AJAB

Asian J Agric & Biol. xxxx(x).
DOI: 10.35495/ajab.2023.300

Original Article

Habitat modelling of *Bombus haemorrhoidalis* Smith (Hymenoptera) under future projected climatic conditions in Pakistan

Imran Bodlah[1*], Ammara Gull E Fareen[2], Umer Ayyaz Aslam Sheikh[3], Muhammad Adnan Bodlah[4], Rehana Bibi[5], Hesham F. Alharby[6, 7], Habeeb M. Al-Solami[6], Naser A. Alkenani[6], Abdullah G. Al-Ghamdi[6]

[1]Insect Biodiversity and Conservation Group, Department of Entomology, PMAS Arid Agriculture University, Rawalpindi, Pakistan
[2]Department of Environmental Sciences, PMAS Arid Agriculture University, Rawalpindi, Pakistan
[3]Department of Entomology, University of Poonch, Rawalakot, Azad Jammu and Kashmir, Pakistan
[4]Fareed Biodiversity Conservation Centre, Department of Agricultural Engineering, Khawaja Fareed University of Engineering and Information Technology, Rahim Yar Khan, Punjab, Pakistan
[5]Department of Plant Protection, Faculty of Agricultural Sciences, Ghazi University D. G. Khan
[6]Department of Biological Sciences, Faculty of Science, King Abdulaziz University, Jeddah 21589, Saudi Arabia
[7]Plant Biology Research Group, Department of Biological Sciences, Faculty of Science, King Abdulaziz University, Jeddah 21589, Saudi Arabia

Received:
November 01, 2023
Accepted:
January 05, 2024
Published Online:
February 15, 2024

Abstract

Bumble bees are among the insects that play a significant role in the pollination of several agricultural crops, fruits, vegetables, and wild flowering plants. Climate change has been discussed as a prospective threat to the biodiversity of these pollinators in different parts of the planet during the next several decades. As a result of expected climate change circumstances, a number of studies have determined that the distribution range of bumble bees will alter, with some species becoming extinct and majority of them relocating to the higher mountainous areas. Numerous countries around the globe have developed conservation measures for these ecologically and economically significant organisms. In Pakistan, *Bombus haemorrhoidalis* (Hymenoptera: Apidae) is more likely to be used as a pollinator in greenhouse vegetable production, as compared to other documented species. Our research aimed to find moderately and highly favorable locations for *B. haemorrhoidalis* in 2050 and 2070 based on two representative concentration pathways (RCP4.5 and RCP8.5) using Maxent. Five key contributing variables including Bio1 (Annual Mean Temperature), Bio12 (Annual Precipitation), Bio14 (Precipitation of Driest Month) and Bio18 (Precipitation of Warmest Quarter) along with 52 occurrence record of the species were utilized in the modeling procedure for determining potential distribution of *B. haemorrhoidalis.* Performance of the model was assessed by calculating the area under the curves (AUC), the partial ROC, the omission rates (E=5%), and the AICc (Model complexity). Regularization multiplier of finally selected model was 2. Based on the results of the Jackknife test, it was determined that only four climatic factors, namely Bio4, Bio12, Bio14 and Bio18 contributed 89.0% to the prediction of the species' prospective distribution. The results indicated that highly suitable distribution areas of this species would be concentrated in upper the mountainous areas of Pakistan under the influence of climate change. The suitability of its habitat, however, will decrease under the forecasted climatic conditions of future scenarios (RCP 4.5 and RCP 8.5) for 2050 and 2070. According to the findings, the area that is anticipated to be moderately suitable will shrink by 320.492083 km^2between the years 2050 and 2070 under RCP 4.5 (70), as compared to RCP 4.5. (50). In the same pattern, according to RCP 8.5 (70), it would shrink by a total of 260.764698 km^2 as compared to RCP 8.5. (50). A similar pattern would be observed for forecasted highly suitable areas, which would shrink by a total of 2492.820215 km^2 under RCP 4.5. (70) compared to RCP 4.5 (50), and by a total of 1363.441658 km^2 under RCP 8.5 (70) in contrast to RCP 8.5. (50). Results indicated that suitable areas for this species would decrease during two scenarios of year 2050 and 2070. This species would leave many areas of its current distribution under the influence of climate change and move upward towards upper mountainous areas of Azad Kashmir, Gilgit Baltistan and Khyber Pakhtunkhwa. Based on the results of our studies, Government along with other stakeholders of bee pollination may develop climate mitigation strategies to conserve pollination services of *B. haemorrhoidalis* on a sustainable basis. More extensive surveys are needed along with other tools of remote sensing for more reliable predictions.

**Corresponding author email:*
imranbodlah@gmail.com

Keywords: *Bombus haemorrhoidalis*, Habitat suitability, Environmental predictors, Maxent, Climate change, Pakistan

How to cite this:
Bodlah I, E Fareen AG, Sheik UAA, Bodlah MA, Bibi R, Alharby HF, Al-Solami HM, Alkenani NA and Al-Ghamdi AG. Habitat modelling of *Bombus haemorrhoidalis* Smith (Hymenoptera) under future projected climatic conditions in Pakistan. Asian J. Agric. Biol. xxxx(x): 2023300. DOI: https://doi.org/10.35495/ajab.2023.300

Introduction

Global biodiversity is threatened by climate change, which affects species and ecosystems. Rising sea levels, shifting precipitation patterns, and rising temperatures cause habitat loss and fragmentation (IPCC, 2021). The IPCC warns that animals that cannot adapt or move may have trouble finding suitable homes. Several species are changing their ranges to locate better conditions. Climate change has major effects on insect species, habitats and culture. Temperature and precipitation affect insect behaviour, distribution, and life cycles (Warren et al., 2021). Due to their vulnerability to environmental changes, insects are changing their geographic distribution and phenological events, including emergence dates and seasonal activity (Bennie et al., 2013). Changes to ecological connections can affect pollination, herbivory and decomposition (Vanbergen and Initiative, 2013).

Bumble bees (Apidae: Hymenoptera) are important pollinators with approximately 250 species worldwide (Williams et al., 2008), distributed across North and South America, Asia and Europe (Hines, 2008). They are pollinators of wild flowers especially in alpine environments (Kevan and Baker, 1983; Yu et al., 2012) and of cultivated fruits, spices and crops like tomato, pepper, cucumber, blueberry, cranberry, cucumber, strawberries etc. grown under protected environment (Abak et al.,1997; Kwon and Saeed,2003; Mackenzie, 2009). Their external morphology (Body size and thick body hairs), speed of pollination, wing vibration to burst the pollen sacs and foraging ability at low temperature, make them efficient pollinators in natural and agricultural ecosystems (Javorek et al., 2002; Abrol, 2012; Williams et al., 2014). On the commercial scale, various species of these bees are being used in pollination in various parts of the world (Velthuis and Van Doorn, 2006; Klein et al., 2007). *B. haemorrhoidalis* is the only bumble bee species reared on small scale and experimented for its usefulness in pollination of crops in neighboring countries of Pakistan and India (Dayal and Rana, 2004; Thakur et al., 2005; Sowmya et al., 2015). In Pakistan, various studies (Sheikh et al., 2014; Imran et al., 2017) have been conducted on this bee for its probable utilization in pollination services under greenhouse system.

Bumble bees have been discussed to be in decline in various parts of the world due to a variety of reasons like loss of suitable habitat (Hoiss et al., 2012;Kerr et al., 2015;Rasmont et al., 2015); modification in agricultural practices and land use (Carvell et al,2006; Cameron et al., 2011;Rundlöf etal.,2015;Jacobson et al., 2018;Prestele et al.,2021); parasites and pathogens (Meeus et al., 2011;Cameron et al., 2011;Goulson et al., 2015;McNeil etal.,2020; Plischuk etal.,2017); lethal and sub lethal effects of pesticides (Phelps et al.,2018;Lämsä et al., 2018; Banks et al., 2020) and climate change effects (Kerr et al., 2015;Soroye etal., 2020;Cameron and Sadd, 2020;Martínez-López et al.,2021). A number of studies concluded expansion, reduction or shifting of their range in various parts of the world as a result of future variations in different environmental drivers. Under future climatic situations, they are expected to either expand their range, become less suitable in distribution, or move up in altitude in various biogeographic regions of the world, including Europe, North America, East Asia, and South America (Hoiss et al., 2012; Kerret al., 2015; Rasmont et al., 2015). Species distribution modeling (SDM) has been used as a powerful tool in various studies to determine distribution of various bumble bees (Kadoya et al., 2009; Martins and Melo, 2010; Bartomeus et al.,2013; Rasmont et al., 2015; Kerr et al., 2015; Martinet et al., 2015; Biella et al., 2017) in different countries under projected future climatic scenarios. Sirois-Delisle and Kerr (2018) used MaxEnt model to determine potential shifts in North American bumblebee distribution for future scenarios. Koch et al. (2019) applied MaxEnt to determine distribution of bumble bees in the Pacific Northwest and reported a reduction in their habitat suitability. Krechemer and Marchioro (2020) used

MaxEnt model to predict past, present and future distributions of six *Bombus* species found in South America and indicated loss of climatically suitable areas under future climate scenarios. Recently, Martínez-López et al. (2021) determined a reduction in potential distribution of bumble bees Mesoamerica region under future projected scenarios. *B. haemorrhoidalis*, an indigenous Bumble species of Pakistan, initial basic studies on its laboratory rearing has been already done. This species may be utilized in future as a successful pollinator in green house system in Pakistan. Keeping in view this situation, these studies were planned for predicting the distribution of *B. haemorrhoidal is* under current and future scenarios in Pakistan.

Material and Methods

The current study was conducted in the Biosystematics Laboratory, Department of Entomology, PMAS Arid Agriculture University, Rawalpindi, Pakistan during 2022-2023. Research funds for field surveys and experimentation were provided by Ministry of Education and King Abdulaziz University, DSR, Jeddah, Saudi Arabia.

Study region: Azad Kashmir, Gilgit Baltistan, Punjab, Khyber Pakhtunkhwa, and Islamabad are the parts of Pakistan that make up the study region (Figure 1).

