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Research Article

Assessing current and future habitat suitability for the Himalayan wolf in the Hirpora Wildlife Sanctuary

Zakir Hussain Najar[1], Bilal A. Bhat[1], Riyaz Ahmad[2], Mohsin Javid[3]

[1]Department of Zoology, University of Kashmir, Srinagar, India, 190006

[2]National Center for Wildlife, Riyadh, Saudi Arabia, 12411

[3]Department of Wildlife Sciences, Aligarh Muslim University, 202001

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Abstract

Climate change poses a significant threat to biodiversity, impacting species distribution and ecological dynamics all across the world. Mammals, including canids, are especially vulnerable to climatic variability which affects their habitat and other ecological processes. This study focuses on the habitat modelling of the Himalayan wolf (*Canis lupus chanco*) in the Hirpora Wildlife Sanctuary, Western Himalayas, using current and future climate scenarios. Field data collection from 2020–2022 yielded 135 geo-referenced presence locations for Himalayan wolves. Advanced modelling techniques, including nine algorithms, were employed to assess habitat suitability. The models indicate that the northeastern and eastern parts of the sanctuary are most suitable for the Himalayan wolf under current conditions, with a substantial increase in suitable habitats predicted under future climate scenarios, especially under the RCP8.5 2050 scenario. This study underscores the importance of integrated conservation strategies in light of climate change and increasing human pressures in this critical region.

Keywords: Climate change, Habitat modelling, Himalayan wolf, Conservation strategies

Introduction

Climate change poses a significant challenge to biodiversity conservation, increasingly influencing species distribution and ecological dynamics (Gaston, 2003; Bellard et al., 2012). Research suggests that many species will experience range contraction, habitat loss, or local extinction due to the ongoing climatic shifts (Thomas et al., 2004; Warren et al., 2013). Among the most vulnerable to these changes are mammals, with their survival and distribution being profoundly affected (Smith, 2013). Interestingly, it is hypothesized that generalist species, due to their ecological plasticity and adaptability, may benefit from these changes, potentially experiencing range expansions (Thomas, 2013).

Human-driven climate and land-use changes are precipitating a global decline in biodiversity (Barnosky et al., 2011). Canids, integral to the Himalayan ecosystems and human civilization, are not immune to these changes (Grytnes & Vetaas, 2002; Olsen & Bhattarai, 2005). Therefore, effective conservation strategies are urgently needed to address the impacts of global climate change on these species (Rana et al., 2017). This study contributes to this goal by providing the first detailed information on Himalayan wolf and its distribution in the Hirpora Wildlife Sanctuary, which may help in local landscape planning and conservation management. Climate change is significantly impacting biodiversity, with many species facing range contraction and potential extinction. Mammals, including canids, are especially vulnerable to climatic variability which affects their habitat and other ecological processes leading to conflict.

In this context, the Himalayan wolf (*Canis lupus chanco*), a 'Vulnerable' species as per the IUCN Red List (IUCN, 2023) and listed in Appendix I of the CITES, becomes a focal point of study. This subspecies of the grey wolf, notable for its distinct genetic lineage and larger size (approximately 35 kg), is endemic to the Himalayas and the Tibetan Plateau (Shotriya et al., 2012; Zhang et al., 2014). Our study provides vital insights into the current and future habitat suitability of the Himalayan wolf in the Pir Panjal range of the Kashmir Himalayas. It underscores the need for integrated conservation strategies, considering the predicted range expansions under climate change scenarios.

Study Area

The study was conducted in the Hirpora Wildlife Sanctuary, located in the Western Himalayas, India. Spanning an area of approximately 341 km², this sanctuary is situated at an elevation range of 2,330 to 4,666 m asl (Fig. 1). Notably, the sanctuary is part of the Pir Panjal range and serves as a vital ecological corridor for wildlife movement between the northern and southern parts of the Himalayas (Kumar & Rawat, 2018). The landscape is characterized by its steep and rugged terrain, interspersed with rolling meadows, dense coniferous forests, and alpine pastures. The climate of the sanctuary is typically Himalayan, with cold winters and moderate summers (Mani, 1981), receiving substantial snowfall during the winter months. Summers are characterized by moderate temperatures, conducive to a rich assemblage of flora and fauna.

