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RESEARCH ARTICLE

A comparative assessment of climate change effect on some of the important tree species of Hindu-Kush Himalayas, using predictive modelling techniques

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Abstract

A comparative assessment of the effect of global climate change on some the ethno-medically and socio-economically important tree species was carried out in the Hindu-Kush Himalayan mountains. The primary study site chosen was the Swat Valley of Northern Pakistan, which is a unique biodiversity hotspot supporting some important ethnomedicinal plant species. The species assessed for the future climate change effects were: *Acacia modesta* Wall., *Abies Pindrow* (Royle ex D.Don), *Pinus wallichiana* A. B. Jackson, Royle. *and Taxus baccata* L. The Maximum entropy (MaxEnt) modelling technique of species prediction and distribution was used, applying HADCM3 (Hadley Centre Coupled Model, version 3) which is a coupled atmosphere-ocean general circulation model (AOGCM) and A2a global climate change scenario. Results suggest that by the year 2080, there will be a significant change in the distribution and density of these species. It was found that *Acacia modesta* will have significantly higher density, expanding to the southern and central parts of the Valley, i.e. the lower basin of Himalayas. The remaining three species have produced opposite results to *Acacia modesta*, as they will significantly reduce in their density and restrict in their distribution in the Valley. The results show that all species will have altitudinal movement to the northern cooler climatic regions of the Himalaya/Hindu-Kush. Results related to the validity of the models indicate “good model” for all species in both present and future predictive models attaining very high AUC values, i.e. 0.989, 0.98, 0.95, and 0.961 for training data for *Acacia modesta*, *Abies pindrow*, *Pinus Wallichiana, and Taxus baccata,* respectively.

The results suggest that in the future, some of the species will have increased population density, probably at the expense of other useful plants while other will get confined to very small sub-climatic regions. These changes will alter the socio-ecological environment of the fragile Himalaya-Hindu-Kush Mountains which can ultimately result in food and medicine scarcity not just for the inhabitants of the area but in the entire network of national and international supply chain.

INTRODUCTION

Northern areas of Pakistan have the famous mountainous ranges of Himalaya and Hindu-Kush, where lies the Swat Valley**,** very well known for its unique biodiversity and aesthetic beauty. In the current geopolitical division, the study area is situated in KPK(Khyber Pukhtun Khwa) Province of Pakistan and can be traced on the globe at 34° 34’ to 35° 55' N and 72° 08' to 72° 50' E (Shinwari et al. 2003). This valley is surrounded by other small valleys, i.e. in the north there are the valleys of Chitral, Ghizer, Indus Kohistan and Shangla, in the east district Bunir, FATA and Malakand Agency lie in the south, and district Dir in the west (GPO, 1998).

These areas of Hindu-Kush Himalaya have a rich biodiversity and are the only viable timber sources for Pakistan and Afghanistan. Due to these rich natural resources, the socio-ecological structure of the valley is under severe threat from anthropogenic activities (Ali et al. 2013). The most subtle of these threats to the floral diversity, especially, tree flora, is the global climate change.

Most of the flora of the valley is known for its immense economic, medicinal, and ecological value (Ali et al. 2014; Shinwari et al. 2003). The Valley in particular and the surrounding districts in general are known for the continuous supply of Medicinal and Aromatic Plant (MAPs), not only to the local markets but for international trading as well (Ali et al. 2014; Shinwari et al. 2003). The history of MAPs goes back to thousands of years back in the human history (Samuelsson, 2004). Apart from the common issues of anthropogenic activities which include forests logging, overgrazing, uprooting, urbanization and contamination of habitats, the new threat is the climate change to the survival of these plant species (Song et al. 2004). Some species are very susceptible to petite changes in the climate as Beigh et al. (2005) have pointed out for *Aconitum heterophyllum* (Wall) and for *Abies Pindrow* (Ali et al. 2014), in the complex Hindu-Kush Himalayan regions. The current study was carried out to assess and compare the impact of changing climate on some of the important tree species of the Hindu-Kush Himalayas as these tree species together provide a lifeline for the people of the area and to the subflora, especially, MAPs of the area.

The species selection for the study was carried out systematically; only those tree species were selected which are indigenous to the area and are known for their ethnomedicinal and economic values. For example, *Acacia modesta* is commonly uses as fodder, and fuel wood, remedy of mouth ulcers, used as tooth brushes for cleaning and protection of teeth, bark of the plant is used in skin diseases, gastric pains and has potential anti bacterial and anti microbial activity (Bashir et al. 2012). Ecological importance of the plant is also worth mentioning, as due to its scented and colourful flowers, it acts as one of the favourite honey bee plants. A kind of gum is also extracted which is of a very good quality and can be compared in utility and use with the gum Arabic. Other uses include as binder, in bakery, and in pharmaceutical industry, etc. Other three species selected belong to Gymnosperms and commonly used for timber wood, fuel wood, scents, resin. There are various ethnomedicinal recipes in currently in use in the area (see Ali et al. 2014).

