

# FATE OF IMPORTANT MEDICINAL PLANTS IN THE EASTERN HIMALAYA IN CHANGING CLIMATE SCENARIOS: A CASE OF *PANAX PSEUDOGINSENG* WALL.

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**Abstract.** Monitoring the impact of climate change on forest ecosystems, particularly at the species level, can be currently observed in many parts of the world. In this study, Maxent species distribution modelling algorithm was used to predict the suitable habitat for the medicinally important species; *Panax pseudoginseng* in Sikkim Himalaya. The nineteen bioclimatic variables from Worldclim database were used to predict the current potential distribution. Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 scenarios of IPCC 5<sup>th</sup> assessment was used for predicting the future distribution of species in 2050 and 2070. The Maxent model performed better than random with an average test AUC (Area under Curve) value 0.927 under the predicted current distribution. The projected distribution in future under the both RCPs scenarios showed upward shift of species (i.e., gain in suitable habitat area) in high elevation area over the years of 2050 and 2070. Areas with suitable climatic conditions predicted to decline by the 2050s and the 2070s under both RCP scenarios. The application of predictive Maxent modelling approach presented here may provide policymakers and conservationists, with a useful tool for prediction of species in future climate with only presence distribution records and therefore, can be an effective approach for species restoration and conservation actions.

**Keywords:** *Himalaya, climate change, conservation, Panax pseudoginseng, medicinal plants*

## Introduction

Various components of a landscape (physical, biological and socio economic) are being affected by climate change, mostly along regional temperature changes where impacts due to changes in snow, ice and permafrost regions have influenced ground instability, enhanced glacial melt, enlargement and increase of glacial lakes in mountain regions, hence early and increased spring peak discharges in rivers (IPCC, 2014). Responses of species to impacts of climate change have been manifested in changes in phenology (Corlett et al., 1998; Settele et al., 2016), earlier onset of spring (Mohandass et al., 2015), migration process (Saltré et al., 2015), and lengthening of growing season (IPCC, 2014; Singh and Kushwaha, 2016). Changes in the abundance and distribution range of some species, changes in community composition, and local extinctions of species have been attributed to climate change (Davis and Shaw, 2001; Thomas et al., 2004; Moritz and Agudo, 2013; Maclean et al., 2015). The response of climate change on species distribution could be more rapid and expected to be faster in higher altitude areas, where species occur close to their physiological tolerance (Innes, 1991; Diaz and Bradely, 1997; Gratani, 2014). At regional scale these changes affects the natural

distribution of species, causing temporal reproductive isolation or even towards the extinction (Araujo et al., 2005; Schröter et al., 2005; Priti et al., 2016; Yi et al., 2016). To reduce the species extinction rates and conservation of its natural habitats in human dominated landscape, delineating protected areas are often the strategy by which conservation can be ensured. Species distribution models (SDMs) is useful in taking important decisions in developing conservation strategies particularly for poorly known or other species (Guisan and Thiller, 2005; Guisan et al., 2013; Cuyckens et al., 2016; de Siqueira et al., 2009; Kumar, 2012; Perez-Garcia et al., 2013; Khanum et al., 2013; Shrestha and Bawa, 2014; Soheli et al., 2016) by providing a strong predictive framework for identifying additional natural populations of species (Menon et al., 2010), and relocating the threatened population of species to natural suitable habitats (Adhikari et al., 2012).

The Himalayan region is experiencing warming at higher rate than the global average (three times high, 0.06 °C/year; Shrestha et al., 2012). Being a biodiversity hotspot region, Himalaya, and sensitivity towards climate change, information in this region is not adequate and limited to few studies on the aspects of response of species towards climate change (Saran et al., 2010; Kumar, 2012; Forrest et al., 2012; Telwala et al., 2013; Shrestha and Bawa, 2014; Manish et al., 2016). Therefore, this globally important region warrants more understanding on species response towards the climate changes and ecosystem functioning also due to its distinctive evolutionary history and rich species diversity (Pandit and Babu, 1998; Pandit et al., 2007).