Hirpora Wildlife Sanctuary is home to a diverse range of mammalian and avian species (Najar et al., 2022). It hosts several endangered and endemic species, including the Himalayan wolf (*Canis lupus chanco*). The major mammal species included Pir Panjal markhor (*Capra falconeri cashmeriensis*), Kashmir musk deer (*Moschus cupreus*), Asiatic black bear (*Ursus* *thibetanus*), Himalayan brown bear (*Ursus arctos*), and leopard (*Panthera pardus*) contributing to its ecological significance (Kaul et al., 2014; Najar et al., 2022).

The region's flora ranges from sub-tropical pine forests at lower elevations to sub-alpine and alpine vegetation at higher altitudes, providing varied habitats for wildlife. However, the area around the sanctuary is experiencing increasing human activities, such as agriculture, livestock grazing, and developmental projects, posing challenges to wildlife and creating human-wildlife conflict scenarios (Ahmad et al., 2014; Bhat et al., 2019)

Given its strategic location and rich biodiversity, the Hirpora Wildlife Sanctuary holds significant importance for conservation efforts in the Himalayan region. Understanding the habitat use and distribution of key species like the Himalayan wolf in this sanctuary is vital for developing effective conservation strategies (Habib et al., 2013), especially in light of climate change and increasing human pressures.

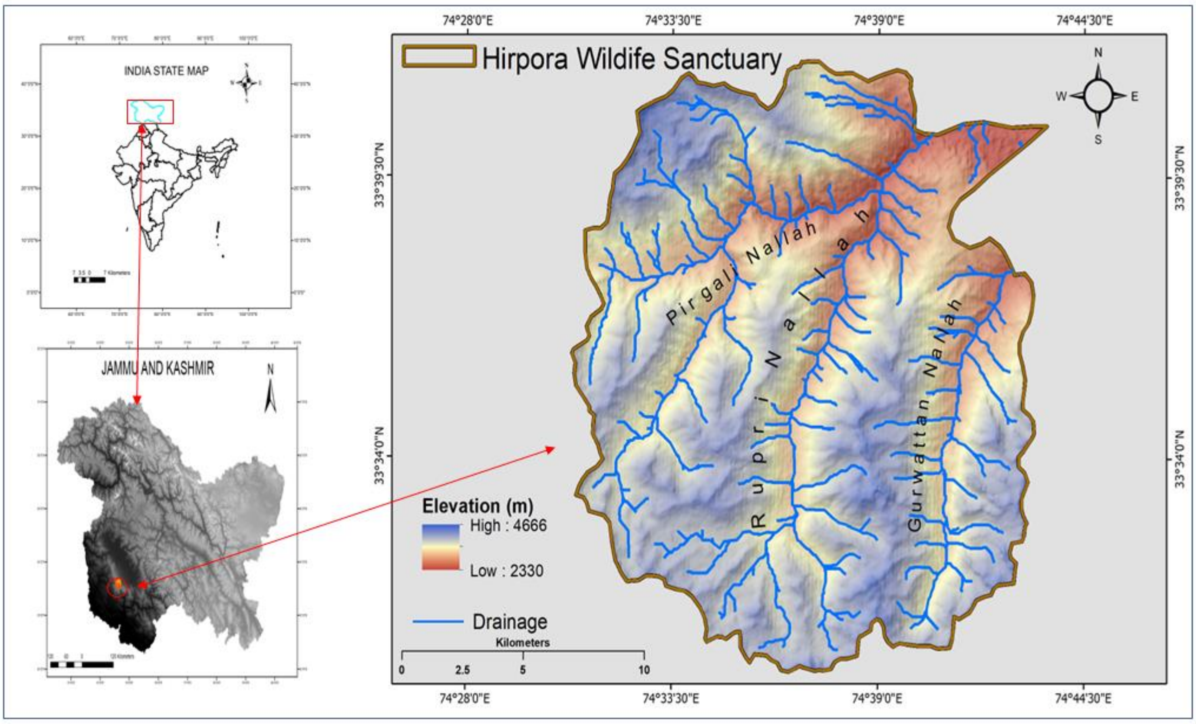

Figure 1. Map of Hirpora Wildlife Sanctuary, Western Himalayas, Kashmir

This study was conducted in the Hirpora Wildlife Sanctuary in the Western Himalayas. We collected extensive field data from 2020-2022, including 135 geo-referenced presence locations of Himalayan wolves. Habitat modelling was performed using the "biomod2" package with nine algorithms. Environmental predictor variables from the WorldClim database were used. Models were validated using Area Under the Curve (AUC) and True Skill Statistics (TSS).

