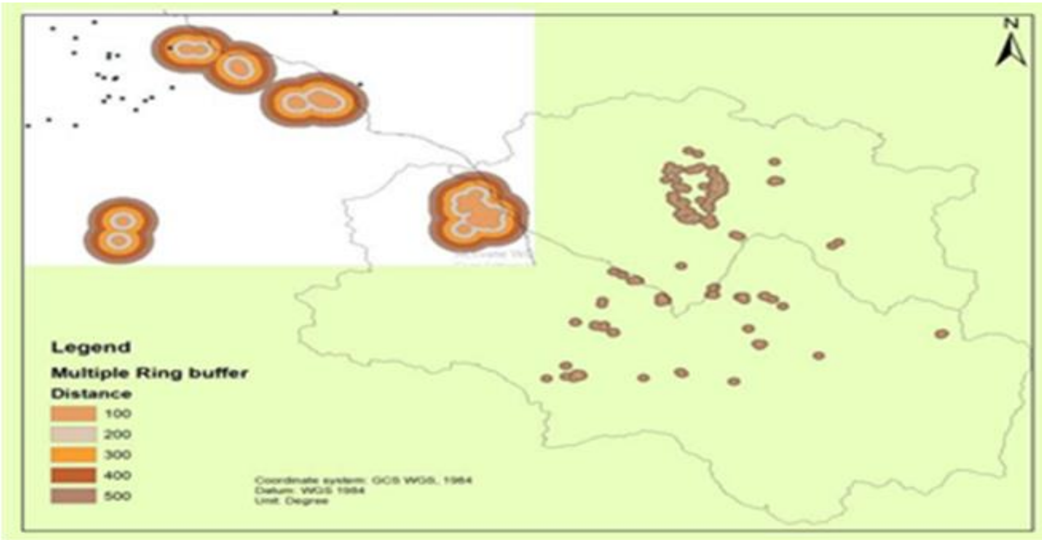

Figure 5. Map showing the multiple buffer of settlement and build-up area, which estimated that, the wolf favours less suitable for its habitat as it comes nearer to these areas.

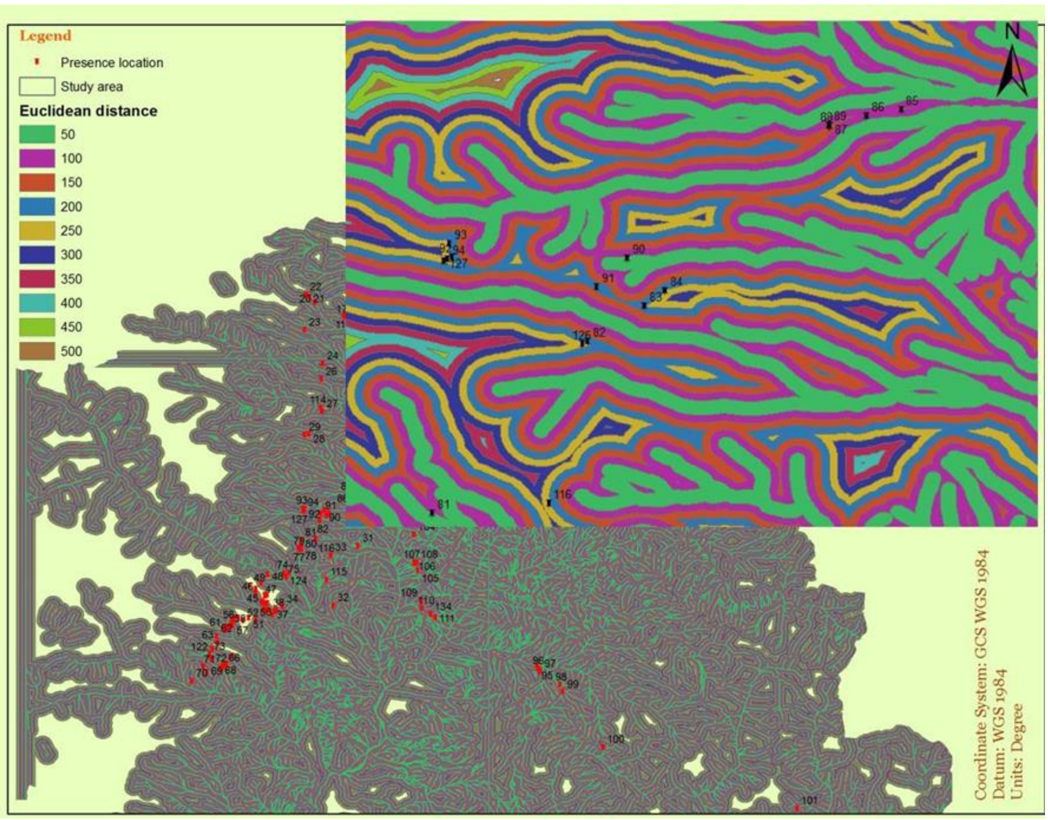

Figure 6. Euclidean distance of river in different categories whereas the distance in between 50m to 200 m is predicted to be higher potential for wolf habitat distribution.

II. Digital Elevation Model

Shutter Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) was downloaded from the open source data of United State Geological Survey (USGS) Global visualization viewer (GloVis) of 1 km resolution from which the aspect, elevation roughness and slope were calculated using the ArcGIS. Use of SRTM is more reliable than other open source data, which is available in 30m resolutions, and it uses the radar technique (Nikolakopoulos *et al.*, 2006). The slope was calculated in the ERDAS Imagine 2015. The smoothness, maximum, and minimum roughness was calculated and the average roughness was computed under the following equation:

$$Rougghness = \frac{(Smooth\ rougghness - Minimum\ rougghness)}{(Maximum\ rougghness - Minimum\ rougghness)}$$

III. Land use land cover data

Land cover land use data calculated from the Landsat TM satellite image were downloaded http://geoapps.icimod.org/landcover/nepallandcover/ which was developed using Object-Based Image (OBI) under the multi-resolution segmentation algorithm base on homogeneity criteria estimated using the parameters shape 0.1, compactness 0.5, and 16 scale factor (Uddin *et al.*, 2015). It alleged the NDVI (Normalized Difference Vegetation Index) classification based on the different land type categorization. The overall areas were categorized under snow/glacier, barren land, water bodies and grassland. The above figure **[Fig.7]** represent the slope, aspect, roughness and land use land cover variable used in for the MAXENT model as background variables.