Materials and methods

The modelling technique applied requires the use of presence-only data of the species. The geo-referenced data about all the four species was collected from randomly selected plots belonging to 23 different localities of the Hindu-Kush Himalayan regions of the district Swat. To obtain a reliable set of geo-referenced data of the selected plant species, a hardware called RedHen DX-GPS system was used. This hardware connects a Garmin GPS and Nikon D300 camera for capturing images along with metadata. Data captured was then extracted with the help of BR's EXIF extractor, a freeware available online [http://www.br-software.com/extracter.html; visited 07/08/2011]. The transformed metadata in the form of CSV comma-delimited text file format can then be used as input files in the Maximum Entropy (MaxEnt) software (Phillips et al. 2004). The method used in Phillips (2006) was followed in a step wise manner. The British Met Office model, HADCM3 (Hadley Centre Coupled Model, version 3) which is a coupled atmosphere-ocean general circulation model (AOGCM) along with A2a climate-change scenario (Collins et al., 2001) was used. The A2a climate change scenario predicts a decrease in precipitation [- 20mm/year] with an increase in temperature of around 4 degree Celsius, up to the year 2080. All 19 bioclimatic layers i.e. bio_1 – bio_19 (see Table 1) were used in the modeling procedure which were downloaded in GIS compatible format from the WorldClim website (WorldClim, 2011).

There are many species prediction models available (Guisan and Thuiller, 2005), but MaxEnt was chosen for the study as it is known for its reliability and is commonly being used in different areas of science for addressing ecological, bio-geographical, and conservation issues of species (Peterson, 2007, Elith et al. 2011). Some of these modelling techniques require presence-absence data while MaxEnt uses "presence only data" and does not require "absence data" or it assumes pseudo-absence (e.g., Soberón and Peterson, 2005; Phillips et al. 2006; Chefaoui and Lobo, 2008; Hirzel and Le Lay, 2008; Jiménez-Valverde et al. 2008; Soberón and Nakamura, 2009; Lobo et al. 2010). According to Thomas, et.al (2004), predictive modelling techniques are useful tools for the conservation of species by estimating the extinction probabilities of species due to the climate change and such integrative programs connect the geospatial data with species-based information which in turn can help us to identify priorities for socio-biological conservation action planning (Scott et al. 1996).

Another positive attribute of MaxEnt modelling technique is that it uses only "presence only" data and creates results using AUC values, relatively easier to be interpreted (Elith et al. 2011). The accuracy of the predictive models was measured by the area under the receiver operating characteristic (ROC) curve. An area of 1 represents a perfect test; an area of 0.5 represents a worthless test. The general agreement on the AUC value is that a model is "good" if the value is over 0.8, while the value of over 0.9 is considered highly accurate (Luoto et al. 2005).

For further elaboration of results and visual clarity, ArcGIS version10.1 (ArcMap) licensed by ESRI (2011) was also used for the development of Chlopleth maps.

Results

The graphical data obtained for all the four species is presented below.

i. Acacia modesta

Results obtained for *Acacia modesta* in the present predictive model, suggest that currently the species has restricted distribution in the lower basin of the Hindu Kush Himalayas, i.e. the lower altitudinal areas of the valley and most of the high altitude areas of the valley provide a little chance for the plant to survive and spread. The high presence probability localities are mostly on the Southern borders of the district Swat. The highest species density probability was therefore recorded for the southern border and the central region of valley (Figure 1 A).

In the future prediction model, *Acacia modesta* shows a high probability of presence in the centre and western borders, even extensive distribution in the neighbouring Dir district (see Figure 1 B).

In the case of *Acacia modesta*, it is also evident (see Figure 2 B) that the future model exhibits a different trend in the distribution of the species. Although, bio_11 is still carrying the most important information in the model and has still the highest regularized training gain. On the other hand, bio_19 showed the least gain when used individually for the gain of AUC and thus is the least important bioclimatic variable for the species distribution (See details of the bioclimatic layer in Table 1). In the future prediction model the regularized training AUC value of 0.986 was recorded (See Table 2).

ii. Abies pindrow

Results for *Abies pindrow* indicate that the current species distribution can extend into the neighbouring districts towards the east and the west with sparse population, and only the highest species density was recorded for the areas of Sulatanr and Mankial in eastern and western borders of the Valley in the (Fig. 3 A and B). In order to evaluate the validity of the present prediction model, a ground-truth survey was carried out, which has confirmed the results of the model.

It is evident from the Jackknife analysis that the highest contributers to the area under curve (AUC) were bio_10 and bio_7 climatic variables, which are (mean temperature of the warmest quarter) and (temperature annual range [bio_5 - bio_6]), respectively. In the future projection, the model showed a different trend: bio_6 was the main contributing variable along with bio_1 and bio_11, while bio_14 was the least contributing variable (Table 2 and Fig. 3 A, B). The AUC values obtained for the species for present distribution models yielded highly significant results (see Table 2).

iii. Pinus wallichiana

Results suggest that this plant is one of the most dominant species of the study area. The current distribution model of the species reveals that it is widespread on the eastern, western and central mountainous ranges of the study area (see Figure 5 A and B).