Figure 2. Himalayan wolf (*Canis lupus chanco*) in Hirpora Wildlife Sanctuary, Western Himalayas, Kashmir

Occurrence Data Collection: Over three years (2020–2022), we conducted extensive fieldwork across the Hirpora Wildlife Sanctuary. This involved collecting both direct and indirect evidence of wolf presence, such as scat locations, pugmarks, tracks, camera trap images, and direct observations. This approach is well-established in Himalayan research (Namgyal & Thinley, 2017). In total, we obtained 135 geo-referenced presence locations of Himalayan wolves. To ensure data quality and reduce bias, we performed spatial thinning across 1×1 km grid cells, ultimately selecting 34 geo-referenced points for our distribution modelling (Rather et al., 2022).

Preparation of Geospatial Layers: We utilized climatic variables from the WorldClim database (version 1.4) (Hijmans et al., 2005). These variables included detailed temperature and precipitation data collected between 1950 and 2000. To avoid multicollinearity, we conducted Pearson's correlation analysis and selected a single variable from each pair of highly interrelated variables ($r>0.75$).

Future Distribution Prediction: For predicting future distribution patterns, we used the Hadley Global Environment Model 2-Earth System (HADGEM2-ES) for two representative concentration pathways (RCP4.5 and RCP8.5) for the years 2050 and 2070 (Moss et al., 2010; Rather et al., 2022). This model is recognized for its reliability in simulating climate phenomena, including temperature changes (Flato et al., 2014). The future distribution of the target species was predicted using the same set of environmental variables as for the current distribution estimation.

Environmental Predictor Variables: Our study used a total of 19 environmental predictor variables, categorized into climatic, topographic, landscape composition, vegetation, and human-influenced factors, as sourced from the WORLDCLIM database (www.worldclim.org). We removed highly correlated predictor variables using the R package "rfUtilities" to avoid multicollinearity among the predictors (Dormann et al., 2013).

Modelling Technique: The "biomod2" package of R statistical software (R Core team, 2022) was employed to investigate species distribution modelling under current and future climate change scenarios, using a total of nine algorithms (Thuiller et al., 2009). Given the challenges in acquiring accurate absence data, we adapted an approach used by Barbet-Massin et al. (2012) and Guisan et al. (2017), generating five hundred pseudo-absences randomly in the study area. The models were created using 80% training set and a 20% validation set. To enhance the robustness of our models, we repeated the modelling approach thrice, generating a total of 81 models for each climate situation and period combination (Rather et al., 2022; Wani et al., 2022).

Results

The models indicated the current and future distribution of the target species under different Representative Concentration Pathway (RCP) scenarios. The northeastern and eastern parts of the sanctuary were identified as the most suitable for the Himalayan wolf under current conditions. The model predicted a substantial increase in suitable habitats for the Himalayan wolf under future climate scenarios, particularly under the RCP8.5 2050 scenario.

Model Accuracy and Variable Importance: The final ensemble models, created through both committee averaging and weighted mean methods, demonstrated high accuracy in predicting the distribution of target species within the Hirpora Wildlife Sanctuary. Specifically, the models generated using committee averaging yielded an Area Under the Curve (AUC) of 0.65 and a True Skill Statistic (TSS) of 0.86, while those using the weighted mean approach showed an AUC of 0.86 and a TSS of 0.85.

Among the various algorithms employed, Gradient Boosting Machine (GBM), Random Forest (RF), Artificial Neural Network (ANN), and Flexible Discriminant Analysis (FDA) showed the highest prediction accuracy for the Himalayan wolf, followed by Generalized Additive Models (GAM), Generalized Linear Models (GLM), Classification Tree Analysis (CTA), and

Maximum Entropy (Maxent). Species Range Ensemble (SRE) and Philips algorithms exhibited the lowest accuracy.