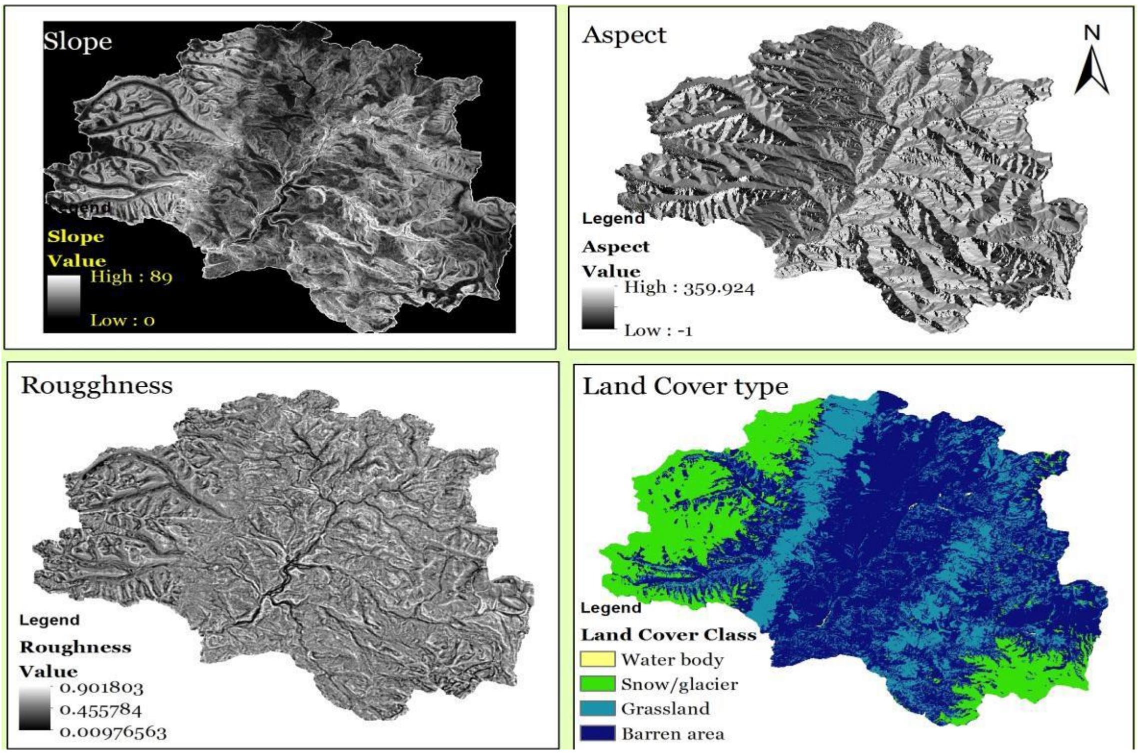

Figure 7. GIS extracted map from the DEM and Land use land cover.

IV. Bioclimatic predictor

Bioclimatic data were obtained from WorldClim which uses the combination of data from 9000 to 60000 weather stations and the data were interpolated using thin splines with covariates including elevation, distance to the coastal and three satellite derived covariates: maximum and minimum land surface temperature as well as cloud cover with the MODIS Satellite platform. These bioclimatic predictors are the climatic conditions that indicate the best to species physiological distribution. In this study, the best climatic conditions that the specific areas well-matched 7 bioclimatic variables were taken into consideration i.e. (Bio1), (Bio7, (Bio10), (Bio11), (Bio18) and (Bio19) extracted for identifying the suitability for the wolf habitat within the study areas **[Fig.8]**. The detail descriptions of the bioclimatic predictors are tabulated in **Table 1.**

Table 1. Showing the description of environmental variables used in predicting the wolf distribution

Bioclimatic variables (30 s -1km)	Land cover type 30m	SRTM-DEM 1km
Annual mean temperature (Bio1)	Grassland	Elevation
Temperature annual range (Bio7)	Barren land	Aspect
Mean temperature of warmest quarter (Bio10)	Water bodies	Slope
Mean temperature of coldest quarter (Bio11)	Snow/Glacier	Roughness
Annual precipitation (Bio12)		
Precipitation of warmest quarter (Bio18)		
Precipitation of coldest quarter (Bio19)		

Throughout the raster analysis all the statistical calculation was carried in ArcGIS 10.5. Preparation of table, chart and write up was carried under Microsoft word and excel 2013. Acquired data are then converted into layers for the map readable for MAXENT program under the ArcGIS 10.5 and ERDAS Imagine 2015.

Each raster data layers were further reclassified under the WGS 84 projection and 30*30 square meter pixel size resolution to combine all the factors into one map for the consistency among the raster dataset. These varied climatic condition and ecosystem support rare and endangered wildlife such as snow leopard, Himalayan lynx, red fox, Tibetan fox, grey wolf, blue sheep and Marmot.

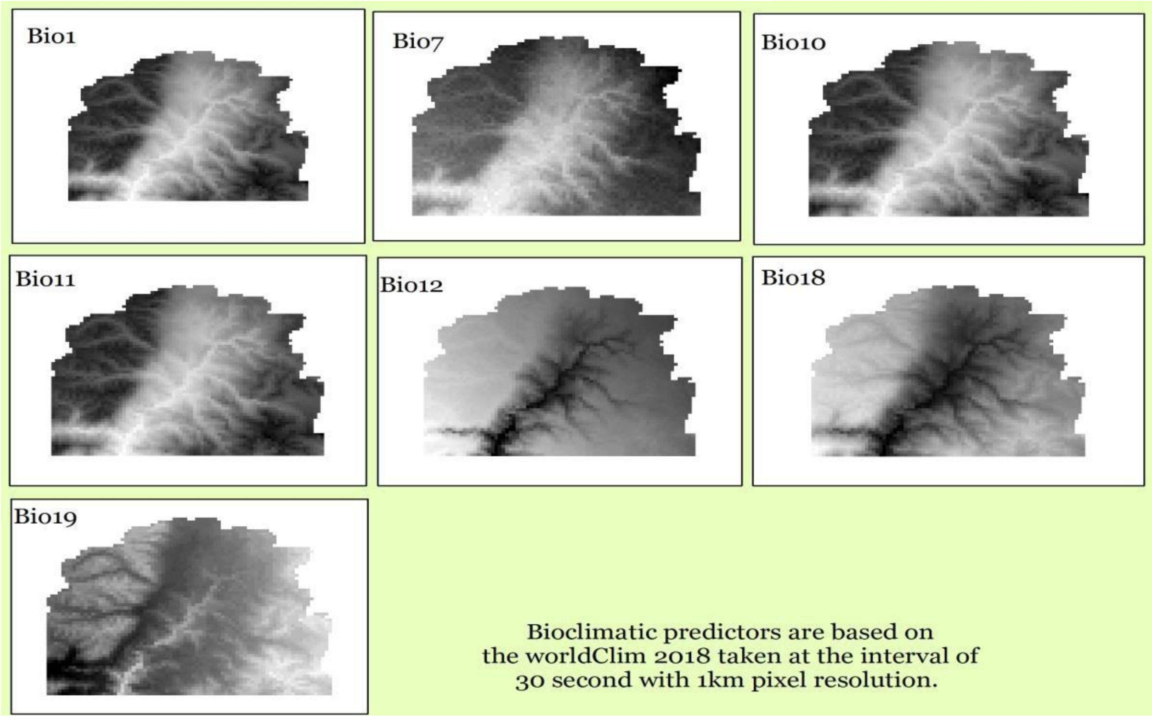

Figure 8. Bioclimatic predictor indicating the temperature and precipitation.

D. Modeling on Maximum Entropy (MAXENT)

According to the FAO, sustainable wildlife management (SWM) is "an effective management of wildlife species such that their populations are sustained and their habitats are maintained keeping in views the social economic aspects and the needs of mankind." Whereas the habitat is defined as space in the forest ecosystem, which is a home to the plant or animal species. The potential distribution describes where conditions are suitable for survival of species and leads to as the great impotence for their conservation and management. Thus, the goal of this study was to predict which areas within the study site satisfy the requirement of the species distribution model.

To address the objective on potential distribution of Himalayan wolf habitat maximum entropy (MAXENT) modeling was used with gathered presence localities coordinate and environmental variables because it needs both the presence-only, together with the environmental information for the whole study areas (Phillips & Elith, 2013). During the model run the Jackknife test was also used in finding the importance of each environmental variable and their impact on model efficacy first omitted and then isolation.