Bumble bee data collection and processing

This study uses occurrence data of *B. haemorrhoidalis* retrieved from relevant online database (Global Biodiversity Information database www.gbif.org), published records (Sheikh et al., 2014) and field surveys (Done by first three authors during various periods of the study). Data (52 occurrences) in the form of geographical coordinates were uploaded in NICHE TOOL BOX for further processing. Spatial autocorrelation between occurrences was removed by filtering the data in such a way two occurrences that fall two kilometers to each other were excluded. This process reduced occurrences to 45. Out of these, the ArcGIS software was used to process 40 of the occurrences, and a buffer of seventy kilometers was created around all of the locations of occurrence in order to set the model calibration area (M) (Fig. 2) (Ashraf et al., 2018). The five occurrences left after those were used as independent data.

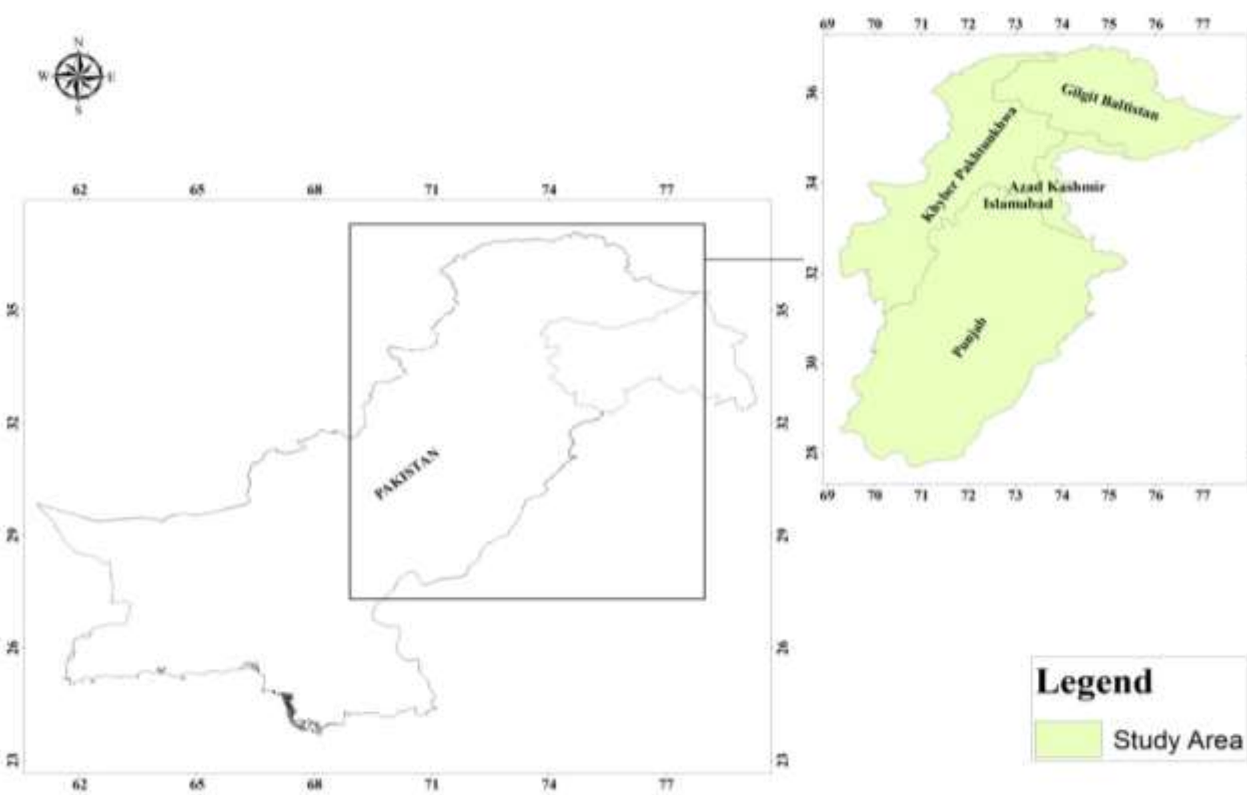

Figure-1. Study area

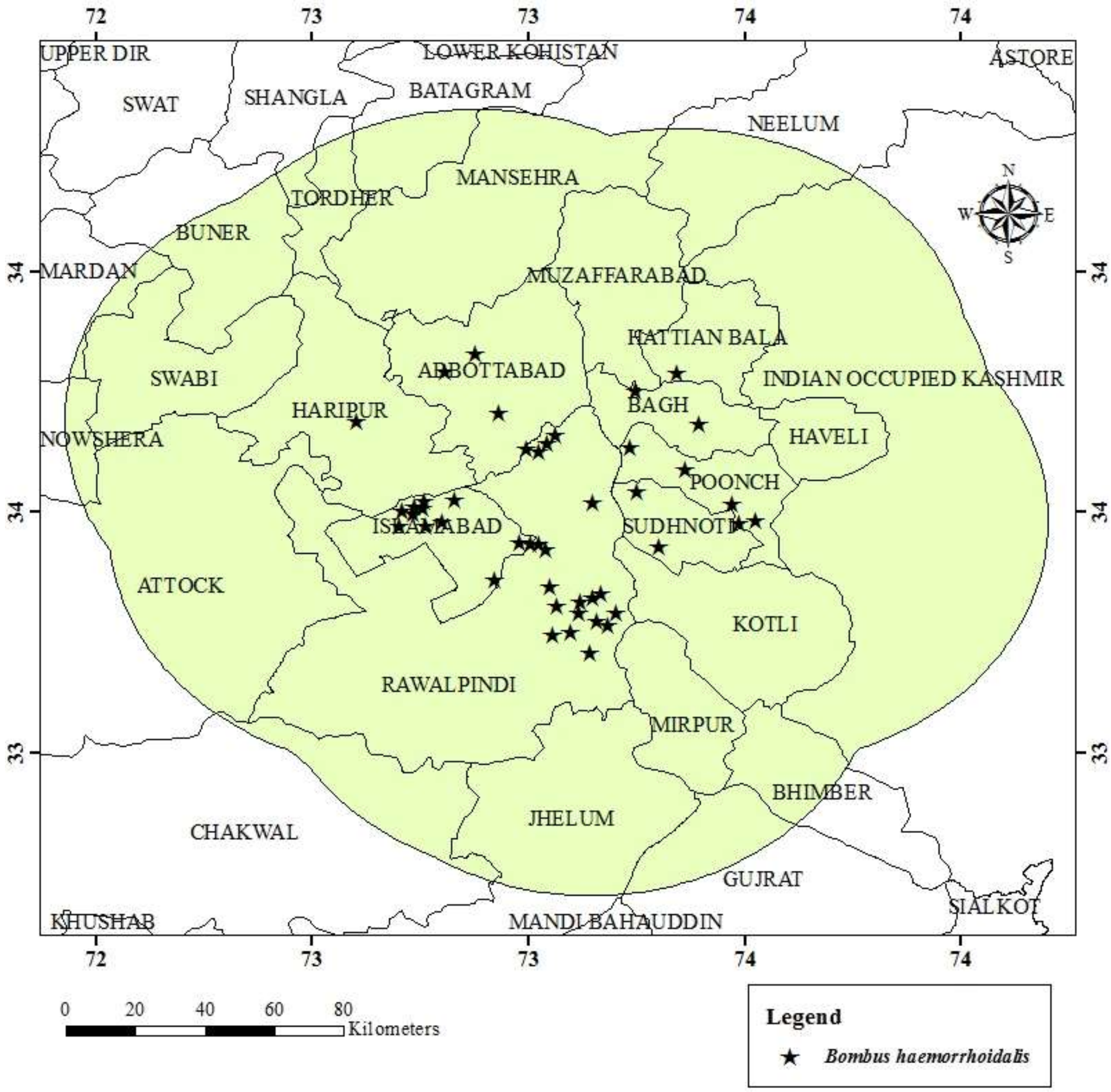

Figure-2. Occurrence points of the species along with buffer of 70 kilometers (M)

Environmental variables selection determining the Bee distribution

In order to analyze the distribution and appropriateness of the *B. haemorrhoidalis*, data for 19 climatic factors were acquired from an official source (The World Clim website; Global Climate Data). World Clim is a worldwide climate layers dataset (Hijmans et al., 2005) that represents average conditions between 1950 and 2000. Within ArcGIS, raster layers were calibrated and then transformed to Ascii. Based on our past information from the research of María et al. (2019), we used the SDM tool box to eliminate pairings of variables with a Pearson's correlation of less than 0.90 in order to narrow down the set of candidates for use in species prediction (Table 1). This approach reduces the possibility of overfitting in the model's prediction outputs. In the end, 9 variables were chosen for inclusion in the model: Bio1 (Annual Mean Temperature), Bio4 (Temperature Seasonality), Bio7 (Annual Range of Temperature), Bio8 (Mean Temperature of Wettest Quarter), Bio12 (Annual Precipitation), Bio13 (Precipitation of Wettest Month), Bio14 (Precipitation of Driest Month), Bio15 (Precipitation Seasonality), and Bio18 (Precipitation of Warmest Quarter). Finally, five of these variables were utilized to estimate the distribution of *B. haemorrhoidalis*: Bio1 (Annual Mean Temperature), Bio4 (Temperature Seasonality), Bio12 (Annual Precipitation), Bio14 (Precipitation of Driest Month), and Bio18 (Precipitation of Warmest Quarter).