Three bioclimatic variables were identified as most influential in determining habitat suitability for the Himalayan wolf: BIO-1 (annual mean temperature), BIO-8 (mean temperature of the wettest quarter), and BIO-18 (precipitation of the warmest quarter). Their importance scores ranged from 0.15 to 0.8, 0.00 to 0.48, and 0.23 to 0.84, respectively, with mean scores of 0.46, 0.13, and 0.37.

For the Himalayan wolf, the prediction accuracy for each employed algorithm revealed that GBM, RF, ANN and FDA algorithms had the highest accuracy followed by GAM, GLM, CTA, and Maxent. Phillips, SRE, and had the lowest accuracy in comparison to other algorithms (Fig. 3). Out of 19 variables only 3 variables BIO-1 (annual mean temperature importance score range is 0.15 to 0.8 and Mean is 0.46), BIO-8 (mean temperature of wettest quarter, importance score range 0.00 to 0.48 and Mean is 0.13) and BIO-18 (precipitation of warmest quarter importance score range is 0.23 to 0.84 and Mean is 0.37) Table 1.

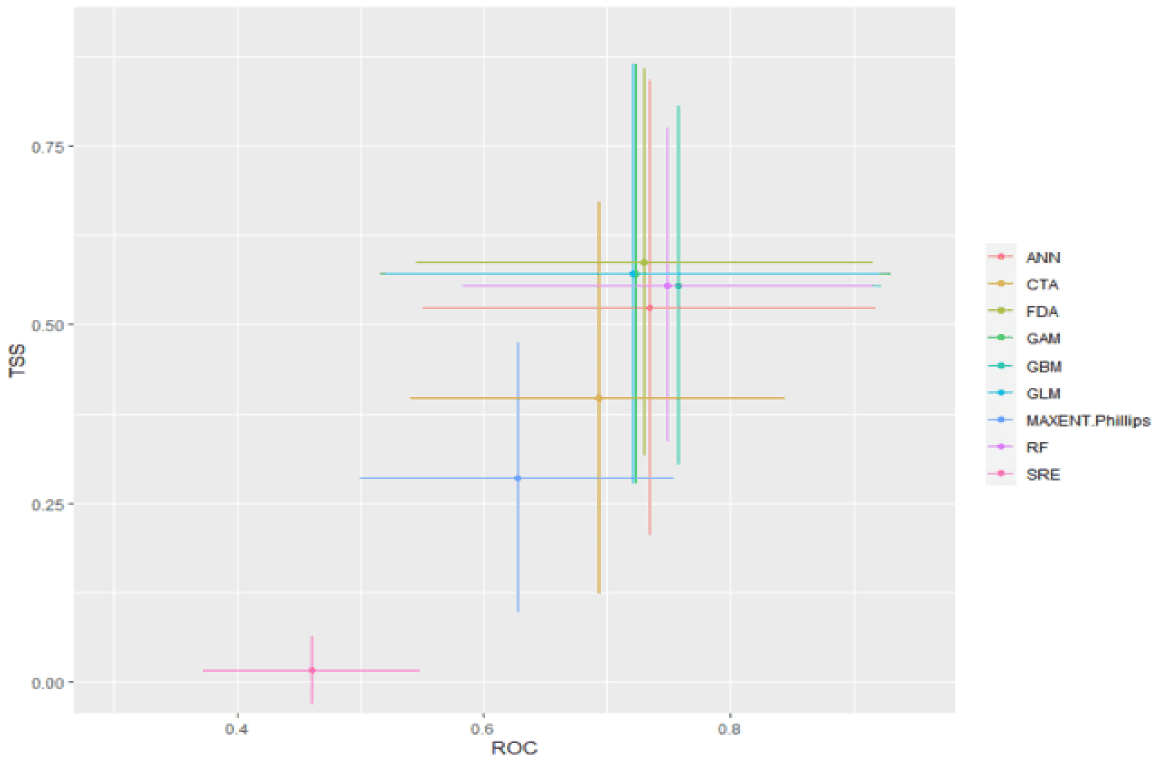

Figure 3. Presents a scatter plot comparing different statistical models based on two metrics: Receiver Operating Characteristic (ROC) and True Skill Statistics (TSS). Each point on the plot represents a model's performance, with the horizontal axis showing the ROC value and the vertical axis showing the TSS value. The inclusion of error bars indicates variability or uncertainty in the measurements, which suggests that the model performance can vary under different conditions or datasets. Models such as Random Forest (RF) and Generalized Linear Models (GLM) show differing levels of performance based on these metrics.