MAXENT typically outperforms excellent based on predictive accuracy. It takes the list of species presence locations s input often called presence-only data as well as set of environmental predictors (e.g. precipitation, temperature, land use land cover) across the defined landscape that is divided into grid cells. When the total population size is known such model predict the occurrence rate in cell defined as expected number of individual in that cells. However, population size is typically unknown, so only relative comparison among these rates are meaningful resulting in a relative occurrence rate (ROR). Here, ROR is the relative probability that a cell is contained in a collection of presence data the ROR corresponds to MAXENT raw output. The MAXENT package is popular in two field i.e. species distribution and environmental niche modeling. Thus, MAXENT model is used for predicting potential distribution of wolf using the presence-only data with the environmental variables.

E. Mapping detail

The result gained from the model was mapped using the ArcGIS. The MAXENT model have provided potential distribution results on .ASCII file which was further calculated and finalized with GIS.. Also in the map potential habitat of Himalayan wolf was further categorized under the high, medium and low potential distribution. The final map was presented in JPG file

5. Data analysis

I. Occupancy distribution

Occupancy distribution of the Himalayan was calculated under the Naïve occupancy. All the data for the occupancy distribution were collected from the single season. Based on the empirical occurrence location Naïve occupancy was calculated under equation mentioned below:

$$Naive\ occupancy = \frac{Total\ occurrence\ records}{Total\ covered\ grids} * 100$$

Similarly, the Relative Abundance Index (RAI) was carried out under the below mentioned equation:

$$RAI = \frac{Number\ of\ occurrence\ locations}{Total\ distance\ travelled\ (Km)}$$

II. Potential suitable habitat

Maximum Entropy is the best (approach of satisfying the approximation from the any unknown distribution with presence-only data (Phillips & Elith, 2013; Elith *et al.,* 2011). Here in the study, to predict the potential habitat in Nepal Himalaya, 7 set of bioclimatic variables with land use land cover 2010 were used. Slope, aspect, elevation, and ruggedness measure were created from SRTM-DEM 1km resolution. Distance to build up areas and distance to settlement were multiple buffered with 100 m interval from 100 to 500m but distance to water bodies (river) was Euclidian distanced of 50m interval from 50m to 500m to identify the intensity of the habitat suitability in the study areas that leads in further conservation and management of Himalayan wolf in Nepalese Himalayas.

All the occurrence locations of the Himalayan wolf sign were confirmed in different land cover type throughout the study areas. Here in **[Fig. 9]** represents the presence of wolves sign in different site where probability of the wolf sign presence in grassland.

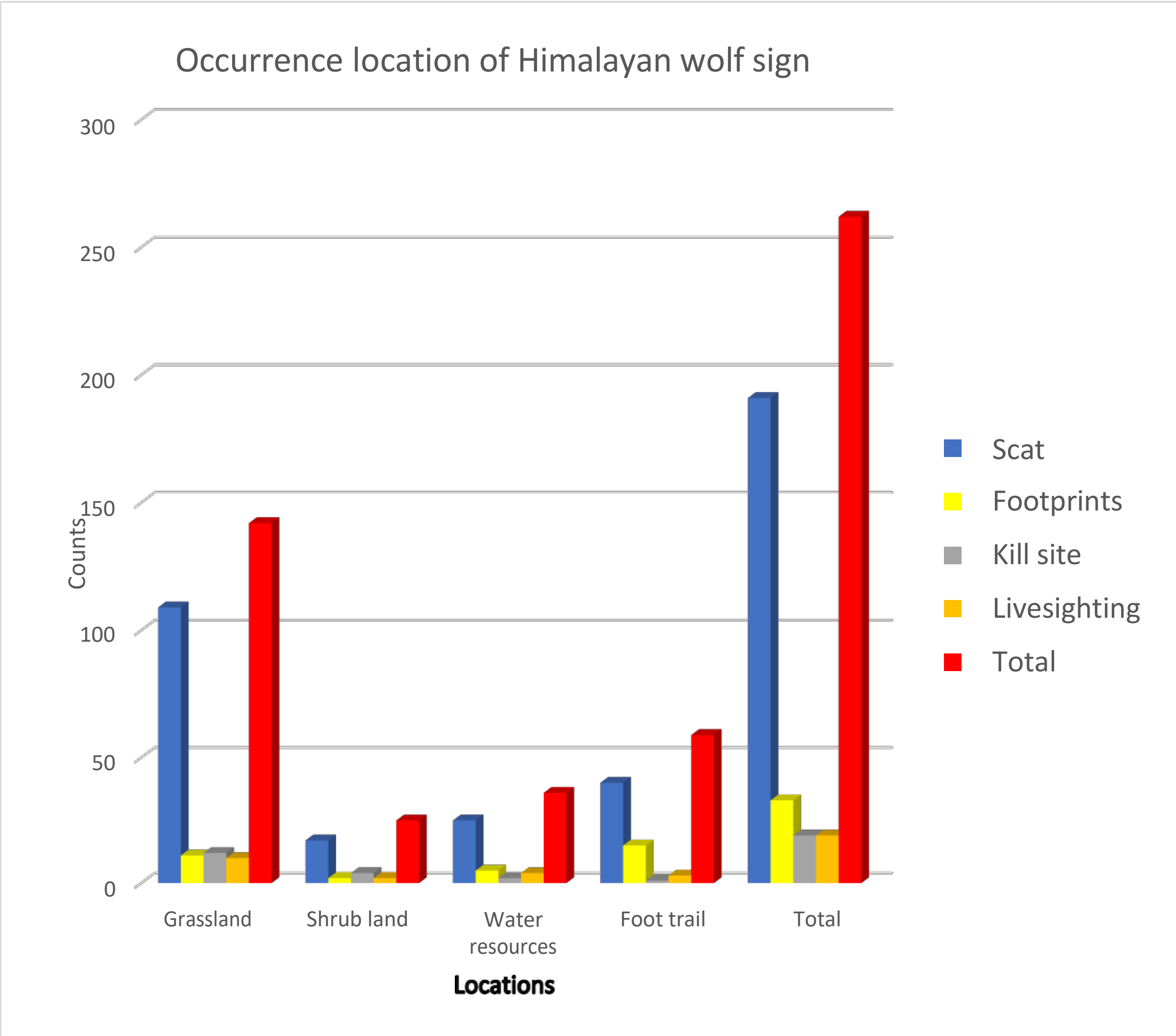

Figure 9. Himalayan wolf Presence sign in Upper Mustang.

All the raster images of environmental variables were screened in ArcGIS ver. 10.5 for spatial autocorrelation using average nearest neighbor analysis to remove correlated sample points and guarantee independence. Compiled raster files of environmental variables and the presence data were found to be highly correlated with a maximum value 0.95 during the multivariate test applied in ArcGIS. Almost 20% of the grids were visited based on the feasible grids gained from the responses perceived during the reconnaissance survey. All .ASCII environmental variable with occurrence location (.shp file) called as training sample were computed in the model and test was run under 17 percentage of test samples as shown in **[Fig.10]** and result are discussed under following chapter. The model was run as 10-percentile training percentage threshold rule.