Table-1. Pearson's correlation among the environmental predictors, used in habitat suitability modelling of *Bombus haemorrhoidalis*

SPECIES	bio_1.asc	bio_2.asc	bio_3.asc	bio_4.asc	bio_5.asc	bio_6.asc	bio_7.asc	bio_8.asc	bio_9.asc	bio_10.asc	bio_11.asc	bio_12.asc	bio_13.asc	bio_14.asc	bio_15.asc	bio_16.asc	bio_17.asc	bio_18.asc	bio_19.asc
bio_1.asc	1	0.9546411	0.960294	-0.069906	0.9917646	0.9653628	0.800438	0.8962889	0.9956471	0.9955018	0.9958395	-0.25912	0.4461606	-0.649568	0.8021852	0.3548858	-0.622177	0.1990483	-0.471214
bio_2.asc	1	1	0.9022593	0.1970725	0.9815486	0.8520793	0.9295004	0.8769836	0.9389369	0.9761213	0.9276779	-0.352772	0.3855265	-0.715643	0.8285383	0.2835354	-0.694732	0.143924	-0.527654
bio_3.asc	1	1	1	-0.19142	0.9370093	0.9670785	0.6831491	0.790561	0.9652661	0.9484984	0.9684485	-0.217752	0.4159091	-0.524734	0.6997831	0.3409356	-0.497501	0.1531635	-0.369081
bio_4.asc	1	1	1	1	0.0407316	-0.313997	0.5027628	0.0216528	-0.121273	0.0179244	-0.159427	-0.418102	-0.229147	-0.380043	0.1970441	-0.266217	-0.413246	-0.294103	-0.377981
bio_5.asc	1	1	1	1	1	0.9275381	0.8679936	0.9089832	0.9826935	0.9983091	0.9782024	-0.29262	0.4301278	-0.683994	0.8188147	0.3320865	-0.657511	0.1955043	-0.493192
bio_6.asc	1	1	1	1	1	1	0.6195128	0.8261845	0.9742086	0.9400016	0.9837409	-0.146578	0.4610217	-0.505078	0.6911705	0.3884301	-0.471884	0.2268623	-0.3429
bio_7.asc	1	1	1	1	1	1	1	0.8114894	0.7696314	0.8478819	0.7475326	-0.419865	0.2908864	-0.765574	0.8014916	0.1814115	-0.754052	0.1092078	-0.580297
bio_8.asc	1	1	1	1	1	1	1	1	0.8882853	0.8983894	0.8847185	-0.128018	0.5288705	-0.614699	0.8050009	0.4256532	-0.577878	0.3869842	-0.390495
bio_9.asc	1	1	1	1	1	1	1	1	1	0.9873428	0.9963346	-0.225467	0.4626956	-0.613488	0.7868143	0.3744498	-0.583617	0.218743	-0.432454
bio_10.asc	1	1	1	1	1	1	1	1	1	1	0.9838598	-0.292742	0.4226734	-0.674342	0.8091267	0.327751	-0.648378	0.1765194	-0.489954
bio_11.asc	1	1	1	1	1	1	1	1	1	1	1	-0.21756	0.4606858	-0.60498	0.7716342	0.373759	-0.574486	0.2251239	-0.427195
bio_12.asc	1	1	1	1	1	1	1	1	1	1	1	1	0.6571029	0.7858732	-0.167476	0.7271316	0.8118842	0.7464828	0.8720357
bio_13.asc	1	1	1	1	1	1	1	1	1	1	1	1	1	0.1041024	0.6151819	0.9872917	0.1370009	0.8018411	0.2874612
bio_14.asc	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-0.685245	0.2109625	0.9905415	0.2987844	0.9373815
bio_15.asc	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.5339107	-0.669219	0.2698368	-0.539898
bio_16.asc	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.2445102	0.794106	0.3710448
bio_17.asc	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.3500262	0.9570551
bio_18.asc	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.5019051
bio_19.asc	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Settings of the Maxent model

The following occurrence data and climatic factors were used in the Maxent model run. We used a random distribution to split the occurrence data (40 points) into 10 testing and 30 training points for model calibration, plus 5 occurrences as independent data for testing the models on our own. Bioclimatic variables were randomly split into three groups (Set1, Set 2, and Set 3) and treated as M variables. In order to execute Maxent, the R package was used. Initially, we utilized the Kuenm and Kuenmceval functions to build our models. By following methodology of Cobos et al. (2019), we utilized a regularization multiplier of 17 and 29 different feature classes to generate candidate models. To determine which models performed best, we used partial ROC (with 500 iterations), omission rates (E=5%), and AICc (Model complexity). The Kuenmceval function was utilized for assessment and best candidate model selection. Both the package's kuenm mod and kuenmfeval functions were used to evaluate and choose the final model. The default settings were used for Maxent's 500 iterations and 10 random replicate studies.

Transfer of calibration area model results

The provinces; KPK, AJK, Gilgit Baltistan, Punjab and Capital territory of Islamabad were used to extrapolate future climate change scenarios using the RCPs 4.5 and 8.5 from the 5th assessment report of the Intergovernmental Panel on Climate Change (IPCC). CMIP5 data was used as it is being still used in real field data research (Khwarahm, 2023) and considered as more reliable in field studies.

Three general circulation models (GCMs) had their bioclimatic data layers compared for this study (HadGEM2-AO, HadGEM2-ES and BCC-CSM1-1). Using ArcGIS, we studied these layers as G variables. There were two potential futures projected by the model. Finally, we investigated a total of 12 possible model transfers into the future based on the results from 3 GCMs, 2 time periods, and 2 RCPs. In order to prepare maps and calculate distribution area for *B. haemorrhoidalis* in the present and the future, results from Maxent were imported into ArcGIS software and processed.

Development of binary models

The connection between the calibration points and the raw model output of maxent was used to construct binary models. ArcGIS software was used to import the raw data and calibrate the data. To determine cutoffs, we used ArcGIS's extract values to point feature, with the highest cutoffs corresponding to omission error rates of 0%, 5%, and 10% (Ashraf et al., 2018). For the purposes of quantifying species distribution ranges under climate change scenarios, the suitability maps were classified as either high (0.28-1), moderate (0.26-0.28; E = 5-10%), or low (0-0.26; E = 0-5%).

Results

Candidate models

All possible permutations of 17 regularization multiplier settings, 29 feature class permutations, and 3 sets of environmental variables were tried out among 1479 candidate models. Statistical significance (Partial ROC), omission rates (OR), and the Akaike information criterion adjusted for limited sample sizes were used to evaluate model performance (AICc). There were 1465 statistically significant models, and 1 met both the omission rate and the AICc cutoff. The final model map was prepared using an average file of this model. The 5% cutoff for the best model performance (Omission rates). This species is currently found in the following locations in Pakistan: Abbottabad, Muzaffarabad, HattianBala, Bagh, Poonch, Sudhnoti, Kotli, Mirpur, Rawalpindi, Islamabad, Haripur, some areas of Mansehra, and limited locations in the districts of Jhelum, Buner, Swabi, Chakwal, and Attock, as shown on the map of calibration area (Fig. 3), which was predicted using maxent.

Percentage contribution of predictor variables

After running Maxent, the Jackknife test revealed the relative contribution of each bioclimatic variable to *B. haemorrhoidalis* prediction (Fig 4). Bio18 (Precipitation of warmest quarter), Bio4 (Temperature seasonality), Bio14 (Precipitation of Driest Month), Bio12 (Annual precipitation), and Bio1 (Annual Mean Temperature) were the main variables for predicting potential distribution of *B. haemorrhoidalis*, contributing 39.3%, 27.3%, 22.7%, 7.2%, and 3.6%, respectively, to the current geographical distribution. Among these factors, Bio1 has the smallest impact. These three variables (Bio18, Bio4, and Bio14) together accounted for 89.3% of the total variance explained by the model, making them the most important in predicting where a given species would be found. Related to permutation, variables namely Bio 18, Bio 4, and Bio 14are the important variables (Figure 5).

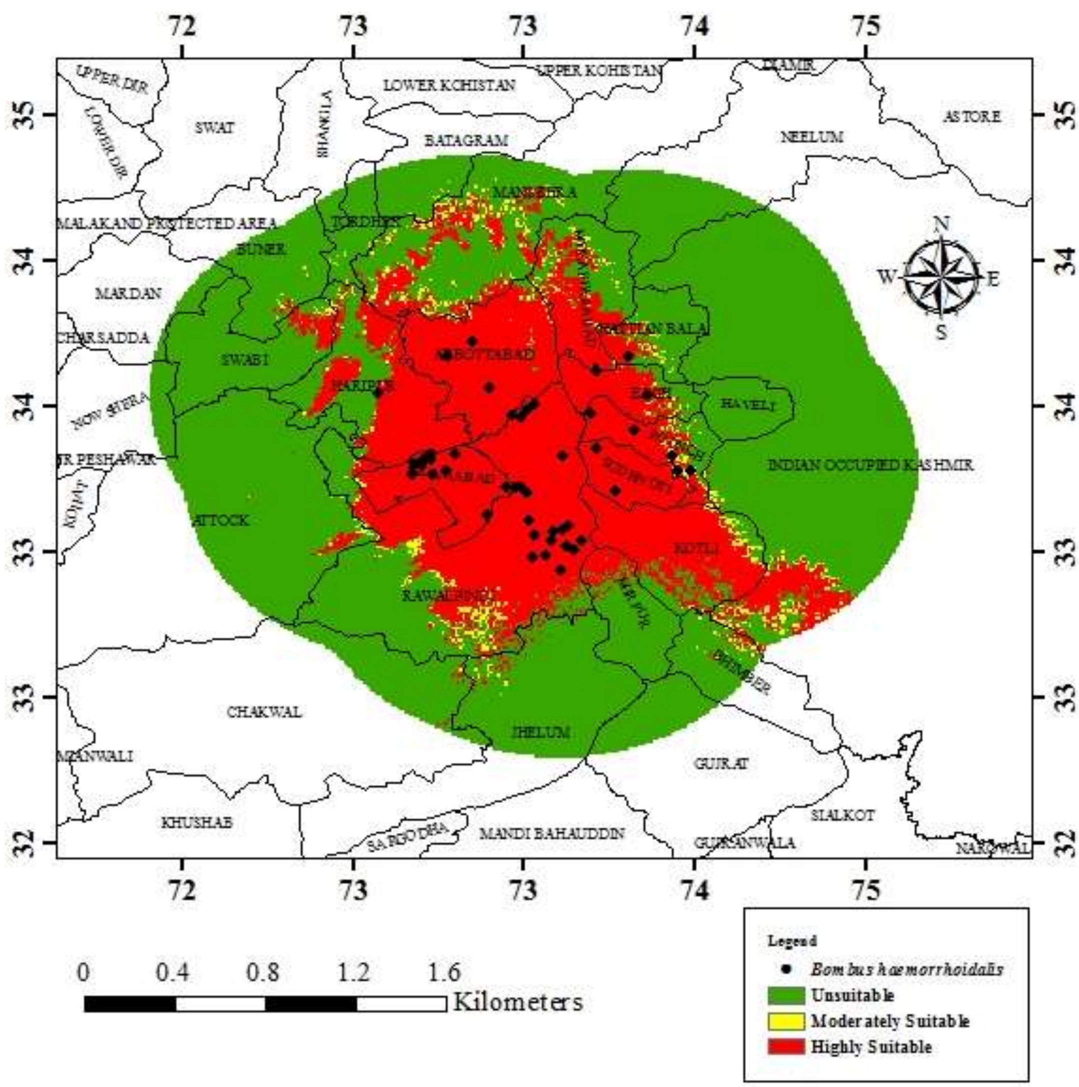

Figure-3. ***Bombus haemorrhoidalis*** **distribution predicted by Maxent in calibration area**