The future distribution map is rather gloomy, the species seems to be changing its habitat moving eastwards with the expense of heavy loss of density (see Figure 5 A and B).

The Jackknife of AUC for *Pinus wallichiana* reveals the total gain of 0.95 for AUC; the highest contributing variable recorded is bio-11 while the least contributing variable for AUC gain was bio-14 (see Figure 6 A and B). The AUC gain values 0.95 for training data shows high reliability of the model.

iv. *Taxus baccata*

The current distribution of the species predicted by Maxent shows that the species density is very low and restricted from medium to high altitudes in the eastern and western borders of the Valley (see Figure 7 A and B).

The future predicted distribution map shows a very high probability of a presence in the centre and north western parts acting as hotspots of the species. A marked movement towards the northern colder areas was also recorded (see

Figure 7 A and B). The sensitivity vs. 1- specificity plot shows a very high score of AUC gain, i.e. 0.962 for training data of the species (see Figure 8 and 9).

Table 1. Bioclimatic variables and their description (source: WorldClim, 2011).

No	Bioclimatic variable	Description
1	bio_1	Annual mean temperature
2	bio_2	Mean diurnal range (mean of monthly (max temp-min temp)
3	bio_3	Isothermality (100*mean diurnal range/annual temperature range) or (bio_2/bio_7*100)
4	bio_4	Temperature seasonality (standard deviation *100)
5	bio_5	Max temperature of warmest month
6	bio_6	Min temperature of coldest month
7	bio_7	Temperature annual range (bio_5 - bio_6)
8	bio_8	Mean temperature of wettest quarter
9	bio_9	Mean temperature of driest quarter
10	bio_10	Mean temperature of warmest quarter
11	bio_11	Mean temperature of coldest quarter
12	bio_12	Annual precipitation
13	bio_13	Precipitation of wettest month
14	bio_14	Precipitation of driest month
15	bio_15	Precipitation seasonality (coefficient of variation)
16	bio_16	Precipitation of wettest quarter
17	bio_17	Precipitation of driest quarter
18	bio_18	Precipitation of warmest quarter
19	bio_19	Precipitation of coldest quarter

Table 2. Regularized Training AUC values and important variables *Acacia modesta*, *Abies pindrow*, *Pinus wallichiana* and *Taxus baccata* for the present and future predictive models.

Plant Species	**Present Model Important variables**	**Future Model Important variables**
Acacia modesta Wall.	bio_11, bio_3, bio_2	bio_11, bio_3, bio_19
Abies pindrow	bio_10	bio_6
Pinus wallichiana	bio_3, bio_6	bio_11
Taxus baccata	bio_15, bio_7	bio_15, bio_7