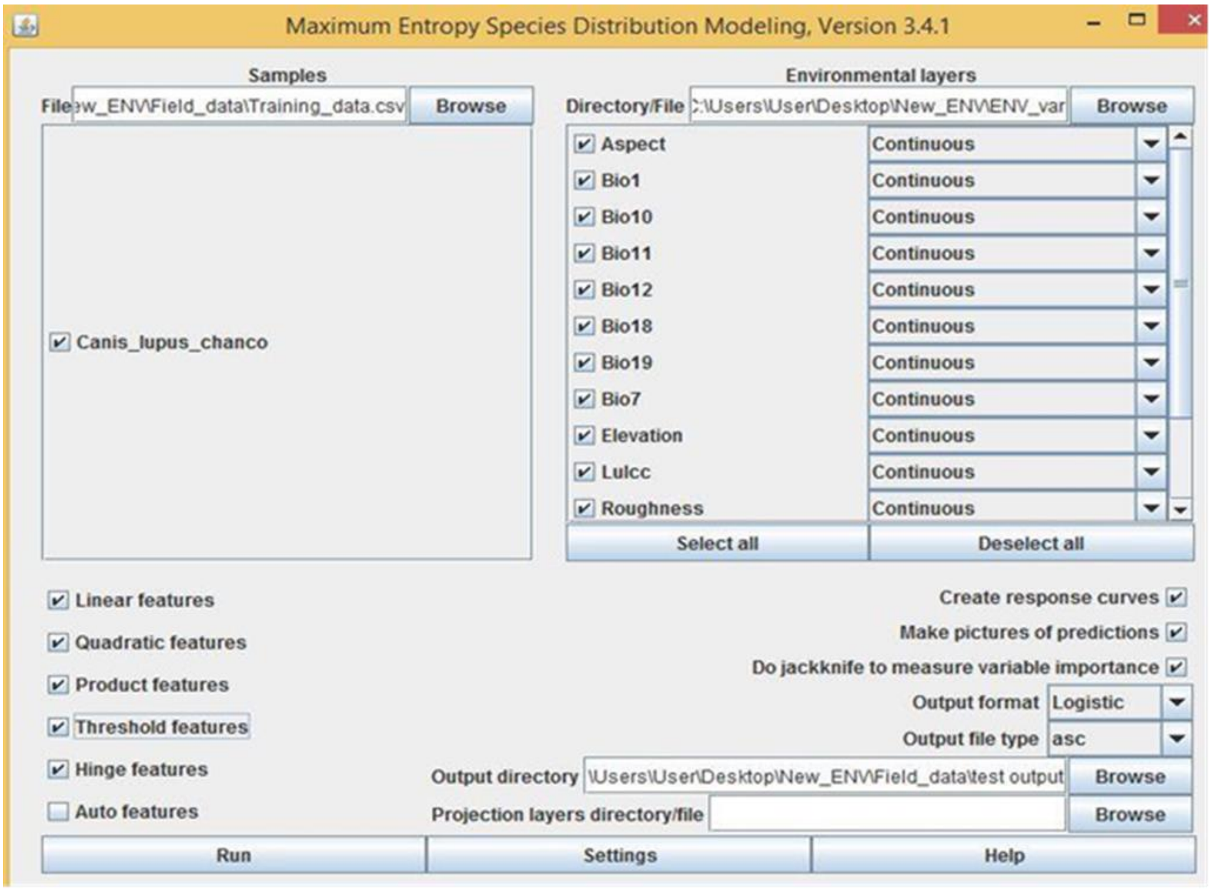

Figure 10 Overview of computed environmental variables and training samples in MAXENT model.

6. Result and Discussion

6.1. Results

6.1.1. Distribution occupancy

Calculating the suitable areas from the reconnaissance survey database it was found that 50% of the total grids were feasible for the wolf potential. The detailed field survey was conducted throughout the study area covering almost 20% of total feasible grids. In total 2076 km^2 was assessed, accounting a linear distance of 187.51km to study wolf occurrence location.


Figure 11. Photograph of Snow leopard (Uncia uncia) at 29007'47"; 840 grassland in busy nature 09'25" nearby Samjhong village 30m distance to water resource. ©Deu Bahadur. Figure 12. Chauri killed by C.

lupus chanco in grassland near Samjhong Village, ACA.

During the visits 262 samples of Himalayan wolf sign [**Fig 4, 9 & 12**] were confirmed however 306 occurrence locations were recorded that represents [**Fig. 11**] other carnivores like snow leopard inhabiting around the study area. Livestock kill sites were mostly found in the flat undulating grassland in busy nature [**Fig. 12**] such as *Carex spp, Kobresia spp*. with *Caragana spp. Sibbaldianthe buifurca* which are largely dominated respectively.

Distribution of Himalayan wolf was calculated under Naïve occupancy method. The Naïve occupancy of *C.l.chanco* was estimated almost 72% **[Fig. 13].** During the survey camera trapping was placed in different locations with an interval of 2 days, unfortunately no any evidences were recorded.

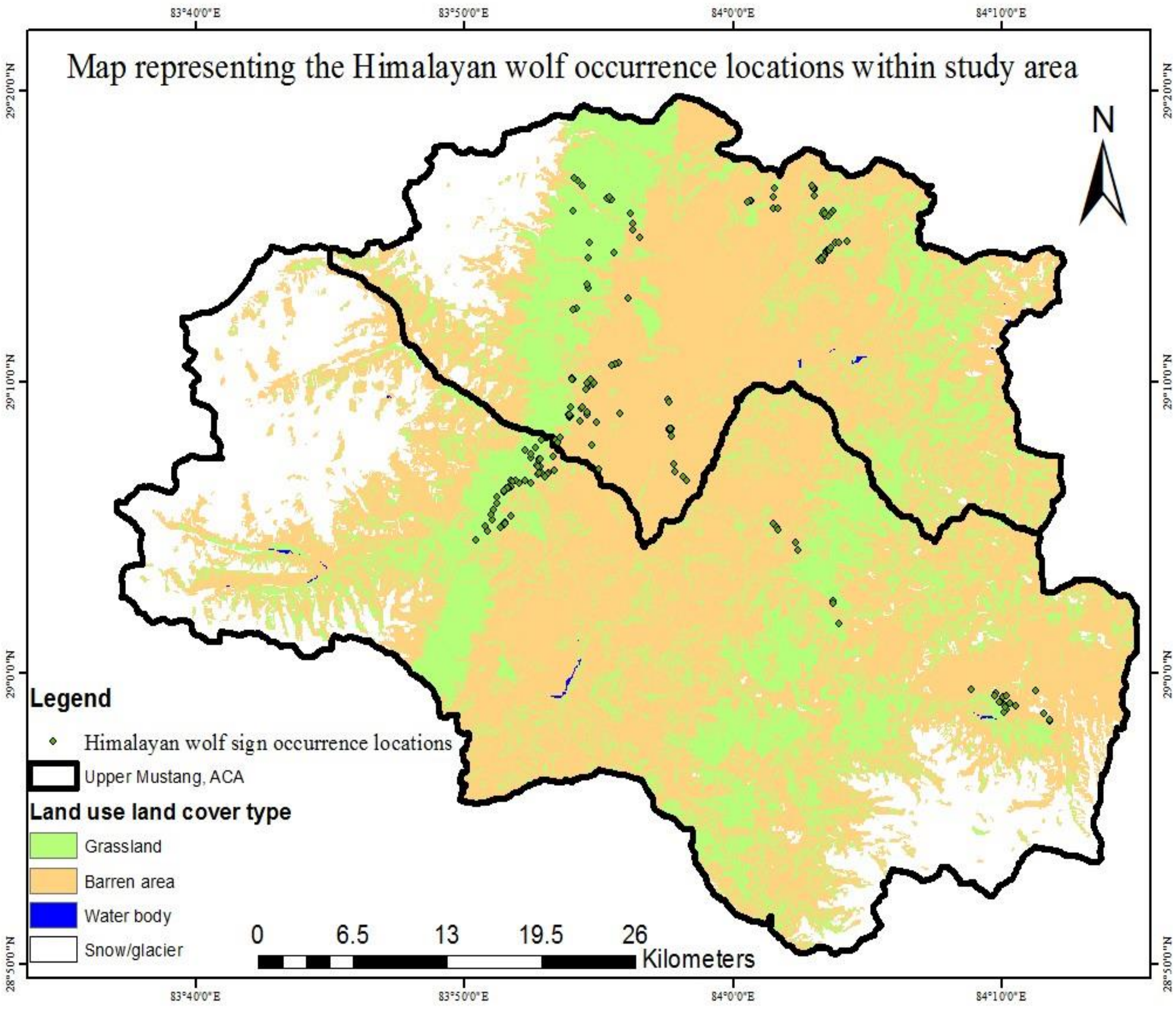

Figure 13. Himalayan wolf occurrence location recorded in Upper Mustang, ACA.