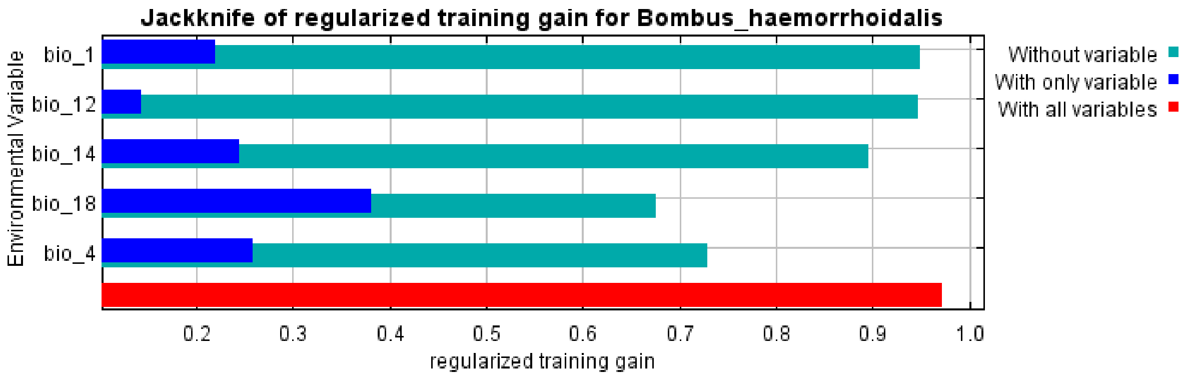

Figure-4. Gains of variables (Jackknife test) in the maxent model for *Bombus haemorrhoidalis*

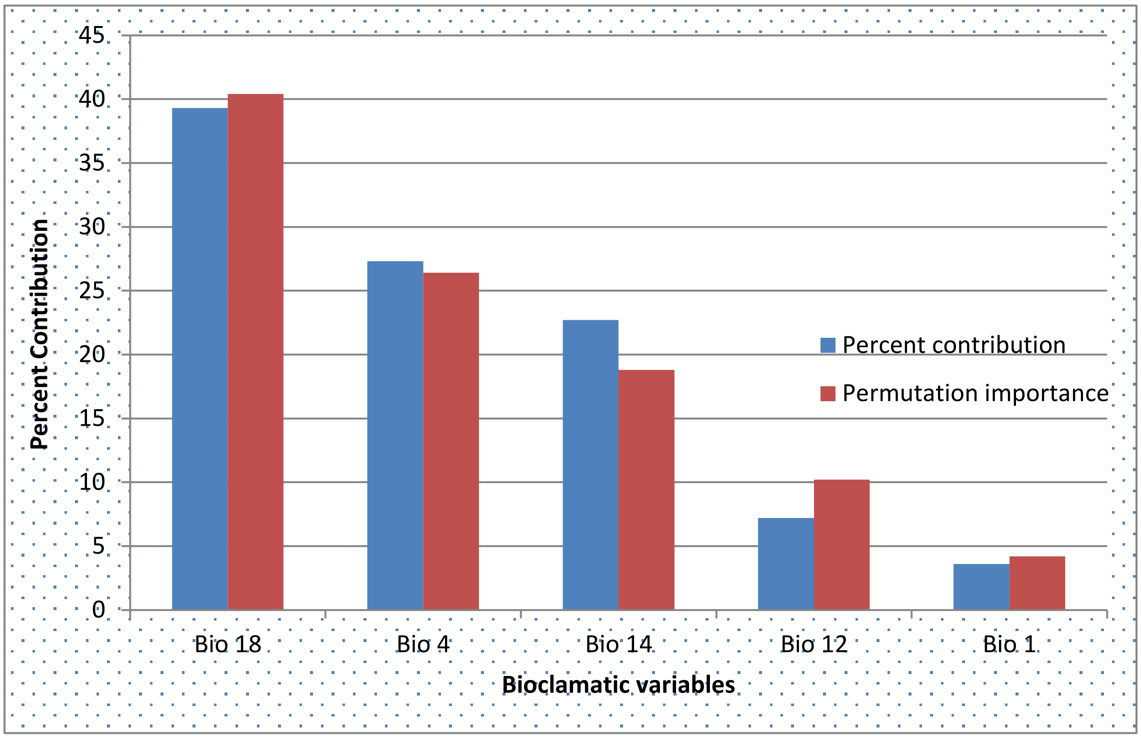

Figure-5. Percent contribution of environmental variables towards MaxEnt model

Model performance evaluation based on AUC values

Areas under receiver operating characteristic curves (AUC) tests for both historical data and forecasts have been found to be 0.988 when the maximum entropy principle of Maxent is used (Fielding and Bell, 1997; Van-der-Putten et al., 2010). As shown by our area under the curve (AUC) calculation, the results are statistically significant (0.914) (Figure 6).

Current habitat suitability of *B. haemorrhoidalis*

The Maxent model provided the current predicted distribution of *B. haemorrhoidalis* under the influence of bioclimatic factors (Fig.7). According to our model predictions, In Pakistan the predicted highly suitable areas are mainly distributed in Abbottabad, Muzaffarabad, Hattian Bala, Bagh, Poonch, Sudhnoti, Kotli, Mansehra, Mirpur, Rawalpindi, Islamabad, Haripur, Narowal, Chakwal, some areas of Swabi, Khushab, Mirpur, Jhelum and very limited areas of Batagram, Buner, Attock, Bhimber, and Karak. While limited moderately suitable areas are concentrated in Narowal, Bhimber, Chakwal, Karak, Attock, Jhelum, Rawalpindi, Islamabad, Swabi, Khushab, Mansehra, Haripur, Hattian Bala, Bagh, Poonch and Muzaffarabad.

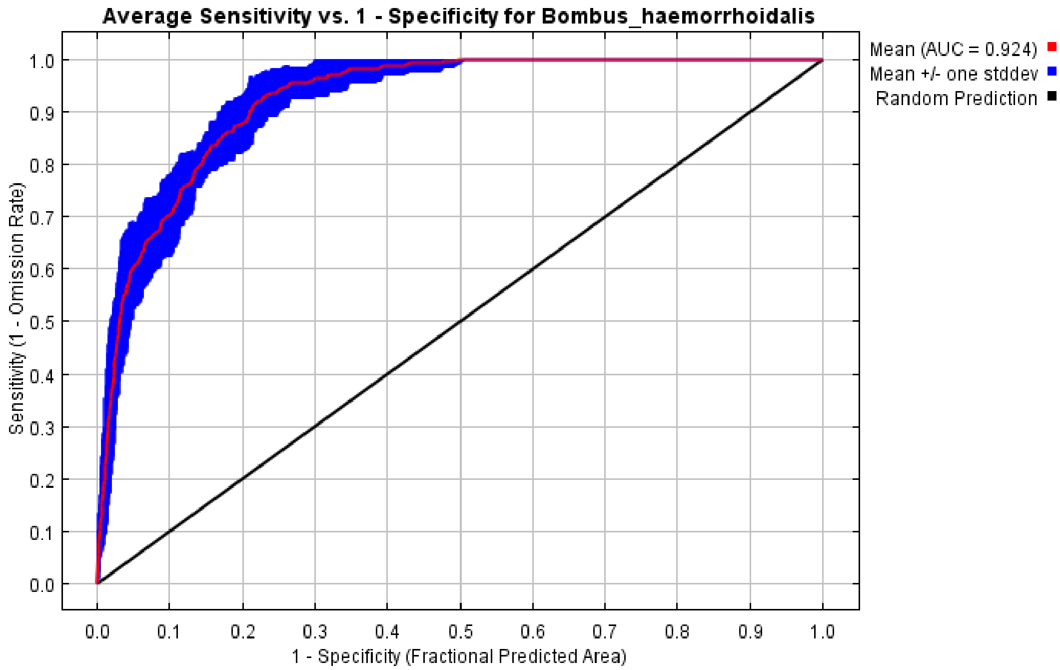

Figure-6. Average sensitivity vs. 1- specificity curve for *B. haemorrhoidalis*

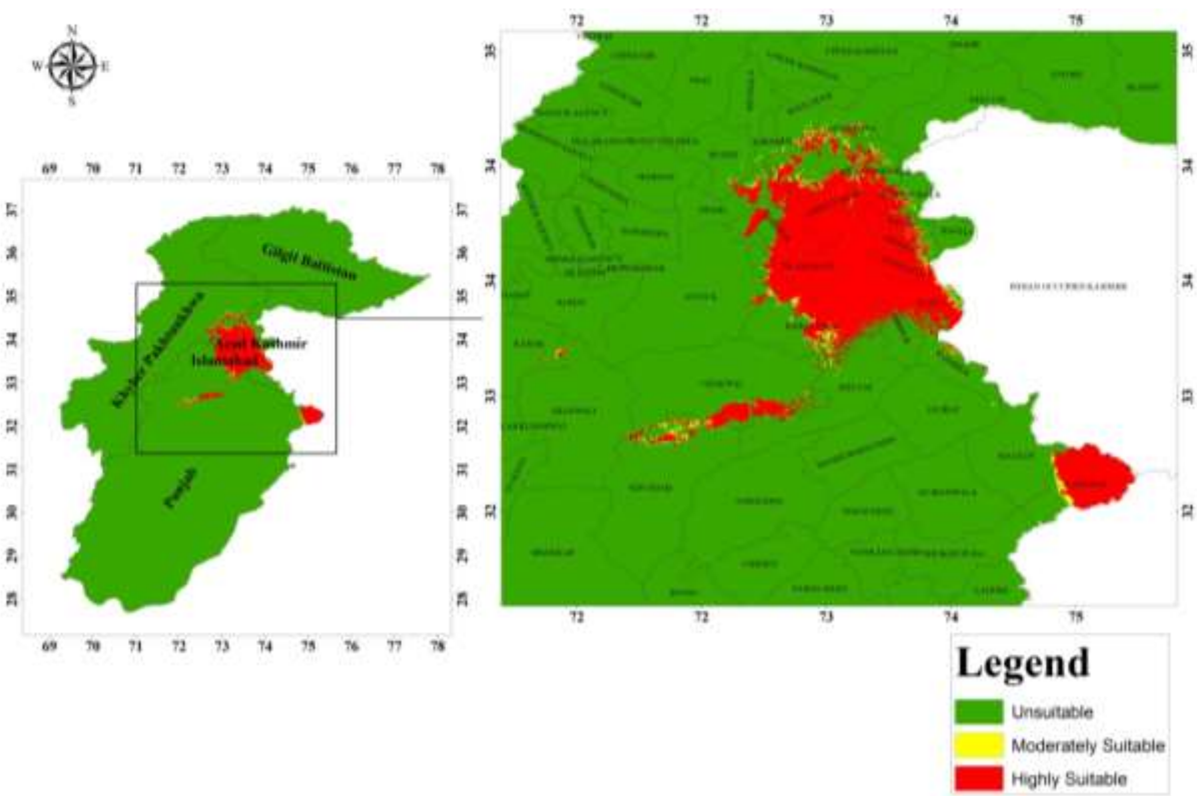

Figure-7. Maxent model's current (1970-2000) estimated distribution of *Bombus haemorrhoidalis* in Pakistan