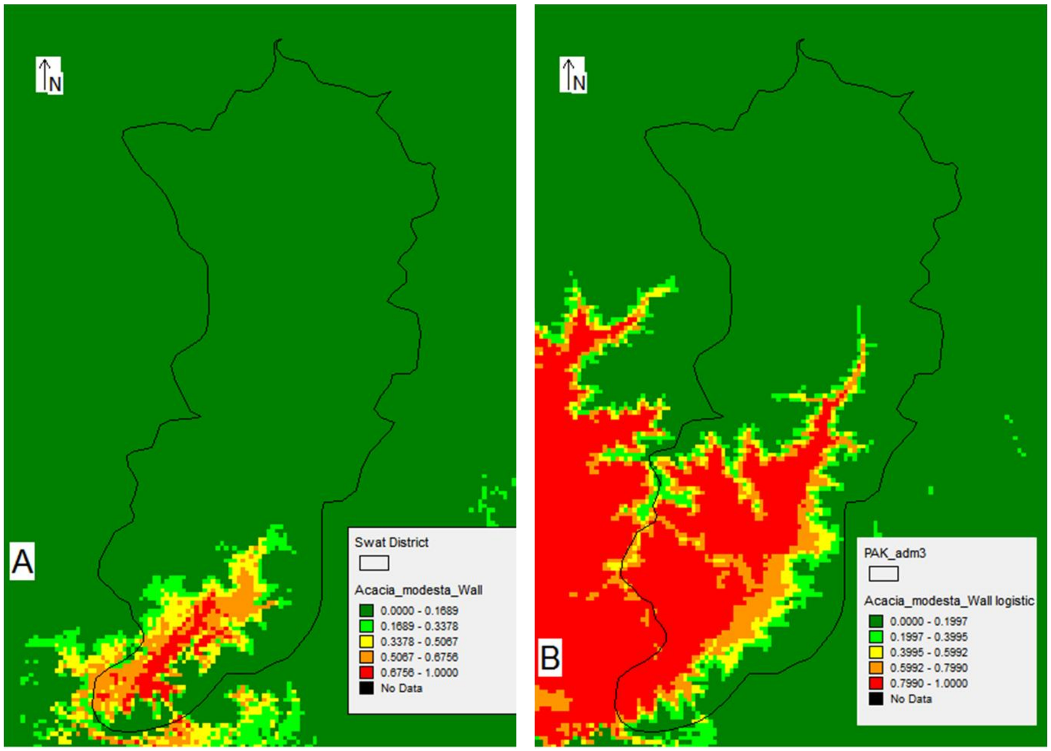

Figure 1. A. Predicted Present distribution of *Acacia modesta*; B. Future projected distribution of *Acacia modesta.*

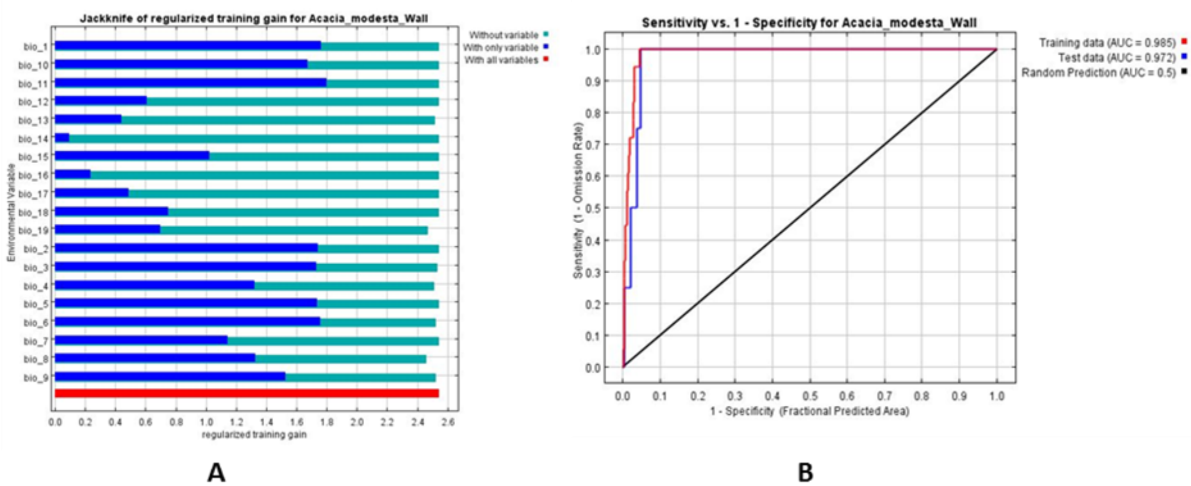

Figure 2. A. Sensitivity vs. 1- Specificity graph; Jackknife of AUC for *Acacia modesta,*

B. Jackknife of AUC for *Acacia modesta*, future prediction model; results obtained using A2a scenario, all presence data of the species and 19 bioclimatic variables (Phillips, 2006).