Detailed field survey was planned to cover most of the feasible areas based on the primary survey database. Stratified random sampling method was used to conduct detail survey. For the identification of signs, photograph of the sample feces, pugmark and wolf were taken into the field.

The Relative Abundance Index (RAI) was calculated based on recorded occurrence locations proportional to total distance travelled. This photograph **[Fig.14]** is the proof that there are Himalayan wolf in the study area and their RAI was estimated with an average 2 sign samples per kilometer. Around 25 livestock were killed in the year 2018 (15 July 2018), leads to increase the conflicts between wolves and human.

Figure 14. Himalayan wolf (C.l.chanco) sighted in Dhakmar, Upper Mustang. (Canis lupus chanco sighted at Coordinate: 83.86E, 29.10 N in Upper Mustang, Annapurna Conservation Area, Nepal). ©Deu Bahardur.

6.1.2. Himalayan wolf potential habitat distribution mapping.

As discussed in earlier chapter, MAXENT model was used for predicting the potential distribution of Himalayan wolf habitat. MAXENT models is a generative approach rather than discriminative, which can be inherent advantage when the amount of training data is limited. The results of MAXENT model are discussed under omission/commission analysis, jackknife test, response curve and potential habitat distribution map.

6.1.3. Analysis of omission/ commission graph.

The graph [Fig. 15] representing the Area under the Receiver Operating Characteristics (ROC) Curve or Area Under Curve (AUC) with greater value of sensitivity omission rate articulates the performance of model run towards the goodness of fit. Model was produced using the climatic, land use type and DEM variable. The proportion of test localities correctly predicted present 1- sensitivity omission rate is sensitivity whereas the quantity 1-specific predicted area that equals the proportion of all map pixel predicted to have species. The [Fig.15] clearly demonstrates that higher the mean area with the mean +/- one standard deviation then the mean omission on test data is higher based on the predicted omission curve.

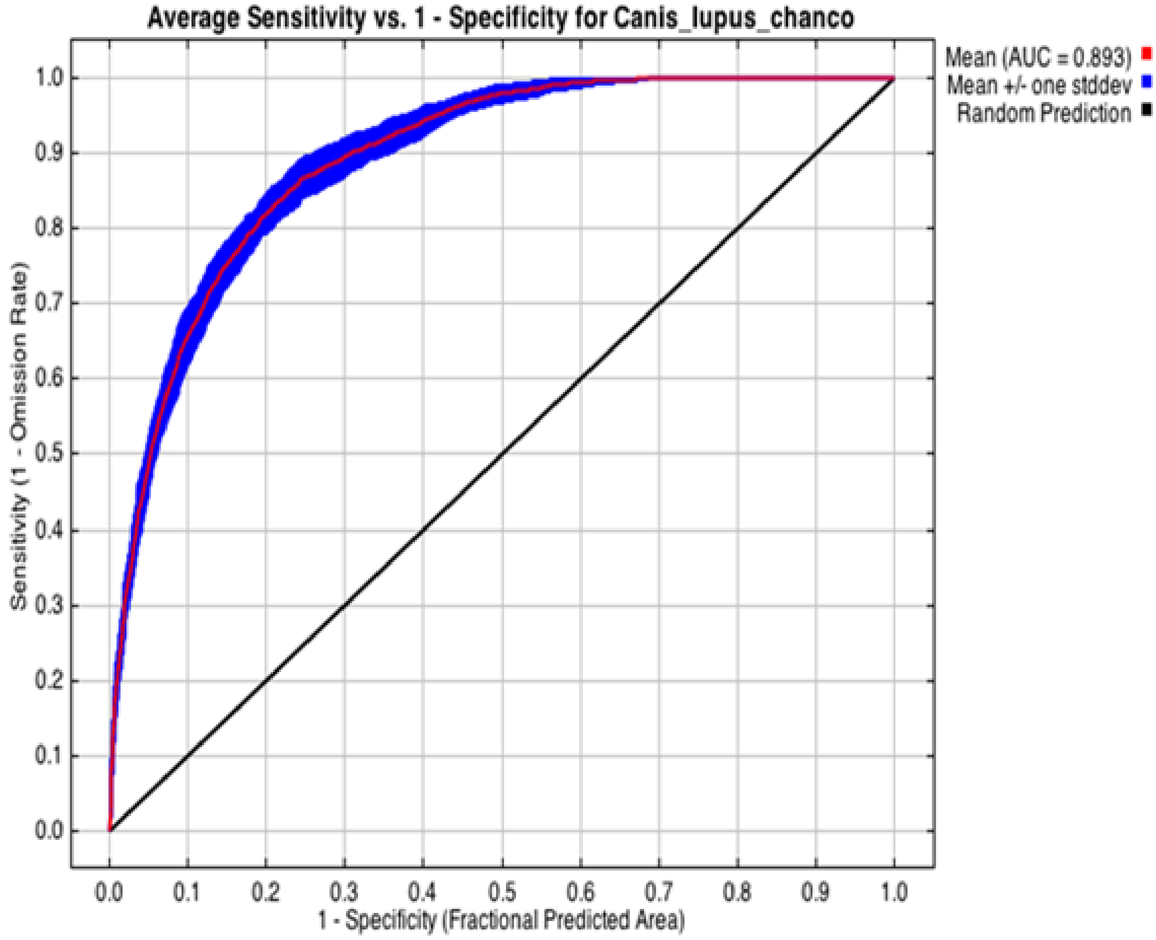

Figure 15 Accuracy of the MAXENT prediction by sensitivity versus 1-the proportion of all map specificity graph for Himalayan wolf.

The minimum predicted value corresponding to an observed presence was selected as a threshold to ensure zero omission. In this graph **[Fig. 15],** the positive difference of AUC for training and test data from that of random prediction measures the accuracy of the model tested. As referring to the result of model the test AUC ranges between 0.727 to 0.987 that, means the suitability of MAXENT model. This result messaged that closer the value to 1 more suitable the model which is illustrated that all the variables used in the model have shown excellent prediction with an average AUC value 0.893 and are significantly better performing for potential habitat of Himalayan wolf in the study area.

6.1.4. Evaluation of predictor performance under Jackknife analysis

The Jackknife test was used to evaluate the importance of each predictor in the MAXENT model. The model was created with an assumption of all the variables are in isolation that provides the accuracy of the variables, which contribute in predicting the species distribution. The use of jackknife test is used to evaluate the importance of each predictor in the MAXENT model. It shows how important each variable is in explaining wolf presence separately and how the model is affected when each variable is left out.