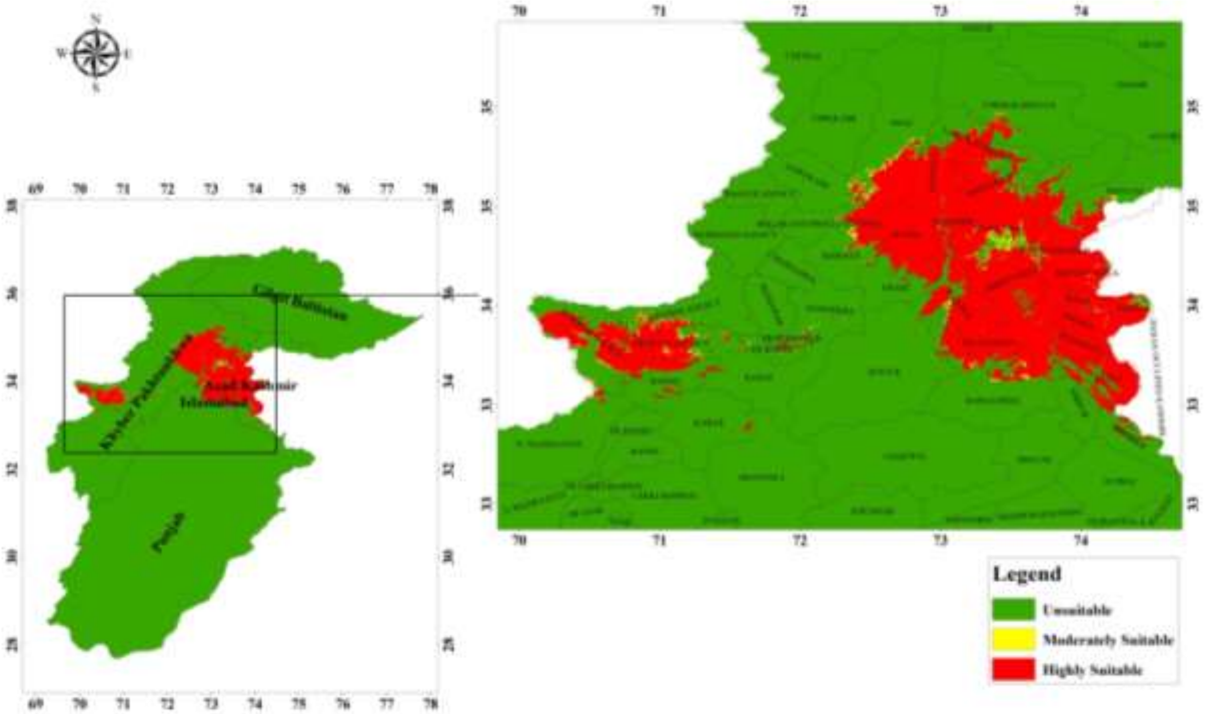

Figure-8. Future estimated distribution of *B. haemorrhoidalis* (RCP 4.5, 2050) by Maxent in Pakistan

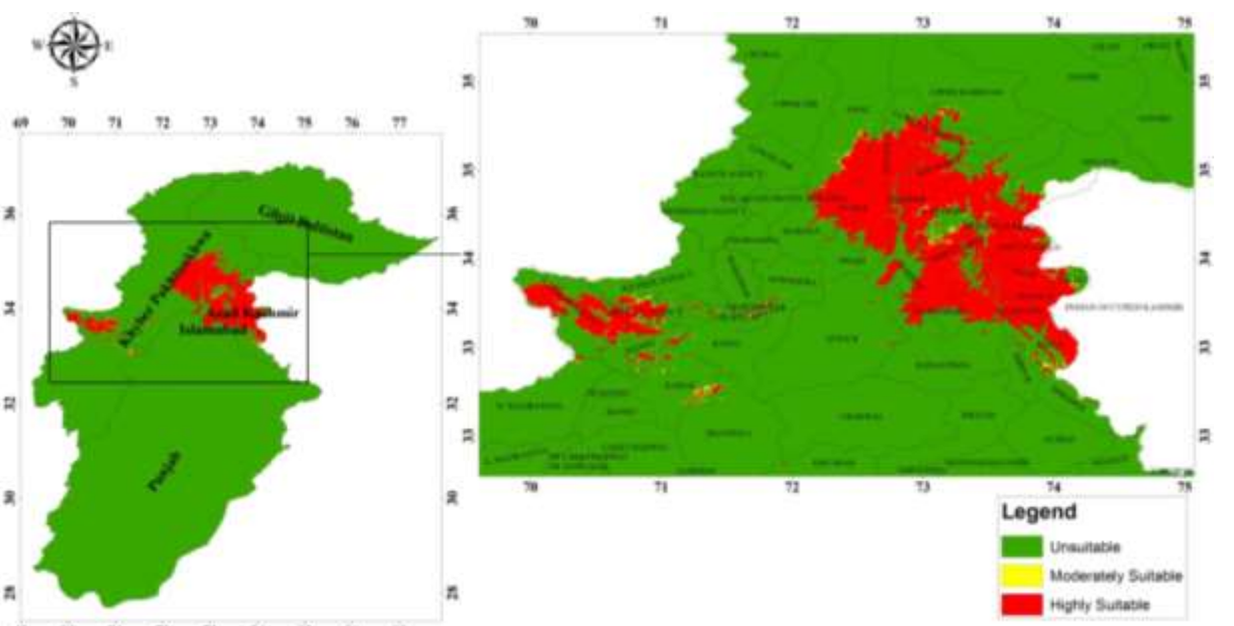

Figure-9. Future estimated distribution of *B. haemorrhoidalis* (RCP 8.5 2050) by Maxent in Pakistan

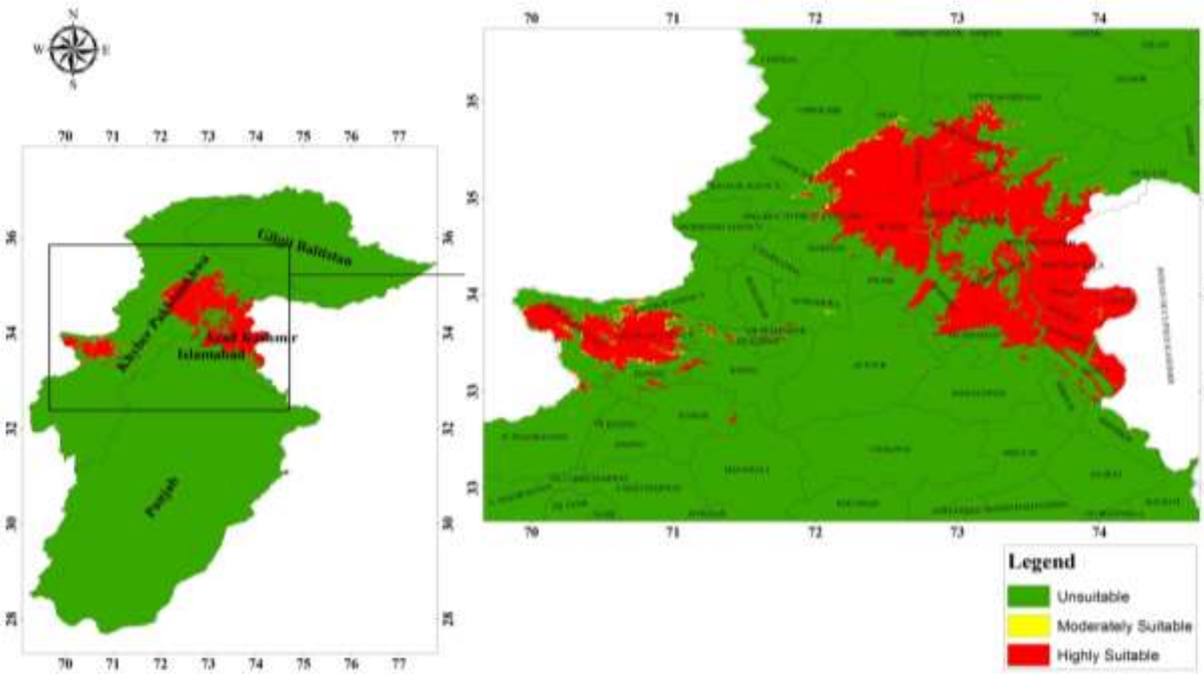

Figure-10. Maxent's forecasted distribution of *B. haemorrhoidalis* (RCP 4.5, 2070) in Pakistan