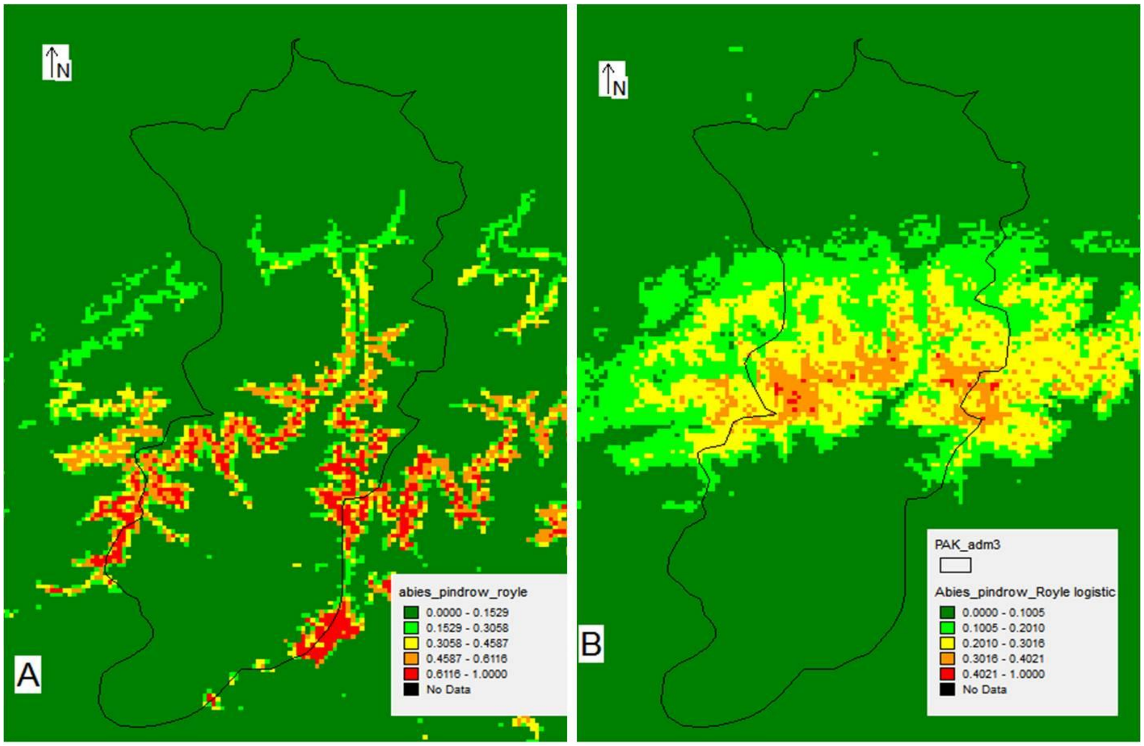

Fig. 3 A. Present distribution of *Abies pindrow*; B. Future projected distribution of *A. pindrow.*

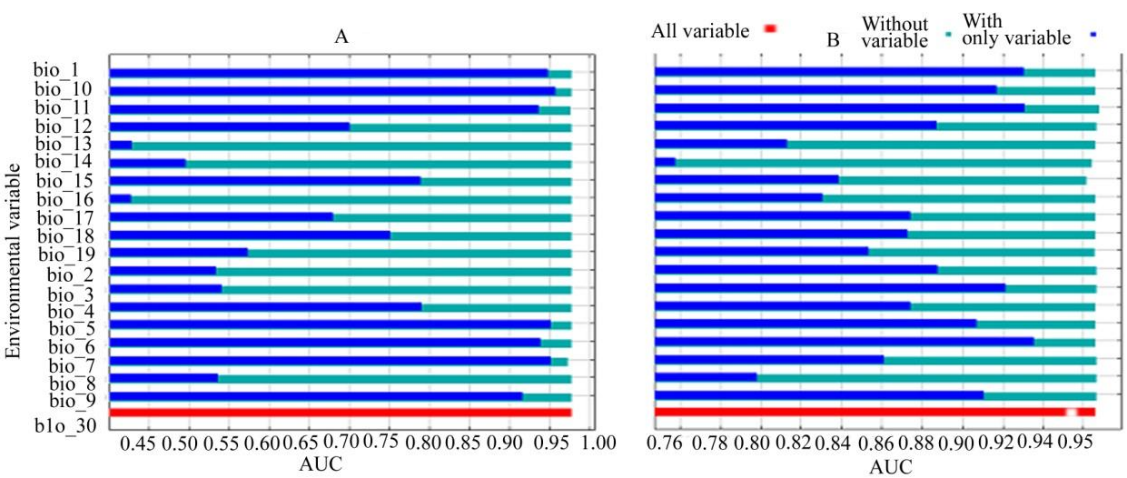

Fig. 4 A. Jackknife of AUC (area under the curve) for *Abies pindrow*, present prediction model; B. Jackknife of AUC for *Abies pindrow*, future prediction model; results of a Jackknife AUC of variable importance for *Abies pindrow* in the A2a scenario using all point localities and 19 bioclimatic variables. (Phillips et al. 2006).