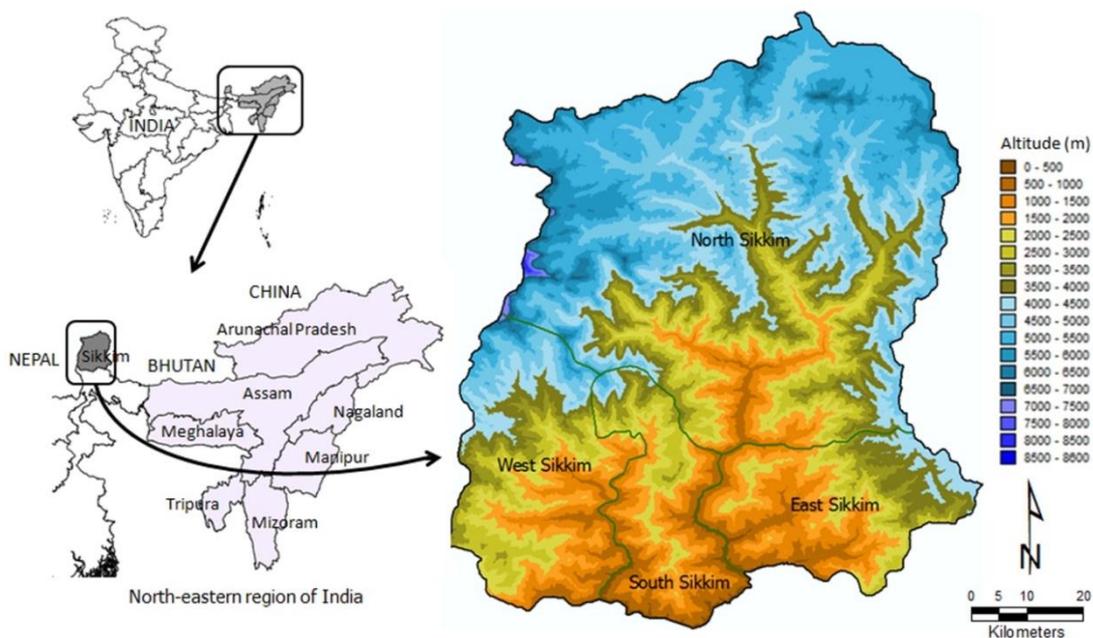
Eastern Himalayan region has unique assemblage of endemic plant species and many of them are known for their medicinal values, and among them is *Panax pseudoginseng* Wall., also known as *Himalayan Ginseng* is a well known high value medicinal plant. The species is also one of the threatened plant species describes in Red Data Book of India (Nayar and Sastry, 1990). State of Sikkim in the Eastern part of Indian Himalayan region has 31% of the total geographical area under legal protection of protected area network through one National Park and seven Wildlife Sanctuaries which is much higher than the average of country (~4% of total geographical area). Whether the current situation of protected area network in Sikkim Himalaya would encompass the distribution of *P. pseudoginseng*, and what level of research and conservation strategies are required for protection and conservation to manage the natural habitats of *P. pseudoginseng* are key questions on the face of rapid climate changing scenario. In this rationale objectives of this study are: (1) to determine the important climatic variables that enhance prediction for *P. pseudoginseng* in current climatic situations, (2) to model the present predictive distribution range of *P. pseudoginseng* and potential future distribution under two climate change emission scenarios i.e., Representative Concentration Pathways (RCP 4.5 and RCP 8.5) for 2050 and 2070 year, and (3) to propose conservation strategies and management options under different scenarios.

## Materials and methods

### Study area

Sikkim State in Indian Himalayan Region (IHR) is located between 27°00'46" to 28°07'48" N latitudes and 88°00'58" to 88°55'25" E longitudes (Fig. 1). The State encompasses four districts (i.e., North Sikkim, East Sikkim, South Sikkim and West Sikkim) covering 7,096 km<sup>2</sup> geographical area. This mountainous state has - natural gradient of altitude ranging from 300 m to 8,586 m amsl. Biogeographically, Sikkim is