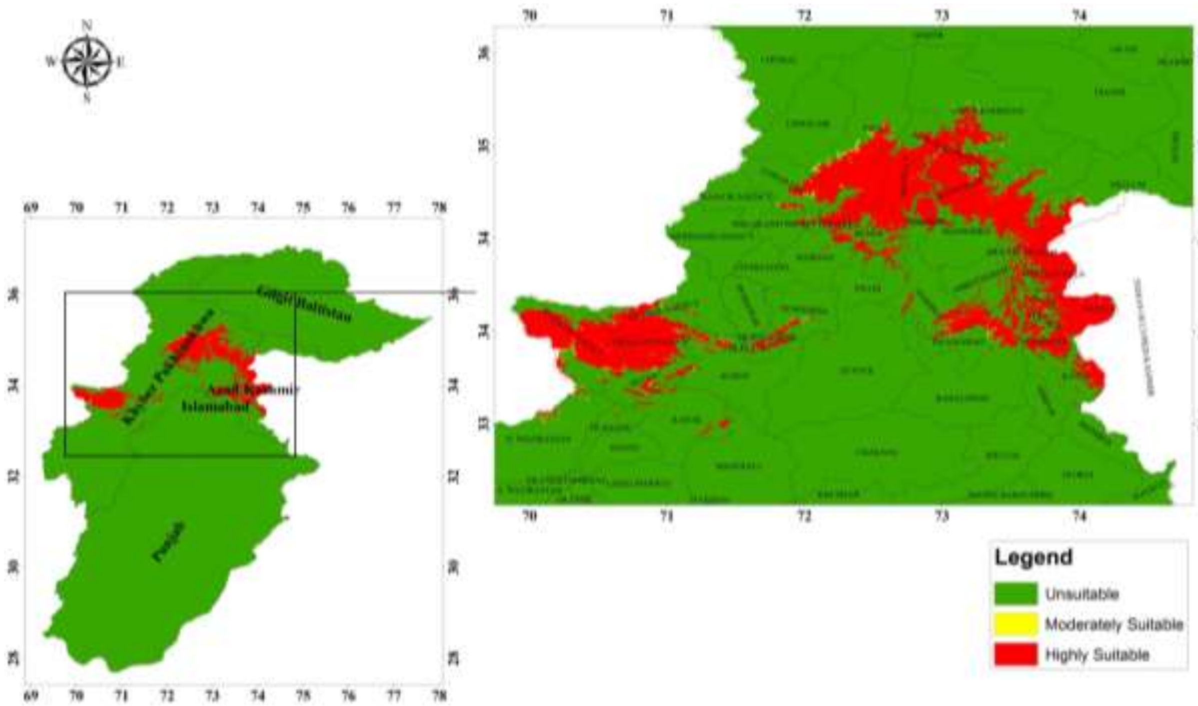

Figure-11. Maxent's forecasted distribution of *B. haemorrhoidalis* (RCP 8.5, 2070) in Pakistan

Future habitat suitability of *B. haemorrhoidalis*

According to the predictions of the model of 2050 (RCP 4.5), highly suitable areas for the species would mainly be Rawalpindi, Islamabad, Haripur, Abbottabad, Buner, Bagh, Poonch, Sudhnoti, Kotli, Hattian Bala, Muzaffarabad, Mansehra, Swat, Neelum, Batagram, Lower Kohistan, Shangla, Haveli, Kurrum Agency, Orakzai Agency, Khyber Agency and Hangu. Some areas of Swabi, Mardan, Malakand protected areas, Bhimber, upper Kohistan and very limited areas of N. Wazaristan, Karak, Attock, FR Kohat, FR Peshawar, Nowshera and Kohat would be highly suitable for this species (Fig.8). Moderately suitable habitats would be district Rawalpindi, Islamabad, Haveli, Neelum, Mansehra, Muzaffarabad, Haripur, Swat, Mardan, Malakand protected areas, FR Peshawar, FR Kohat, N. Wazaristan, Kurrum Agency, Orakzai Agency, Khyber Agency, Lower Kohistan, upper Kohistan and Batagram. Under projected climate of RCP 4.8 (2050), district Islamabad, Sudhnoti, Poonch, Bagh, Haveli, HattianBala, Abbottabad, Haripur, Mansehra, Muzaffarabad, Turdher, Shangla, Batagram, Lower Kohistan, Kurrum Agency and Orakzai Agency (Fig.9). Some areas of district, Swabi, Mardan, Rawalpindi, Karak, Khyber Agency, Hangu, upper Kohistan and very limited areas of Bhimber, Attock, Nowshera, FR Kohat, FR Peshawar, N. Wazaristan and Kohat would be highly suitable for this species. Karak, Hangu, Khyber Agency, Kohat, Nowshera, FR Kohat, FR Peshawar, Batagram, Lower Kohistan, upper Kohistan, Swat, Mardan, Shangla, Muzaffarabad, Neelum and Haripur would be the representative of moderately suitable habitats for the species.

According to the predictions of the model by 2070 (RCP 4.5), highly suitable areas would include Kotli, Rawalpindi, Islamabad, Haripur, Abbottabad, Buner, Bagh, Poonch, Sudhnoti, Haveli, HattianBala, Mansehra, Muzaffarabad, Neelum, Buner, Turdher, Shangla, Batagram, Lower Kohistan, Kurrum Agency and Orakzai Agency and Khyber Agency (Fig.10). Some areas of Swabi, Mardan, upper Kohistan, Mardan, Lower Dir and limited areas of Malakand protected areas, FR Kohat, FR Peshawar, Karak, N. Wazaristan and Nowshera would also representing highly suitable habitats for this species. Very limited areas of Districts, N. Wazaristan, Hangue, Kurrum Agency and Orakzai Agency and Khyber Agency, FR Kohat, FR Peshawar, Neelum, upper Mansehra, Batagram, Lower Kohistan, upper Kohistan, Swat, lower Dir, Shangla, Nowshera and areas of Malakand protected would moderately suitable. By 2070 (RCP 4.5), highly suitable districts would include Kotli, Rawalpindi, Islamabad, Sudhnoti, Bagh, Poonch, Haveli, Hattian Bala, Mansehra, Muzaffarabad, Haripur, Abbottabad, Turdher, Batagram, Shangla, Swat, Neelum, Buner, lower Dir, upper Koistan and lower Koistan (Fig.11). Some areas of Islamabad, Swabi, Mardan, Hangue, upper Dir and very limited areas of Malakand protected areas, FR Kohat, FR Peshawar, Karak and N. Wazaristan would also be moderately suitable. Moderately suitable areas would be N. Wazaristan, Kurrum Agency and Orakzai Agency, Khyber Agency, FR Kohat, FR Peshawar, Nowshera, upper Koistan, Lower Kohistan, Neelum, Mansehra, Shangla, Batagram and Swat.

Area calculation of current and future habitat suitability

According to the average projections of our models, the moderately appropriate area in 2050 will decline by 135.282299 km^2 (RCP 4.5) and 309.612119 km^2 (RCP 8.5) compared to its current distribution (Table 2). In 2050, highly suitable areas would expand by 9827.779597 km^2 (RCP 4.5) and 5182.693655 km^2 (RCP 8.5) relative to their current distribution. Comparing the current distribution to that of 2070, it was estimated that moderately suitable regions will decline by 474.906352 km^2 (RCP 4.5) and 570.376817 km^2 (RCP 8.5), while very appropriate areas will grow by 7334.959382 km^2 (RCP 4.5) and 3819.251997 km^2 (RCP 8.5).

According to the projections of two future scenarios for 2050 and 2070 (Table3), the area deemed moderately appropriate would shrink by 320.492083 km^2 under RCP 4.5 (70) compared to RCP 4.5 (50). Similar to RCP 8.5 (70), it would decline by 260,764698 km^2 under RCP 8.5 (70). (50). The anticipated highly suitable area would decrease by 2492.820215km^2 RCP 4.5 (70) compared to RCP 4.5 (50) and by 1363.441658km^2 RCP 8.5 (70) compared to RCP 8.5 (50). (50). It is possible to conclude that appropriate habitats for this species would decline between 2050 and 2070 under two different scenarios. Comparing the years 2050 and 2070, highly and moderately appropriate regions for this species would decrease in 2070 compared to 2050.

Table-2. Comparison between current and future distribution area of *Bombus haemorrhoidalis*

	Suitability Class	Threshold	Current and future distribution area of *Bombus haemorrhoidalis* (km²)					
			Current distribution	Future distribution RCP (4.5)	Change in area	Current distribution	Future distribution RCP (8.5)	Change in area
2050	Unsuitable	0-5	374447.286596	364735.051565	9712.235031	374447.286596	369556.756211	4890.530385
	Moderately Suitable	5-10	930.680734	795.398435	135.282299	930.680734	621.068615	309.612119
	Highly Suitable	>10	14210.68353	24038.463127	-9827.779597	14210.68353	19393.377185	-5182.693655
2070	Unsuitable	0-5	374447.286596	367550.346832	6896.939764	374447.286596	371177.001028	3270.285568
	Moderately Suitable	5-10	930.680734	474.906352	455.774382	930.680734	360.303917	570.376817
	Highly Suitable	>10	14210.68353	21545.642912	-7334.959382	14210.68353	18029.935527	-3819.251997

Table3: Comparison of RCP (4.5 and 8.5) under projected climatic conditions for year 2050 and 2070

Future distribution area of *Bombus haemorrhoidalis* (km²)							
Suitability Class	Threshold	Future distribution RCP 4.5 (50)	Future distribution RCP 4.5 (70)	Change in area	Future distribution RCP 8.5 (50)	Future distribution RCP 8.5 (70)	Change in area
Unsuitable	0-5 %	364735.051565	367550.346832	-2815.295267	369556.756211	371177.001028	-1620.244817
Moderately Suitable	5-10 %	795.398435	474.906352	320.492083	621.068615	360.303917	260.764698
Highly Suitable	>10 %	24038.463127	21545.642912	2492.820215	19393.377185	18029.935527	1363.441658

Discussion

Results indicated that distribution pattern of this species is dominantly influenced by five bioclimatic variables namely Bio1, Bio 4, Bio12, Bio14 and Bio18, which are different variables of temperature and precipitation. Both of these environmental factors can have a direct impact on bumble bees by killing a lot of overwintering queens or colonies (see, for example, Vesterlund and Sorvari,2014; Oyen et al., 2016) or dampen their vital foraging activities as indicated by Bergman et al. (1996). It has been established that these two parameters influence the mortality and reproductive success of bumble bees both directly and indirectly through modifications to available floral resources. Results from research by Gérard et al. (2020) show that increased temperature ranges during development have negative effects on the pollination effectiveness of *B. terrestris* colonies, as well as on the size and shape of the wings. According to Guiraud et al. (2021), greater temperatures can have detrimental effects on *B. terrestris*, including smaller workers with inferior flight performance, decreased foraging efficiency, and stunted colony growth. The bees' reduced size poses a threat to the colony's ability to gather food and may slow the growth of the colony as a whole. Studies of Miller-Struttmann et al. (2015) and Gérard et al. (2018) concluded that elevated temperature may result in decrease of tongue and body size in workers and queen of some bumble bees and ultimately affecting pollination efficiency and colony development. The study conducted by Kerr et al. (2015) examines the crucial impact of climatic factors on the growth and progress of bumble bee colonies. Based on a comprehensive field survey, the researchers noted that temperature changes had a significant impact on the development and survival rates of bumble bee colonies. Their research reveals a direct relationship between elevated temperatures and enhanced rates of colony expansion in the early phases. Nevertheless, an excessive amount of heat stress can result in a decrease in the effectiveness of searching for food and eventually affect the long-term survival of colonies. Furthermore, the distribution of rainfall greatly influences the amount and accessibility of flowers, hence influencing the capacity of bumble bee colonies to find food and maintain their general well-being. According to the findings of study conducted by Colla et al. (2012), the patterns of rainfall have a major impact on the availability of floral resources, which are essential for optimal development and the viability of colonies. When it comes to anticipating and protecting bumble bee populations in the face of shifting environmental circumstances, having a solid understanding of these climatic factors is absolutely necessary.