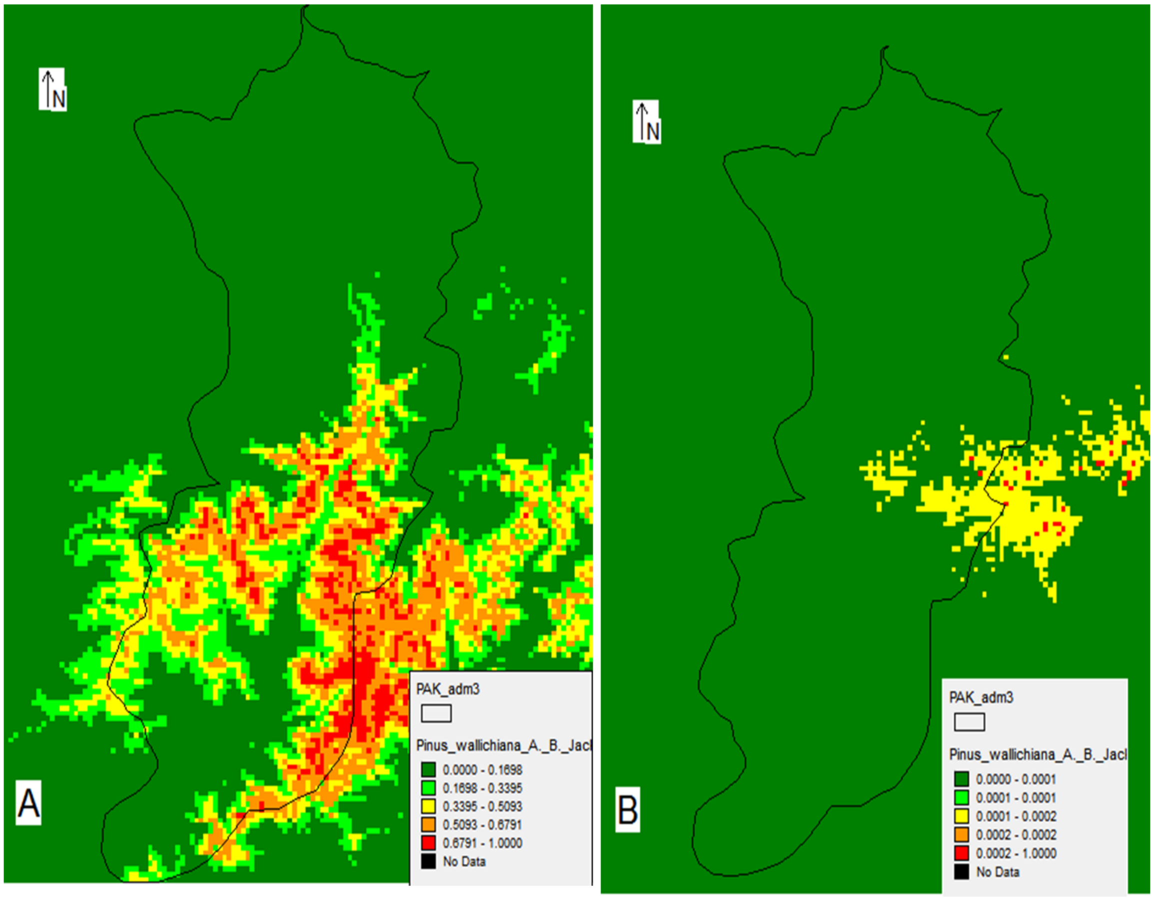

Figure 5 A. Present predicted distribution of *Pinus wallichiana*; B. Future predicted distribution of *Pinus wallichiana.*

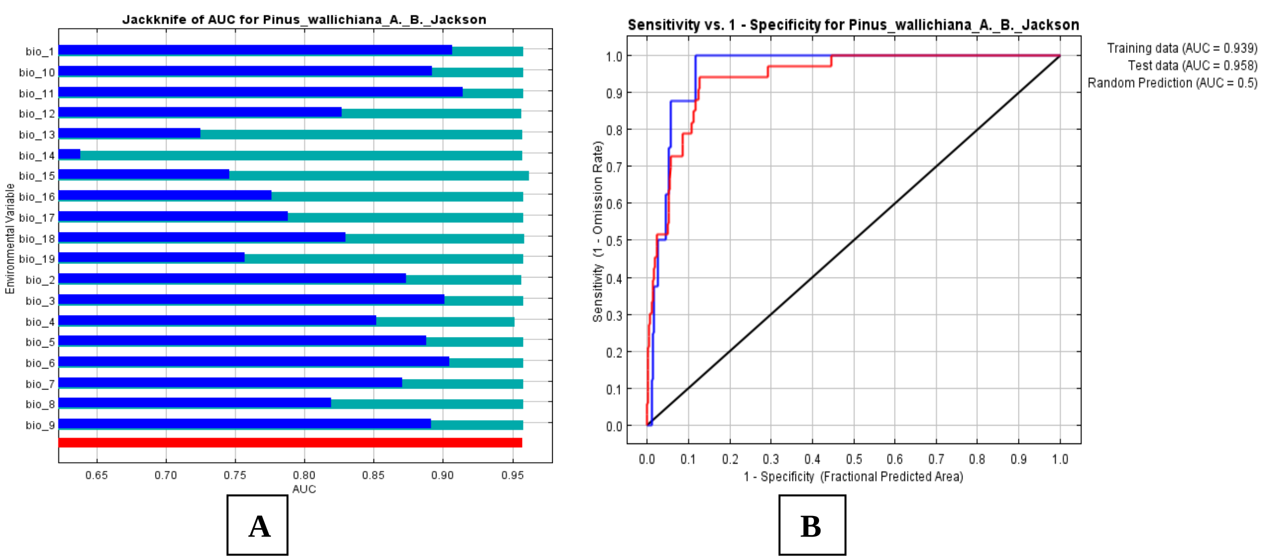

Figure 6. A. Jackknife of AUC for *Pinus wallichiana*, present predictive model.