Table 1. Scores of Himalayan wolves for the selected bioclimatic variables, both overall and algorithmically

Variable	GLM	GBM	GAM	CTA	ANN	SRE	FDA	RF	MAXENT, Philips	Mean
BIO-01	0.48	0.50	0.33	0.54	0.8	0.41	0.15	0.24	0.56	0.46
BIO-08	0.01	0.01	0.05	0.01	0.30	0.26	0.00	0.05	0.48	0.13
BIO-18	0.39	0.24	0.39	0.39	0.32	0.29	0.84	0.23	0.67	0.37

Current Distribution: The ensemble models indicated that under the current climatic conditions, the northeastern and eastern parts of the sanctuary are the most suitable habitats for the Himalayan wolf. In contrast, the southern, southeastern, and western parts of the sanctuary exhibited poor suitability (Fig. 4).

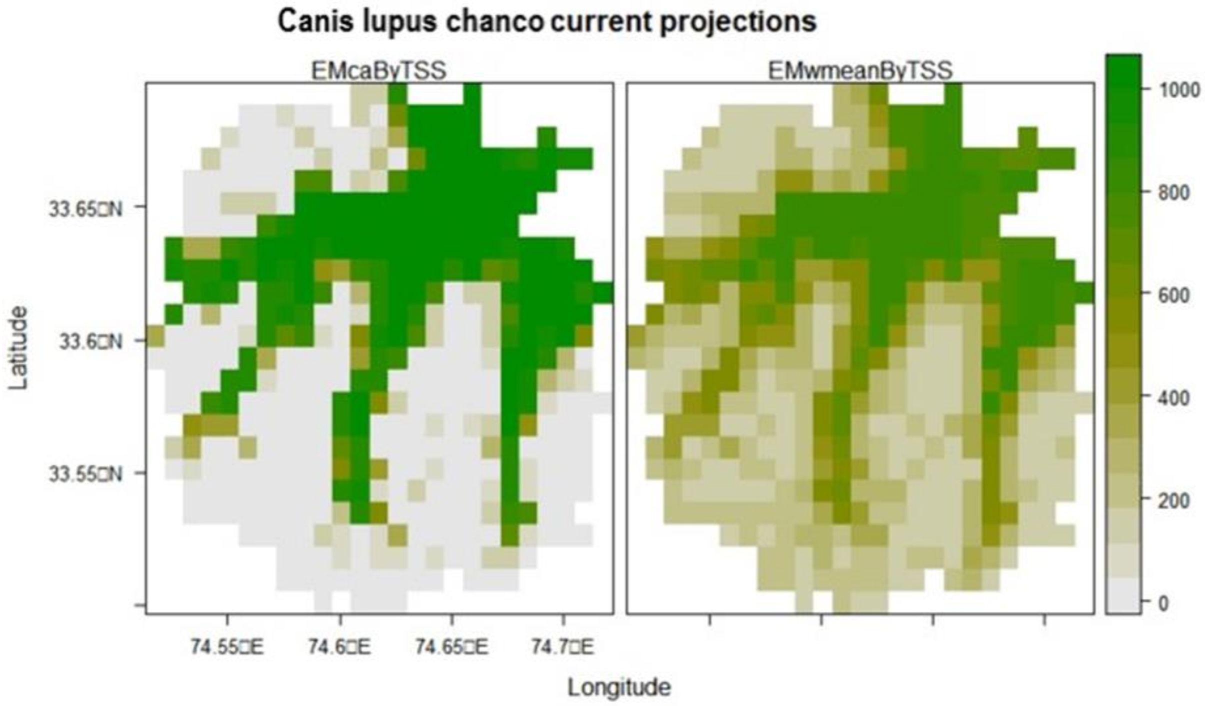

Figure 4. Displays the current projections of habitat suitability for *Canis lupus chanco*. The maps utilize a color gradient to indicate the level of habitat suitability, with darker shades representing higher suitability. These projections are based on two different modelling approaches, as indicated by the labels on the maps. The geographical focus is marked by latitude and longitude coordinates, highlighting a specific area of interest.