From these results of Maxent model, it can be concluded that *B. haemorrhoidalis* would decrease its moderately suitability areas in future as compared to its current distribution and increase its highly suitable areas upwardly in the mountainous areas of Pakistan. However, its habitat suitability would be reduced under projected climatic condition of various scenarios (RCP 4.5 and RCP8.5) of future for 2050 and 2070. Results also indicate that it would undergo habitat losses under projected climatic conditions of various scenarios in addition to the loss of current habitat suitability in comparison to the future. It would undergo habitat losses in its current distribution in comparison with the future in the areas of Chakwal, Khushab, Jhelum, Bhimber, Narowal, Rawalpindi and Islamabad. Similarly habitat losses would also occur by two scenarios of 2070 in comparison to 2050 in the areas of Rawalpindi and Islamabad, Kotli, Haripur, Abbottabad, Mansehra, Swabi, Buner, Muzaffarabad, Turdher, HattianBala, Bagh, Poonch and Batagram. Its distribution range would also expand to various areas of N. Wazaristan, Hangue, Kurrum Agency and Orakzai Agency, Khyber Agency, FR Kohat, FR Peshawar, Neelum, upper Mansehra, Batagram, Lower Kohistan, upper Kohistan, Swat, lower Dir, upper dir, Shangla, Nowshera, areas of Malakand protected, Hattian Bala, Bagh, Abbottabad, Mansehra, Neelum, Swat, Buner, Batagram, Shangla, Nowshera, Mardan and Hangu in future projected climate in comparison to its current distribution. Additionally, there would be a decrease of highly and moderately suitable areas under two scenarios of projected climatic conditions of year 2050 and 2070.

Recent climate change has generated larger and more widespread bumble bee reductions than have been recorded previously, notably in Europe, according to a number of studies that make use of future estimates. Soroye et al. (2020) found that the ranges of 66 bumble bee species from across North America and Europe were negatively affected by climate change, whereas the ranges of another 13 were either unchanged or expanded. In another study, Suzuki-Ohno et al. (2020) found that estimated distribution ranges of five species of bumble bees were reduced in some locations of Japan as a result of increasing temperature induced by global warming.

According to the studies of Rasmont et al. (2015)25 European bumble bee species would lose almost all of their climatically suitable area under projected climatic conditions while 53 species would lose the main part of their suitable area. Biella et al. (2017) modeled *B. alpinus* (Linnaeus, 1758) for Fennoscandia and the Alps and reported a strong altitudinal shift in its distribution. *B. vandykei*, *B. sylvicola*, and *B. bifarius* would undergo habitat loss in the Pacific Northwest under the influence of climate change (Koch et al., 2019). According to studies by Marshall et al. (2020), bumble bees along with their associated plant communities shifted their distribution ranges to higher elevations during two surveys conducted 115 years apart in Pyrenees (Western Europe). Six *Bombus* species found in South America would also lose suitable habitats under future climate scenarios (Krechemer and Marchioro, 2020). Martínez-López et al. (2021) modeled 18 Mesoamerican bumble bee species and their results indicated that all species would undergo a reduction in their potential distribution and habitat suitability due to projected climatic conditions.

Conclusion

It may be concluded from the future predicted maps by Maxent model, future climate change would influence the potential distribution of *B. haemorrhoidalis*. It would leave its current distribution areas and expand its distribution in the upper mountainous areas of Pakistan. Its predicted highly suitable areas would be reduced under various scenarios of future projected climatic conditions during the year 2050 and 2070.Enhancing public awareness, formulating plans for the preservation of bumble bee habitats, and engaging non-governmental organizations and the government are crucial for ensuring the long-term availability of these bees for pollination services in Pakistan.

Acknowledgment

This research work was funded by Institutional Fund Projects under grant no. (IFPIP: 798-130-1443). The authors gratefully acknowledge technical and financial support provided by the Ministry of Education and King Abdulaziz University, DSR, Jeddah, Saudi Arabia.

Disclaimer: None.
Conflict of Interest: None.
Source of Funding: Ministry of Education and King

Abdulaziz University, DSR, Jeddah, Saudi Arabia.

Contribution of Authors

Bodlah I, Fareen AGE & Bodlah MA: Surveyed the study area and wrote the manuscript.
Sheik UAA, Bibi R & Alharby HF: Reviewed the literature, read and approved the final manuscript.
Al-Solami HM, Alkenani NA & Al-Ghamdi AG: Helped in making graphs, tables of manuscript and experimentation.

References

Abak K, Dasgan HY, Ikiz O, Uygun N, Sayalan M, Kaftanoglu O and Yeninar H, 1997. Pollen production and quality of pepper grown in unheated greenhouses during winter and the effects of bumblebees (*Bombus terrestris*) pollination on fruit yield and quality. Acta Hortic. 437: 303–307.

Abrol DP, 2012.Pollination biology: Biodiversity conservation and agricultural production. Springer. New York. pp.792.

Ashraf U, Chaudhry MN, Ahmad SR, Ashraf I, Arslan M, Noor H and Jabbar M, 2018. Impacts of climate change on *Capparis spinosa* L. based on ecological niche modeling. Peer J. 6: e5792.

Bergman P, Molau U and Holmgren B,1996. Micrometeorological impacts on insect activity and plant reproductive success in an alpine environment, Swedish Lapland. Arct. Alp. Res. 28, 196-202.

Bartomeus I, Ascher JS, Gibbs J, Danforth BN, Wagner DL, Hedtke SM and Winfree R, 2013. Historical changes in northeastern US bee pollinators related to shared ecological traits. Proc. oft Nat. Acad. Sci., 110(12), 4656-4660.

Bennie J, Hodgson JA, Lawson CR, Holloway CT, Roy DB, Brereton T and Wilson RJ, 2013. Range expansion through fragmented landscapes under a variable climate. *Ecol. Lett*. 16(7): 921-929.

Biella P, Bogliani G, Cornalba M, Manino A, Neumayer J, Porporato M, Rasmont P and Milanesi P, 2017. Distribution patterns of the cold adapted bumblebee *Bombus alpinus*in the Alps and hints of an uphill shift (Insecta: Hymenoptera: Apidae). J. Insect. Conserv. 21: 357-66.

Banks JE, Banks HT, Myers N, Laubmeier AN and Bommarco R, 2020 Lethal and sublethal effects of toxicants on bumble bee populations: a modelling approach. Ecotoxicology. 29: 237-245. https://doi.org/10.1007/s10646-020-02162-y.

Carvell C, Roy DB, Smart SM, Pywell RF, Preston CD and Goulson D, 2006.Declines in forage availability for bumblebees at a national scale. Biol. Conserv. 132: 481-489.

Cameron SA, Lozier JD, Strange JP, Koch JB, Cordes N, Solter LF and Griswold TL, 2011. Patterns of widespread decline in North American bumble bees. Proceed.Nat. Acad. Sci. 108: 662–667.

Cameron SA and Sadd BM, 2020.Global Trends in Bumble Bee Health. Ann. Rev. Entomol. 65: 209–232. https://doi.org/10.1146/annurev-ento-011118-111847.

Colla SR, Gadallah F, Richardson L, Wagner D and Gall L, 2012. Assessing declines of North American bumble bees (Bombus spp.) using museum specimens. Biol. Conserv. 21: 3585-3595.

Cobos ME, Peterson AT, Barve N and Osorio-Olvera L, 2019.Kuenm: an R package for detailed development of ecological niche models using Maxent. Peer J. 7:e6281.

Dayal K and Rana BS,2004. Record of domestication of *Bombus* species (Hymenoptera: Apidae) in India. Insect Envir.10:64-65.

Fielding AH and Bell JF,1997. A review of methods for theassessment of prediction errors in conservation presence/absence models. *Environ. Conserv*. 24: 38 - 49.

Goulson D, Nicholls E, Botías C and Rotheray EL, 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science. 80:347.1255957.

Gérard M, Vanderplanck M, Franzen M, Kuhlmann M, Potts GS, Rasmont P, Sweiger O and Michez D,2018. Patterns of size variation in bees at a continental scale: Does Bergmann's rule apply? Oikos. 127: 1095–1103.

Gérard M, Vanderplanck M, Wood T and Michez D, 2020. Global warming and plant-pollinator mismatches. Emer. Topics Life Sci. 4: 77-86.

Guiraud M, Cariou B, Henrion M, Baird E and Gérard M, 2021. Higher developmental temperature increases queen production and decreases worker body size in the bumblebee, *Bombus terrestris*. J. Hym. Res. 88: 39-49.

Hijmans RJ, Cameron SE, Parra JL, Jones PG and Jarvis A, 2005. Very high resolution interpolated climate surfaces for global land areas. Int. J. Climatol.25: 1965–1978. http://dx.doi.org/10.1002/joc.1276.

Hines HM, 2008.Historical biogeography, divergence times, and diversification patterns of bumble bees (Hymenoptera: Apidae: *Bombus*). Syst. Biol. 57: 58-75.