B. Sensitivity vs. 1- specificity for *Pinus wallichiana*, present prediction distribution model.

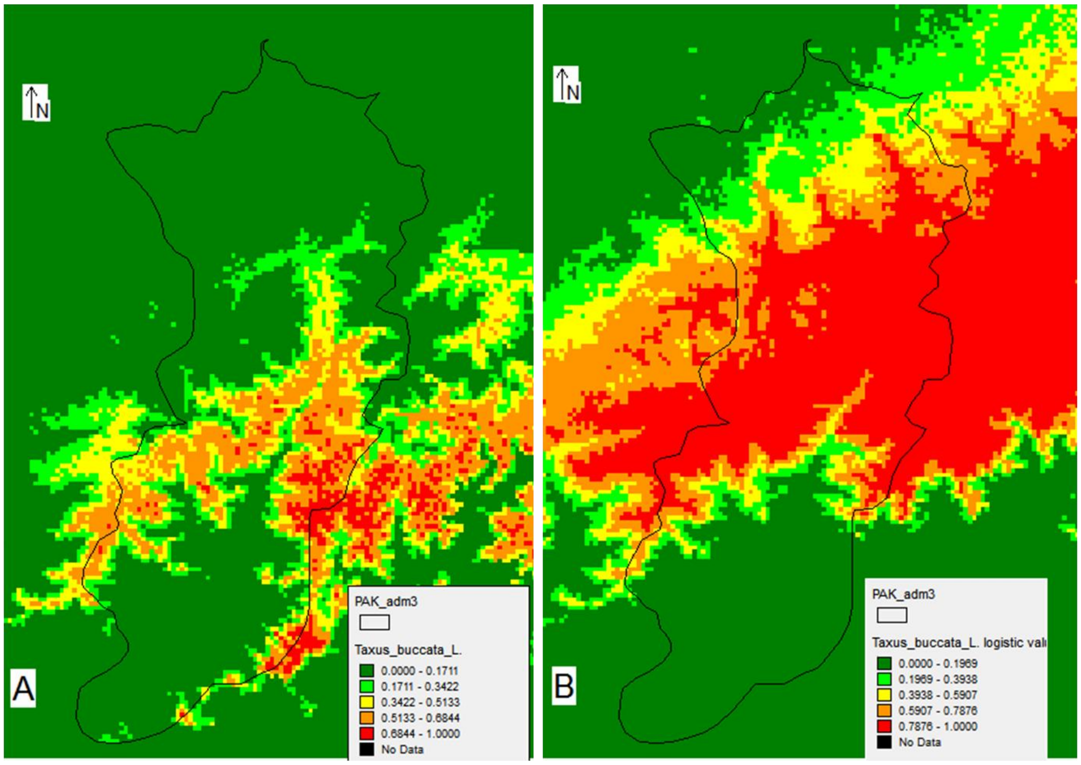

Fig 7. A. Present distribution of *Taxus baccata* ; B. Future projection of *T. baccata.*

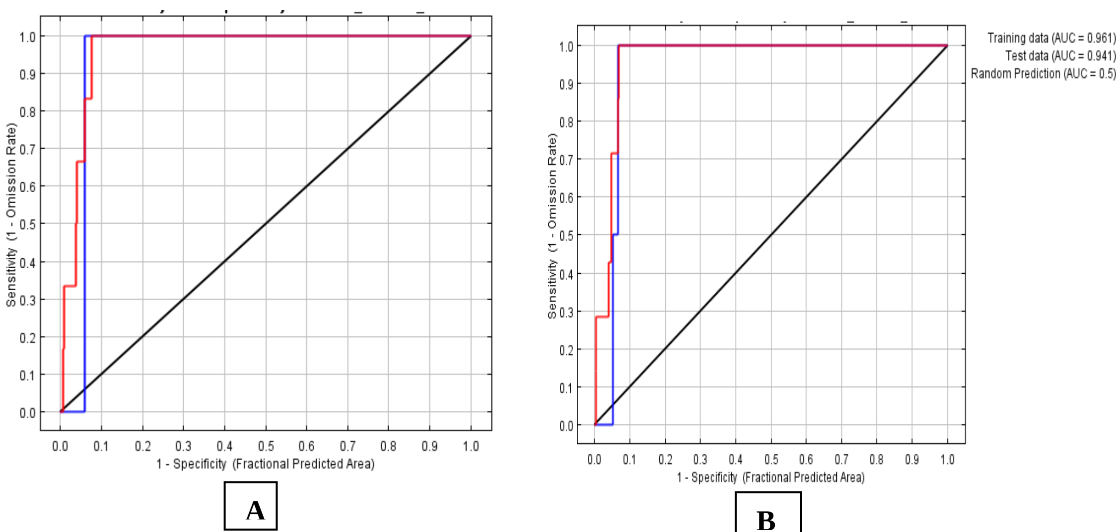

Figure. 8 A. Sensitivity vs. 1- specificity for *Taxus baccata.* In the present model