Future Potential Distribution: The study revealed notable changes in the distribution of the Himalayan wolf under future climatic conditions. There is an expected increase in habitat suitability across all future climate scenarios. Under future scenarios, the northeastern and eastern regions will maintain their suitability, while the southern and southeastern parts will continue to exhibit poor suitability for the Himalayan wolf (Fig. 5).

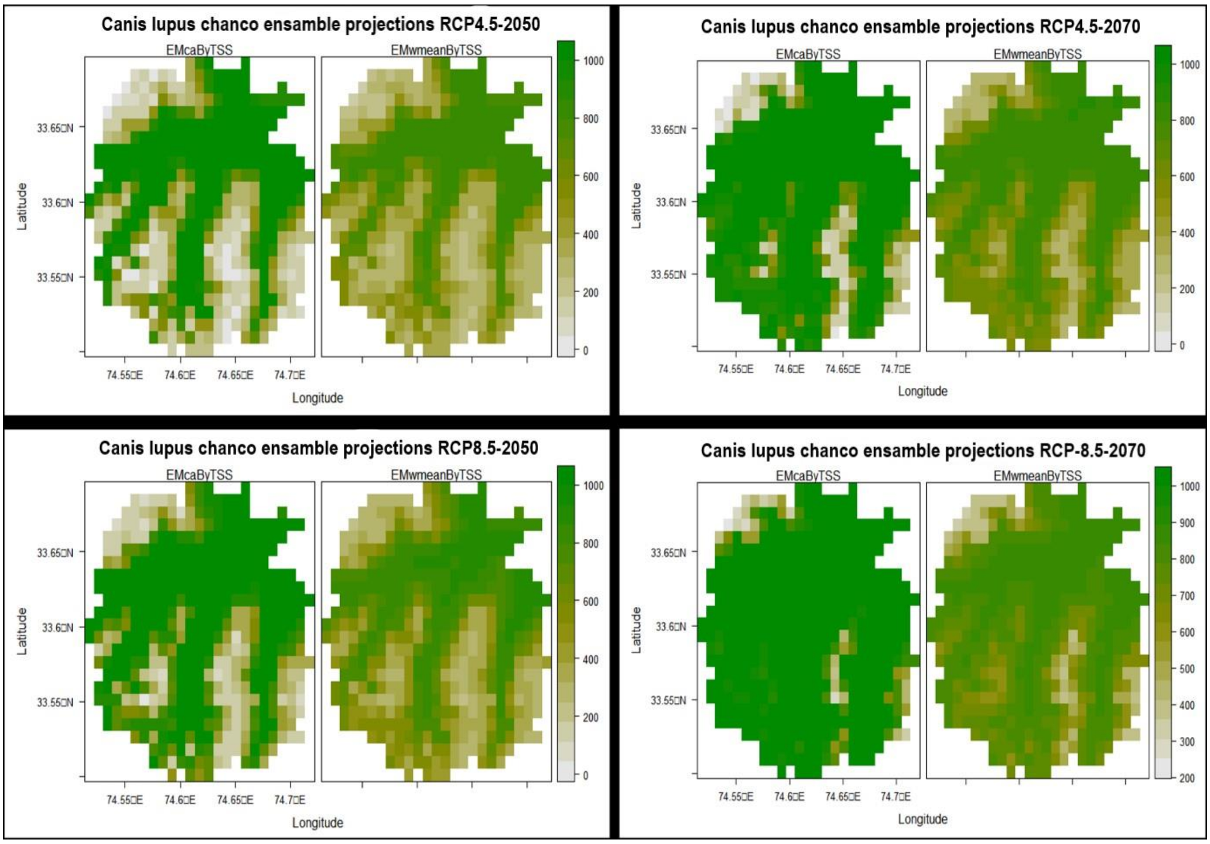

Figure 5. Set of maps depicting future projections of habitat suitability for Himalayan wolf *Canis lupus chanco* under two different Representative Concentration Pathways (RCPs): RCP4.5 and RCP8.5. These RCPs are used in climate modelling to estimate greenhouse gas concentrations. The maps provide projections for the years 2050 and 2070, indicating how habitat suitability is expected to change over time. The use of colour gradients serves to visualize the levels of habitat suitability, with darker colours denoting more suitable areas for the species.