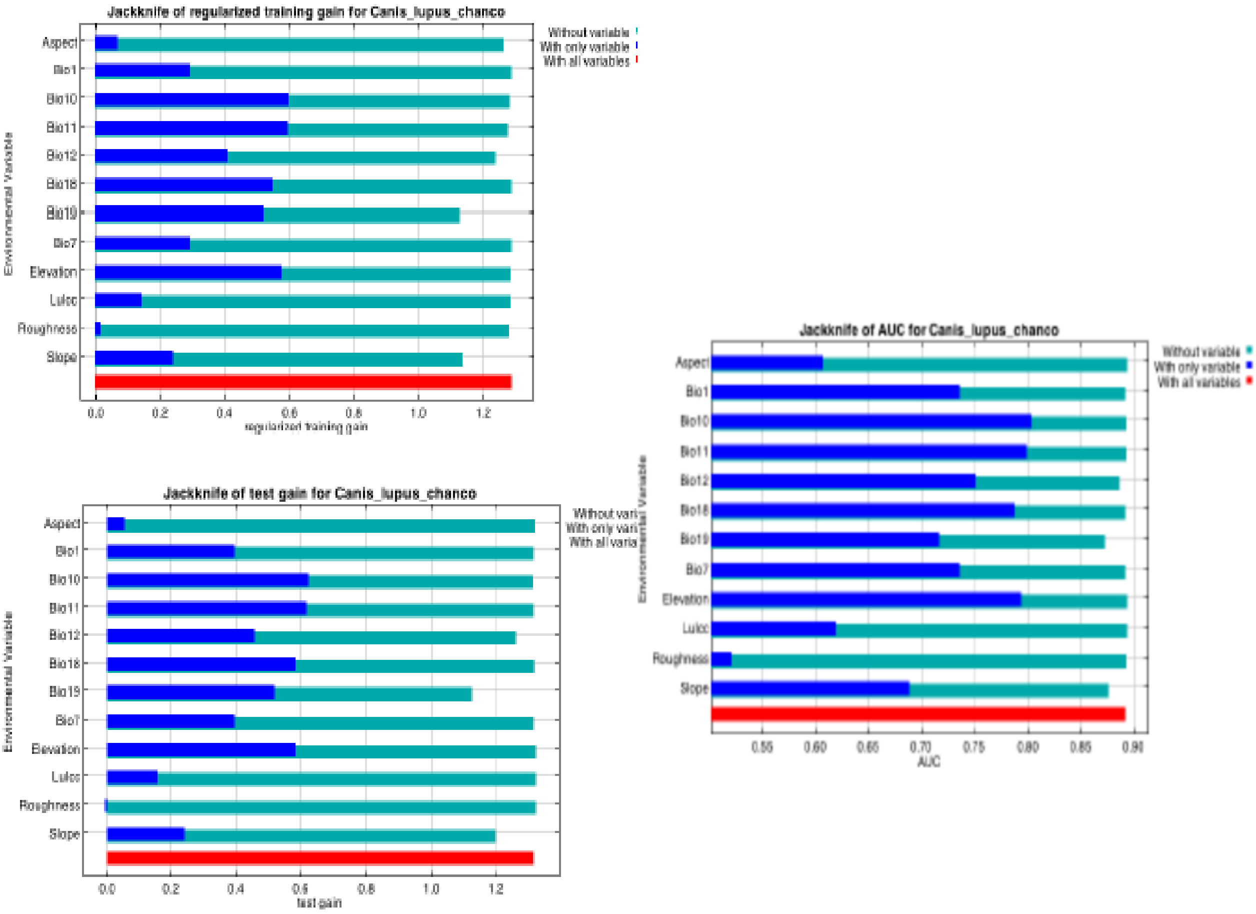

Figure 16 Results of jack-knife evaluations of relative importance of predictor variables for C. l. chanco MAXENT model.

The above [Fig.16] provides the overview on how important each variable is in explaining Himalayan wolf occurrence when uses separately and how the model is affected when each variable is left out. Dark blue color indicate the importance of single variable, light blue bar indicates the loss in model gain when variable is omitted. The red bar is the total model gain during the jackknife analysis. Bio1= Annual mean temperature, Bio7= Temperature annual range, Bio10= Mean temperature of warmest quarter, Bio11= Mean temperature of coldest quarter, Bio12= Annual precipitation, Bio18= Precipitation of warmest quarter, Bio19= Precipitation of coldest quarter and LULCC= Land use land cover change type.

The regularized training gain is 1.29, which proves that the use of different variables shows all the environmental variables and the occurrence location performs excellent to predict the best potential habitat in the study area. Jackknife model state that the contribution of roughness has almost no any gain and has less impact on the potential distribution of wolf in the areas. Conversely, the precipitation mean temperature of coldest and warmest quarter entertains high contribution followed by the elevation and has the remarkable influence in describing the potentiality of wolf distribution.

Comparing all these three AUC plots predicting the distribution of occurrence data leads by the mean temperature of warmest quarter and mean temperature of coldest quarter which was set aside for testing during the predictive performance in the AUC model. The comparatively the importance the mean temperature at warmest quarter and mean temperature at coldest quarter is increasing in the test gain and Jack knife of AUC. Also, the magnitude of light bars is also significantly increasing when the corresponding variables are not used.

6.1.4. Analysis of variables contribution

The following table gives estimates of relative contributions of the environmental variables to the MAXENT model. To determine the first estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative. For the second estimate, for each environmental variable in turn, the values of that variable on training presence and background data are randomly permuted. The model is re-evaluated on the permuted data, and the resulting drop in training AUC is shown in the table, normalized to percentages.

Table 2. Representing the analysis of variables contribution in the model

Variables	Percent contribution (%)	Permutation importance (%)
Bio19	25.5	33.1
Bio12	17.5	21.5
Bio18	15.1	0.9
Slope	14.1	10.9
Bio1	11.8	17.3
Bio11	6.1	3.2
Elevation	2.5	2.3
Aspect	2.4	1.9
River	2.2	2.2
Roughness	1.4	1.2
Bio7	1.1	3.8
Bio10	0.2	1.4
LULCC	0.1	o.2

Above **[Table 2]** showing analysis of variables contribution with their percentage prediction contribution of each variable in the model. It is predicted that the precipitation of coldest quarter (Bio19) gains the major role in predicting the potential habitat of wolf in the high Himalayas with 25.5 % contribution followed by annual precipitation and precipitation f coldest quarter. Furthermore, the model explored the land cover type has minor contribution in the habitat suitability of wolves.