B. Sensitivity vs. 1- specificity for *Taxus baccata*; future prediction model.

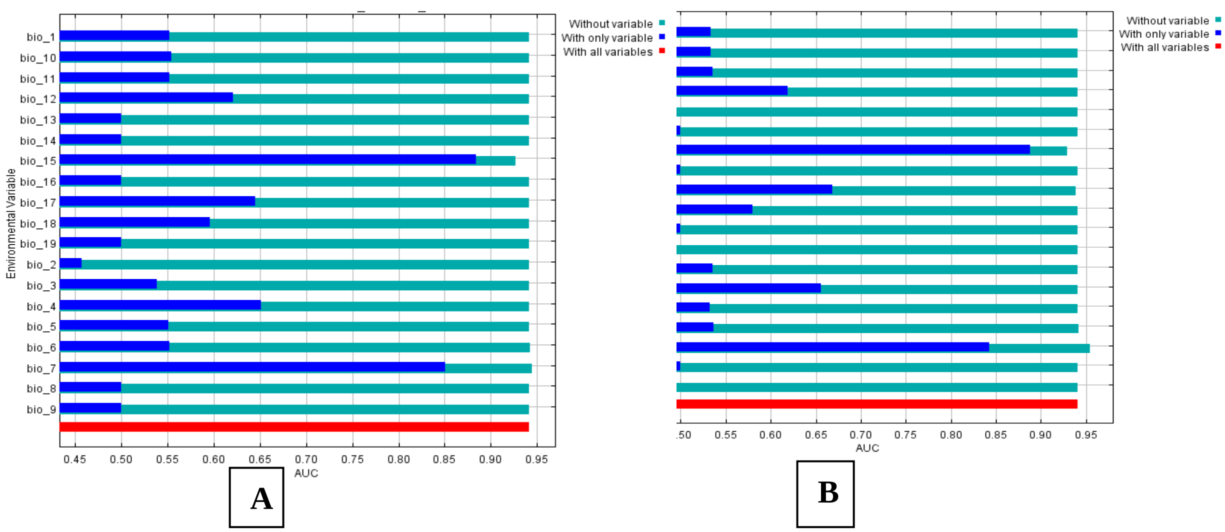

Figure. 9 A. Jackknife of AUC for *Taxus baccata,* present model B. Future model

Conclusions and Discussion

Some common conclusions drawn are; all the species assessed for the climate change effect show significant change in the density and distribution. All species show a movement to the northern colder areas of the Hindu-Kush Himalayas. Some species specific conclusions can also be drawn, i.e. It can be easily concluded that the *Acacia modesta's* population density in the Swat district will be positively affected by the climate change, meaning that in general the Himalayas and especially the Swat valley will have more space for *Acacia modesta* stands in 2080.

The population density of *A. pindrow* was predicted to be negatively affected by climate change. The Swat Valley would support fewer A. pindrow in 2080 and the southern parts of the Valley would not support the species by 2080.

Being the biotic component of the ecosystem, all living organisms live in association with each other species and interact with their physical environment (Hizrel and Le Lay, 2008). While interacting with their environment, some species have developed a balance with their climate and are thus very prone to minute changes in the climate as Beigh et al. (2005) highlighted this for *Aconitum heterophyllum* in the complex Himalayan region. As suggested by the results of the current study, the current species might not completely disappear, but their current habitats and population densities will be significantly affected, as a result, the plants and animals dependant on these trees will either have to disappear or dapt to the new climate by "walking effect". In general it is highly improbable for the species to adapt in such a speedy manner with the changing climate.

In the Hindu-Kush – Himalayas, one of the general trends of conservation of species in response to climate change is the altitudinal movement (Song et al. 2004). Trees like *Abies pindrow* and *Picea smithiana* were also reported by Song et al. (2004) to show northwards movement in distribution due to the availability of suitable climatic conditions. The current study suggests similar response of *Acacia modesta* and *Taxus baccata*, in total agreement with Song et al. (2004). The northern parts of the valley have comparatively higher altitudes and are currently significantly colder than the southern parts of the study area, but by 2080 these parts will exhibit the climatic conditions similar to the current southern parts of the valley.

Considering the fact of species competition and the utmost dependence of subflora on the tree canopies, the global climate change will bring about a significant change in the distribution of not some of the important tree flora but the dependant sub-flora of the valuable non-timber forest products (NTFPs). The fact has already been established that most of the MAPs in the study area in Hindu-Kush Himalayas grow under shady or semi-shady habitats of the forests (Adnan and Hölscher, 2011) and prefer to establish a close association with other species (Khan et al. 2014). The shift in distribution of these species will possibly create serious socio-economical issues related to the health and economy of the local and regional communities (Ali et al. 2014). Many researchers of the area have already established a close coordination between the financial conditions of the community and the preferential use of the traditional medicines (i.e. Khan, 2002). This could mean that the loss of these valuable plants will cost the valuable ethnomedicinal knowledge of the communities (Ali et al. 2013; Diallo et al. 1999) and could ultimately result in food and medicine scarcity not just for the inhabitants of the area but in the entire network of national and international supply chain.

It is recommended that a large scale climate change assessment studies should be carried out in the fragile Hindu-Kush Himalayas and people must be educated regarding the conquences of the climate change. The government and local authorities of the region must address the issue effectively and must adopt a suitable conservation policy.

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