Species Range Change: In the RCP4.5 2050 scenario, using committee averaging, there was a negligible loss in the current range with significant gains, indicating an 84.956% range change. The weighted mean method showed no loss, a 45.732% range change with significant gains. In the RCP8.5 2050 scenario, both ensemble types predicted nearly a complete retention or increase of the suitable range, with the weighted mean method indicating a 76.829% range change.

Looking further into the future, the RCP4.5 2070 and RCP8.5 2070 scenarios show an even greater increase in suitable habitat, particularly in the RCP8.5 2070 scenario with the weighted mean method, which predicts a 156.707% range change (Fig. 6).

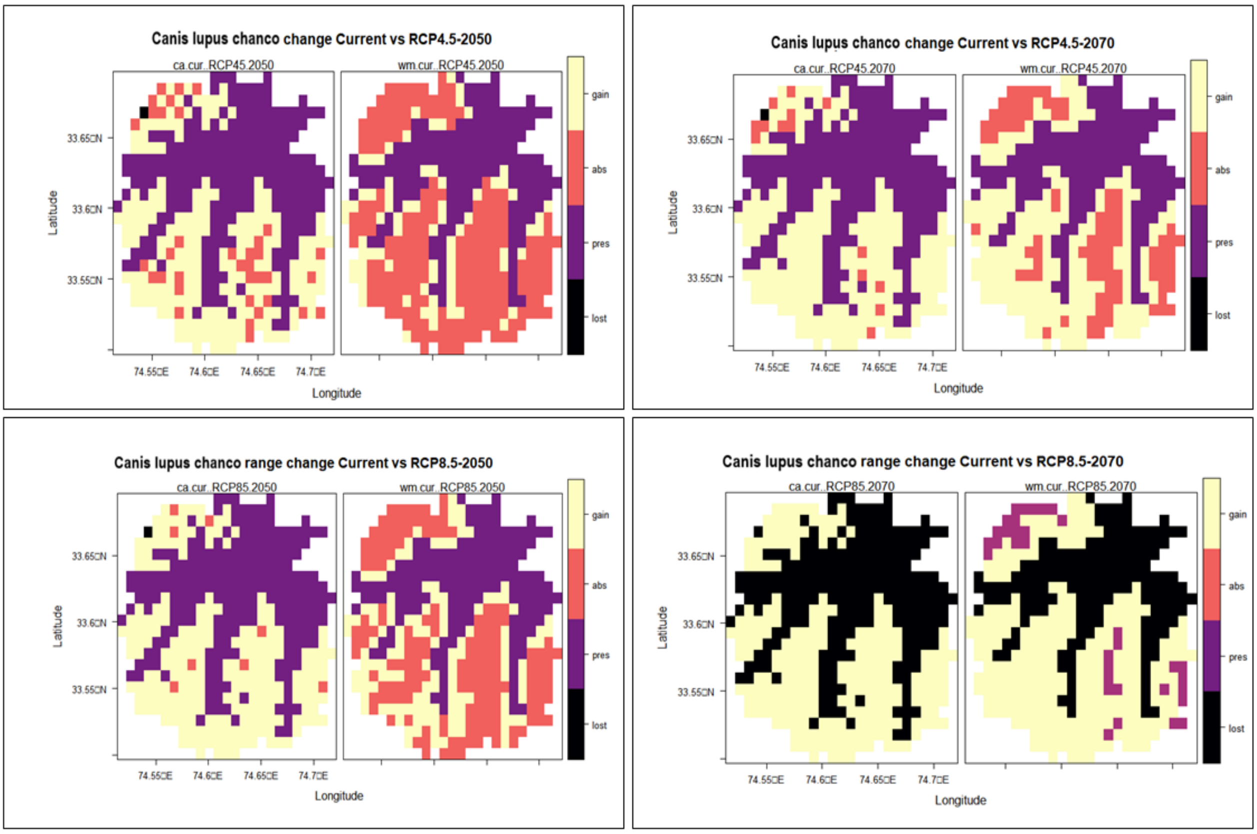

Figure 6. Himalayan wolf *Canis lupus chanco* range change comparison under RCP4.5 and RCP8.5 scenarios: The maps illustrate predicted changes in the geographic range for the years 2050 and 2070, compared to the current distribution. Two modelling approaches are compared (denoted as 'ca' and 'wm'), highlighting areas of potential range loss (black), persistence (red), gain (yellow), and no significant change (purple) under moderate (RCP4.5) and severe (RCP8.5) climate change scenarios. These projections are instrumental for identifying future conservation priorities and action plans for the species.