6.1.5. Predictor analysis through response curve

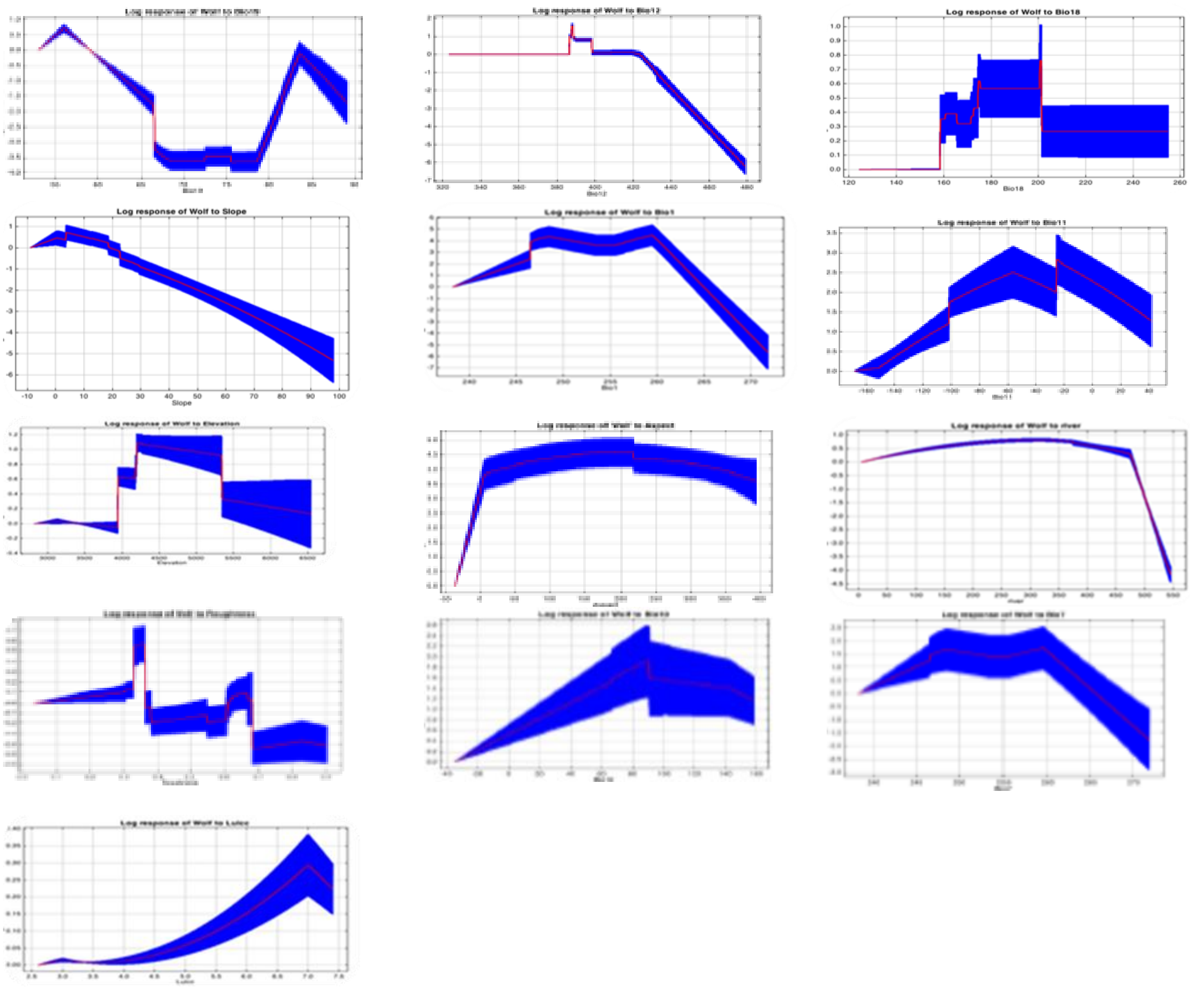

Figure 17 These plots reflect the relationships between top environmental predictors and the Probability of occurrence of wolf in upper mustang, ACA: a) Precipitation of coldest quarter, b) Annual precipitation, c) Precipitation of warmest quarter, d) slope, e) Annual mean temperature, f) Mean temperature of coldest quarter, g) Elevation, h) Aspect, i) Roughness, j) Temperature annual range, k) Mean temperature of warmest quarter, l) Land use land cover change.

While evaluating the above graph **[Fig.17],** response curve of individual variables that reflects the predictive suitability. In the graphs precipitation of coldest quarter plays an important role in predicting the potential distribution of Himalayan wolf habitat ranges from 45mm to 60mm. Similarly, annual precipitation ranging from 320mm to 420 mm found to be suitable with the probability of wolf occurrence in slope less than 20 degree in around the grassland with shrub land. The distribution of wolf habitat increases in higher elevation between 3000m to 5300m. Furthermore, it has been found that wolves prefer habitat nearby rivers whereas the human settlement and other build up areas are found highly disturbed for their potential habitat.

Table 3. Overview test gain of MAXENT model

#Training samples	Regularized training gain	Un-regularized training gain	Iterations	Training AUC	#Test samples	Test gain	Test AUC	AUC Standard Deviation	Entropy
145	1.296	1.865	1843.333	0.937	5	1.397	0.898	0.044	7.929

Above **[Table 3]** reveal the results gained from the model run based on the occurrence locations and environmental variables as demonstrating, lower the value of Standard Deviation (SD) lesser the over fitting among the presence data. In most of the published models the AUC value is >0.8 e.g. Herman, 2011; which means the model showed considerable predictive performance for Himalayan wolf within the study areas.

6.1.6. Potential habitat of Himalayan wolf

The MAXENT model have now resulted the potential habitat of *C.l.chanco* throughout the study area Upper Mustang, ACA. As mentioned below map **[Fig.18]** shows the potential habitat ranging from low (Red), medium (Yellow) to high (Green). The MAXENT model result of suitability mapping was further calculated in ArcGIS and was estimated 52% of the total areas are highly suitable. The total potential suitable area for *Canis lupus chanco* accounts almost 1089.90 square kilometers within the study areas.

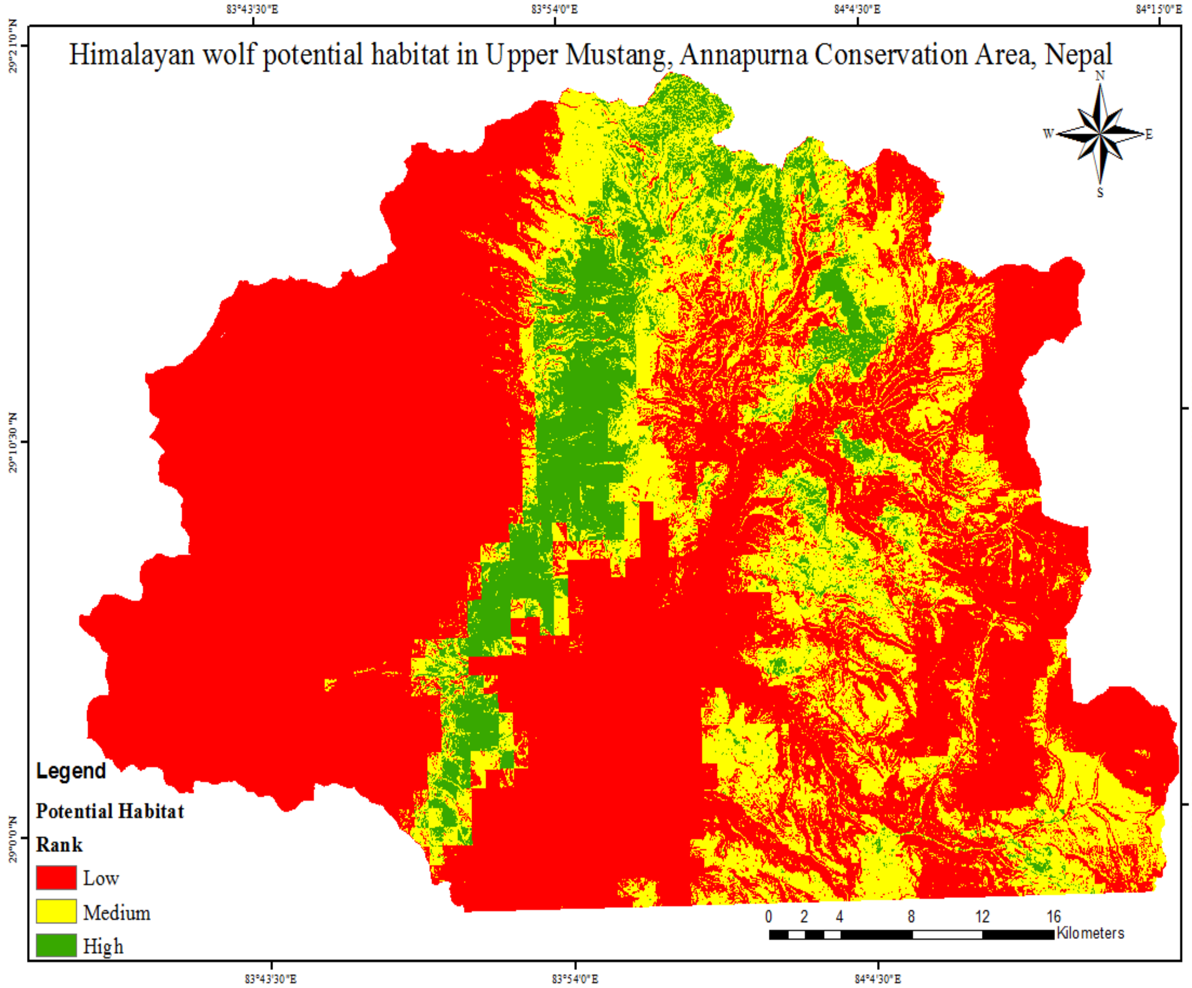

Figure 18. Potential habitat of Himalayan wolf in Upper Mustang, ACA, Nepal.