Hoiss B, Krauss J, Potts SG, Roberts S and Steffan-Dewenter I, 2012. Altitude acts as an environmental filter on phylogenetic composition, traits and diversity in bee communities. Proc. Royal Society B: Biol. Sci. 279: 4447–4456. https://doi.org/10.1098/rspb.2012.1581.

Imran M, Ahmad M, Naeem M, Nasir MF, Bodlah I, Nasir M and Sheikh UAA, 2017. Effect of Different Types of Boxes on Rearing of Bumble Bee, *Bombus terrestris*. Pak. J. Zool. 49(1):169-174.

IPCC, 2021. Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V. et al. (eds.)]. Cambridge University Press.

Javorek SK, Mackenzie KE and Vander Kloet SP, 2002. Comparative pollination effectiveness among bees (Hymenopter: Apoidea) on lowbush blueberry (Ericaceae: *Vaccinium angustifolium*). Ann. Entomol. Soc. Am. 95: 345-351.

Jacobson MM, Tucker EM, Mathiasson ME and Rehan SM, 2018. Decline of 410 bumble bees in northeastern North America, with special focus on *Bombus terricola*. Biol. Conserv. 217: 437–445.

Kevan PG and Baker H, 1983. Insects as flower visitors and pollinators. Annu. Rev. Entomol.28: 407-453.

Kwon YJ and Saeed S,2003. Effect of temperature on the foraging activity of *Bombus terrestris* L. (Hymenoptera: Apidae) on greenhouse hot pepper (*Capsicum annuum* L.). Appl. Entomol. Zool. 38:275–280.

Khwarahm NR, 2023. Predicting the Spatial Distribution of *Hyalomma* ssp., Vector Ticks of Crimean–Congo *Haemorrhagic* Fever in Iraq. *Sustainability. 15:* 13669. https://doi.org/10.3390/su151813669.

Klein AM, Vaissiere BE, Canem JH, Steffandewenter I, Cunningham SA, Kremen C and Tscharntke T , 2007. Importance of pollinators in changing landscapes for world crops. Proc. Royal Soc. B: Biol. Sci. 274(1608): 303–313.

Kadoya T, Ishii HS, Kikuchi R, Suda SI and Washitani I, 2009. Using monitoring data gathered by volunteers to predict the potential distribution of the invasive alien bumblebee *Bombus terrestris*. Biol. Conserv.142:1011-1017.

Kerr JT, Pindar A, Galpern P, Packer L, Potts SG, Roberts SM, Rasmont P, Schweiger O, Colla SR, Richardson LL, Wagner DL, Gall LF, Sikes DS and Pantoja A,2015. Climate change impacts on bumblebees converge across continents. Science (New York). 349(6244): 177–180. https://doi.org/10.1126/science.aaa7031

Koch JB, Looney C, Hopkins B, Lichtenberg EM, Sheppard WS and Strange JP, 2019. Projected climate change will reduce habitat suitability for bumble bees in the Pacific Northwest. BioRxiv. 610071.

Krechemer FSand Marchioro CA, 2020. Past, present and future distributions of bumblebees in South America: Identifying priority species and areas for conservation. J. Appl. Ecol. 57: 1829-1839. https://doi.org/10.1111/1365-2664.13650

Lämsä J, Kuusela E, Tuomi J, Juntunen S and Watts PC,2018. Low dose of neonicotinoid insecticide reduces foraging motivation of bumblebees. Proc. Biol Sci. 285(1883):20180506. https://doi.org/ 10.1098/rspb.2018.0506.

Mackenzie K, 2009. Pollination practices and the use of bees in the Vaccinium crops. Acta Horticulturae. 810:207-213.

Martins AC and Melo GA,2010. Has the bumblebee *Bombus bellicosus* gone extinct in the northern portion of its distribution range in Brazil? J. Insect Conserv.14: 207-210.

Meeus I, Brown MJ, De Graaf DC and Smagghe G,2011. Effects of invasive parasites on bumble bee declines. Conserv. Biol. 25(4): 662–671. https://doi.org/10.1111/j.1523-1739.2011.01707.x.

Miller-Struttmann NE, Geib JC, Franklin JD, Kevan PG, Holdo RM, EbertMay D, Lynn AM, Kettenbach JA, Hedrick E and Galen C,2015.

Functional mismatch in a bumble bee pollination mutualism under climate change. Science. 349: 1541-1544.

Martinet B, Rasmont P, Cederberg B, Evrard D, Ødegaard F, Paukkunen J and Lecocq T, 2015. Forward to the north: Two Euro-Mediterranean bumblebee species now cross the Arctic Circle. Ann. Soc. Entomol. France. 51: 303–309.

María G, Guzmán NV, Montemayor SI, Confalonieri VA and Lanteri AA, 2109. Potential geographic distributions of two parthenogenetic weevils (Coleoptera: Curculionidae) associated with citrus in Argentina and Brazil. Florida Entomol.102(3): 459-463.

Marshall L, Perdijk F, Dendoncker N, Kunin W, Roberts S and Biesmeijer JC, 2020. Bumblebees moving up: Shifts in elevation ranges in the Pyrenees over 115 years. Proc. Royal Soc. B: Biol. Sci.287:20202201. https://doi.org/10.1098/rspb.2020.2201.

McNeil DJ, McCormick E, Heimann AC, Kammerer M, Douglas MR, Goslee SC and Hines H M, 2020. Bumble bees in landscapes with abundant floral resources have lower pathogen loads. Sci. Rep. 10: 22306. https://doi.org/10.1038/s41598-020-78119-2.

Martínez-López O, Koch JB, Martínez-Morales MA, Navarrete-Gutiérrez D, Enríquez E and Vandame R, 2021. Reduction in the potential distribution of bumble bees (Apidae: Bombus) in Mesoamerica under different climate change scenarios: Conservation implications. Glob. Change Biol. 27(9): 1772–1787. https://doi.org/10.1111/gcb.15559.

Oyen KJ, Giri S and Dillon ME, 2016. Altitudinal variation in bumble bee (*Bombus*) critical thermal limits. J. Therm. Biol. 59: 52–57.

Plischuk S, Salvarrey S, Arbulo N, Santos E, Skevington JH, Kelso S and Lange CE, 2017. Pathogens, parasites, and parasitoids associated with bumble bees (Bombus spp.) from Uruguay. Apidologie. 48(3):298-310.

Phelps JD, Strang CG, Gbylik-Sikorska M, Sniegocki T, Posyniak A and Sherry DF, 2018. Imidacloprid slows the development of preference for rewarding food sources in bumblebees (Bombus impatiens). Ecotoxicol. 27: 175-187.

Prestele R, Brown C, Polce C, Maes Jand Whitehorn P, 2021. Large variability in response to projected climate and land-use changes among European bumblebee species. Glob.Change Biol. 27: 4530–4545. https://doi.org/10.1111/gcb.15780

Rasmont P, Franzén M, Lecocq T, Harpke A, Roberts SPM, Biesmeijer JC, Castro L, Cederberg B, Dvorák L, Fitzpatrick Ú, Gonseth Y, Haubruge E, Mahé G, Manino A, Michez D, Neumayer J, Ødegaard F, Paukkunen J, Pawlikowski T, Potts SG, Reemer M, Settele J, Straka J and Schweiger O,2015. Climatic Risk and Distribution Atlas of European Bumblebees. Biorisk 10 (Special Issue). p. 246.

Rundlöf M, Andersson GK, Bommarco R, Fries I, Hederström V, Herbertsson L, Jonsson O, Klatt BK, Pedersen TR, Yourstone J and Smith HG,2015. Seed coating with a neonicotinoid insecticide negatively affects wild bees. Nature. 521:77–80.

Sowmya KS, Srikanth CD and Sudha M, 2015.Bumble bees ascrop pollinators. Glob J. Adv. Res.2:1-4.

Sirois-Delisle C and Kerr JT,2018. Climate change-driven range losses among bumblebee species are poised to accelerate. Sci. Rep.8: 14464. https://doi.org/10.1038/s41598-018-32665-y.

Sheikh UAA, Ahmad M, Imran M, Nasir M, Saeed S and Bodlah I, 2014. Distribution of bumblebee, *Bombus haemorrhoidalis* Smith, and its association with flora in lower Northern Pakistan. Pak. J. Zool. 46(4): 1045-1051.

Soroye P, Newbold T and Kerr J, 2020. Climate change contributes to widespread declines among bumble bees across continents. Science (New York).367(6478):685–688. https://doi.org/10.1126/science.aax8591.

Suzuki-Ohno Y, Yokoyama J, Nakashizuka T and Kawata M, 2020. Estimating possible bumblebee range shifts in response to climate and land cover changes. Sci. Rep. 10: 19622.

Thakur RK, Gupta JK and Gupta PR, 2005.Investigation on rearing of bumble bee (Bombus sp.) in captivity. Proceedings of International Beekeeping Congress, Banglore, India. p. 18.

Velthuis HHW and Van Doorn A,2006. A century of advances in bumble bee domestication and the economic and environmental aspects of its commercialization for pollination. Apidologie. 37(4): 421-451.

Van-der-Putten WH, Macel M and Visser ME, 2010. Predicting species distribution and abundance responses to climate change: why it is essential to include biotic interactions across trophic levels. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 365(1549): 2025-2034.

Vanbergen AJ and Initiative TIP, 2013.Threats to an ecosystem service: pressures on pollinators. Front. Ecol. Environ. 11: 251-259.

Vesterlund SR and Sorvari J, 2014. Longevity of starved bumblebee queens (Hymenoptera: Apidae) is shorter at high than low temperatures. Eur. J. Entomol.111: 217-220.

Williams PH, Cameron SA, Hines HM, Cederberg B and Rasmont P, 2008. A simplified sub generic classification of the bumblebees (Genus *Bombus*). Apidologie. 39: 46–74.

Warren DL, Dornburg A, Zapfe K and Iglesias TL, 2021. The effects of climate change on Australia's only endemic Pokémon: Measuring bias in species distribution models. Methods Ecol. Evol. 12: 985-995.

Williams PH, Thorp RW, Richardson LL and Colla SR,2014. Bumble Bees of North America: An Identification Guide. Princeton University Press, Princeton, New Jersey.

Yu BW, Li ZD and Wang H,2012. Highly efficient pollination by bumblebees 530 ensures seed production in *Pedicularis lachnoglossa* (Orobanchaceae), an early-531 flowering Himalayan plant. J. Syst. Evol. 50: 218-226.