Table 2. Shows a detailed comparative analysis of climate impact projections under different Representative Concentration Pathways (RCPs) for the years 2050 and 2070. It includes two distinct scenarios, RCP4.5 and RCP8.5, each analyzed using two methods: Committee Averaging and Weighted Mean. The table methodically lays out key metrics such as Loss, Stable0, Stable1, and Gain, along with percentage changes in Loss and Gain, and the overall Range Change. This data is crucial in understanding the varying impacts of climate change under different greenhouse gas concentration trajectories, providing a clear perspective on how different approaches to model aggregation can yield different projections. The table serves as an invaluable resource for researchers and policymakers in assessing the potential outcomes of climate change and the effectiveness of mitigation strategies.

Table 2. Range change statistics for Himalayan wolf under different climate change scenarios

Scenario	Ensemble Type	Loss	Stable0	Stable1	Gain	Loss (%)	Gain (%)	Range Change (%)
RCP4.5 2050	Committee Averaging	1	36	225	193	0.442	85.4	84.956
RCP4.5 2050	Weighted Mean	0	216	164	75	0.000	45.7	45.732
RCP8.5 2050	Committee Averaging	1	14	225	221	0.442	97.788	97.345
RCP8.5 2050	Weighted Mean	0	94	164	126	0.000	76.829	76.829
RCP4.5 2070	Committee Averaging	1	8	225	215	0.442	95.133	94.690
RCP4.5 2070	Weighted Mean	0	165	164	197	0.000	120.122	120.122
RCP8.5 2070	Committee Averaging	0	0	225	229	0.000	101.327	101.327
RCP8.5 2070	Weighted Mean	0	34	164	257	0.000	156.707	156.707

Discussion

This study presents a comprehensive assessment of the current and future distribution of the Himalayan wolf in the Hirpora Wildlife Sanctuary, Kashmir Himalayas, employing advanced ensemble modelling techniques. Our findings align with and extend the work of Ahmad et al. (2019), who emphasized the potential of ensemble modelling in wildlife conservation and species distribution mapping (Ahmad et al., 2019).

We observed that the current habitat suitability for the Himalayan wolf is primarily confined to the northeastern, northern, and central regions of the Sanctuary. This distribution pattern echoes the observations of Linshan et al. (2017) in the Koshi Basin, indicating a preference for regions with less human disturbance and ample prey availability (Linshan et al., 2017). The northeastern and eastern regions, currently the most suitable habitats, are characterized by a mix of forest patches and sub-alpine meadows, similar to habitats preferred by wolves in other mountainous regions (Kruuk & Parish, 1982; MacDonald, 1983).

In terms of future scenarios, our study predicts a significant expansion of suitable habitats under RCP 8.5 2050, with the potential for range expansion into central and eastern Himalaya, including parts of Nepal and southwestern China. This is consistent with the findings of

Linshan et al. (2017), who reported increased habitat suitability in similar regions (Linshan et al., 2017). However, our study provides a more extensive spatial scale analysis, offering broader implications for regional conservation strategies.

The predicted habitat changes also indicate the potential impact of human activities, especially in emerging tourist areas, on the movement and distribution of the Himalayan wolf. These insights align with studies in other regions where human activities influence wolf distribution, such as findings by Mech & Boitani (2003) and Rigg & Gorman (2005). Furthermore, our findings suggest that wolves may adapt to human-modified landscapes, as indicated by their use of secondary roads and proximity to human settlements, a trend also observed in other studies (Fuller et al., 2003; Theuerkauf, 2003).

Riparian habitats emerged as crucial in our study, corroborating the findings of previous research on their importance for hunting and denning (Harrington & Mech, 1982; Ballard et al., 1991). The tendency of wolves to concentrate in lower areas during winter, as observed in our study, is supported by research on wolf behaviour in frozen terrains (Mech, 1970; Peterson et al., 1984).

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