The above map **[Fig.18]** also attributes that most of the potential habitat of Himalayan wolf are predicted east southern part of the neighboring Dolpa district. Moreover, the best predicted potential habitat of Himalayan wolf using MAXENT model was found to be extended to the Northern southern border of China. Based on the empirical data, this research was conducted for the first time in Nepal about the potential distribution of wolf in the Nepalese Himalayas especially in the upper Mustang, ACA with maximum entropy gain 7.929. The selected environmental variables used in the model are good for the prediction of wolf potential habitat.

6.1.7. Conservation awareness campaign

According to output of the model we could identify two key conflict areas which was selected each site from two rural municipality. The awareness campaign was followed by poster/pamphlet and power-point presentation. All total of 47 participants were present incorporating herdsmen, local women group, youth club, conservation officials and local political leaders. The program was outlined with introduction on wolf, its importance, conservation threat, conservation practices, legal status, and guidelines. Different visual documentary based on wolves and wildlife conservation was displayed in between the program.

6.2. Discussion

6.2.1. Distribution occupancy

This study strongly revealed that the Himalayan wolf are inhabiting in the Nepalese Himalayas **[Fig.14].** Wolf habitat was predicted as highly preferable closer to river however distance near to village and other build up areas are found to be disturbed due to the human influence (Habib *et al.,* 2013; Kabir *et al.,* 2017). Overlapping habitat of wolf with Snow leopard, Red fox other for predation competition and intensive livestock grazing have significant impact on recolonization of wolf in the Nepalese Himalayas. As arguing the results of (Chetri *et al.,* 2017; Shrotriya *et al.,* 2013) high number of Hill Cow (Chauri), goats, cattle and horses kill predation with NTFP and dung of horses and yak collection in the region may lead to increase human-wolf conflict in future. All seasonal occurrence location could increase the probability of occupancy of the wolf in the areas. Since the disturbances seems high in the study areas if the issues are not addressed in conservation and management plan at present there could be the extinction of those elusive species from the Nepalese mountain.

6.2.2. Potential distribution of Himalayan wolf habitat

The study predicted 52% of the total area in ACA as the potential distribution of wolf based on available empirical presence record the result of MAXENT model identify regions with the similar environmental conditions to occurrence localities across the species distribution range (Pearson *et al.,* 2007). Precipitation of coldest quarter followed by annual precipitation and precipitation of warmest quarter plays an important role in predicting the distribution of wolf ranges from 45mm to 84mm. This study also assists to prepare the conservation and management plan in and around the Himalayan range of Nepal. In most of the published mode the value of AUC is listed >0.8 (Mladenoff & Sickley, 2016; Herrmann, 2011) which means the model showed considerable predictive performance gaining the average AUC value 0.898 in the result.

This study has resulted that the most suitable habitat of wolf is northeast of the Dolpa region to the south of the study area with an elevation ranging from 3000m to 5300m. The model also predicted that the distance near to the river/water source was good for the distribution of wolf habitat likely the grassland and the slope <20 degree is suitable habitat. It is also found that the roughness has the less impact on the distribution of wolf in the areas. The result also indicated the habitat of wolf seems highly affected by the human settlement and other build area that needs to be taken into consideration during the formulation of conservation plan. It was also clear that wolves are relatively flexible in their use of habitat at the landscape scale. In general wolves could potentially live in any area where human tolerance and prey abundance are adequate to support viable number (Bocci *et al.,* 2017).

During the detailed survey, occurrence recorded on sign of (kill site, wolf attack) predation by wolf was observed high in grassland and closer to river habitat which also conclude that the areas of grassland with busy nature are extremely preferable habitat. Majority of the wolf signs were recorded in periphery of river, grassland, shrub land and human trails, which was preferably used. Steep terrain may reduce wolf hunting success rates due to increased prey maneuverability and ability to spot incoming predators for some ungulates on steep terrain (Kabir *et al.,* 2017; Glenz *et. al.*, 2001). Despite a possible reduction in efficiency at high slope, wolf kills occurred most often in areas of the lowest bushy grassland primarily due to a concentrating of prey in these areas It could be due to the seasonal variation in prey behavior that requires wolf territories to contain both bushy and stony areas, as well as rangeland where there is high intensity of grazing of livestock. Other environmental variables such as roughness, temperature annual range, mean temperature of warmest quarter and land use land cover were among the variables that lead to least contribution in wolf potential habitat distribution.

6.2.3. Conservation implication

Majority of the people in the areas are highly dependent on holding livestock. Grazing livestock in considerable number were found during the field visit, which is conflicting to the habitat of wolves and other wild animals Awareness towards the wolf conservation such as avoiding the grazing, camping and other activities near river/water resources, safeguarding tools (keeping the livestock in corral or in safely rounded with stone of wooden log) and information on the insurance scheme from the wolf predation against livestock is the imminent issues to building communal harmony and protect the elusive mountain species. The output of this study provides some basic information on the potential distribution of wolf in the Upper Mustang which will be one benchmark for further research and monitoring and conservation planning.

7. Conclusion and Recommendation

7.1. Conclusion

The model output represented the potential wolf habitat mostly in Northeast to south aspect with an elevation between 3000m to 5300m. Among the environmental variables the precipitation of coldest quarter was recorded as the most important influencing factors followed by the annual precipitation and precipitation of warmest quarter. Distance close to the river was found to be highly preferable habitat rather than the distance near to village and build up areas. Most of the wolf signs (pugmark, scat, kill site etc.) were recorded in and around the grassland with bushy and stony nature following with closer to river and human trail. It is estimated that the area under the grassland and barren area were highly preferable for the wolf habitat for their habitation and predation. It can be inferred that wolves prefer human trails for their movement. In general livestock are predated on the course of grazing. Besides the wild ungulates like marmot, pika; domestic livestock were also equally preferable by the wolf. It is observed that the predation by a pack of wolves can hunt up to 5 numbers of livestock at a time which is exception and implausible. This study only assessed the potential habitat of Himalayan wolf in the Upper Mustang, however their population status remains unknown.

7.2. Recommendation

This study recommends the following considerable points:

- Seasonal occurrence should be included to estimate the actual potential habitat of wolf in the Nepalese Himalaya.
- Further research on prey based study and the habitat corridor for understanding the movement of wolf should be carried out intensively.
- Effort to minimize the human influence in its core habitat would increase the harmony and co-existence between human and wildlife.
- It is highly recommended that wolf conservation Action Plan should be initiated and implemented.

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Thank you!!