part of Eastern Himalayan region and has been categorized in two biogeographic zones (Trans Himalaya and Himalaya) of India (Rodgers et al., 2002) - Trans-Himalaya - Sikkim (1C) and Eastern Himalaya (2D). Broad representative vegetation types (Champion and Seth, 1968) of the Eastern Himalayan region of India are tropical moist deciduous, subtropical broad leaved forests, Broad leaved and conifer mixed forests, wet temperate forests, sub alpine forests, and alpine meadows (moist and dry alpine scrubs). Protected Area Network in the Sikkim includes seven Wildlife Sanctuaries (Shingba Rhododendron Sanctuary, Kyongnosla Alpine Sanctuary, Pangolakha Wildlife Sanctuary, Fambonglho Wildlife Sanctuary, Maenam Wildlife Sanctuary, Barsey Rhododendron Sanctuary and Kitam Bird Sanctuary), and one National Park (Khangchendzonga NP), covering a total area of 2183.1 km<sup>2</sup>, which is 30.8% of the total geographical area of the State.



**Figure 1.** Map of study area showing the districts and elevation gradients of Sikkim Himalaya

### Study species

*Panax pseudoginseng* Wall. (Araliaceae) [syn. *Aralia pseudoginseng* (Wall.) Benth. ex C.B. Clarke; *Aralia quinquefolia* Decne. & Planch. var. *pseudoginseng* (Wall.) Burkill; *Panax schinseng* var. *nepalensis* Nees; *Panax sikkimensis* R.N. Banerjee] is commonly known as *Himalayan Ginseng*, *Indian Ginseng* and *False Ginseng*. It is a perennial herb that grows up to 50 cm in height (Clarke, 1879). It is distributed in temperate zone of thick conifer-oak mixed and Himalayan birch forests where the soils has deep humus content. The species starts flowering during the months of May-June and fruiting during July-October. The flowers are terminal, unequal, umbellate and pale green or orange-yellow in colour. Its bear's dull green to black fruits measuring 3-5 mm with a black spot at the top part. Medicinally the Himalayan Ginseng is well-liked to known as elixir of life and its rhizomes uses for preparation of rejuvenating and revitalizing tonic. It is used to increase longevity, mental agility and to check hypertension. Locally it is used as a haemostatic for treating conditions such as

vomiting and coughing up of blood, blood in the urine or stool, bleeding nose and hemorrhagic disease.

Known habitats of *P. pseudoginseng* in this study are under sub-alpine zone between 3000 and 4000 m amsl, which comprises locations those remain moist for 8-9 months, and dry season for 3-4 months. A cold climate is normal for all the locations and dew, frosts or days under snow occur as regular events at some locations. The plant normally grows under shade and most abundantly under canopy of *Abies densa*, *Betula* spp., *Lithocarpus pachyphyllus* and *Rhododendron* spp., however, occasionally it can be found in open forests also.

### ***Species presence data***

Herbarium records of the species were analyzed from the collection of Botanical Survey of India, Sikkim Office. All the herbarium sheets (12 in number) were geo-referenced through location of collections on the maps, this was followed by field surveys and ten new locations were also recorded, thus leading to a total of 22 locations for current presence data. These locations were transferred to GIS platform using Arc GIS software.

### ***Environmental predictors***

Nineteen bioclimatic variables are available from WorldClim database (<http://www.worldclim.org>) at a resolution of approximately 1 km (Hijmans et al., 2005) was used for distribution modeling of *P. pseudoginseng*. These variables, derived principally from monthly temperature and precipitation data (*Table 1*), have proven relevance in modeling species distribution (Pearson and Dawson, 2003; Irfan-Ullah et al., 2007; Loiselle et al., 2008; Khanum et al., 2013). Intergovernmental Panel on Climate Change (IPCC) 5 data for future climate projection conditions for the years 2050s and 2070s were obtained from the Consultative Group on International Agricultural Research (CGIAR)'s Research Program on Climate Change, Agriculture and Food Security (CCAFS) climate data archive (<http://www.ccafs-climate.org/>) to project the potential distribution in future.

The future climatic projection datasets are based on of IPCC 5<sup>th</sup> assessment and were calibrated and downscaled using the current climatic data. Instead of using single global circulation model (GCM), we used data from three different global climate models for reducing the uncertainty. MRI-CGCM3, CSIRO-MK3.6 and HadGEM2-CC global climate models were selected for modeling the future prediction (Khanum et al., 2013; Barber, 2015; Dotchamou et al., 2016). Each GCM was tested under two future greenhouse gas concentration trajectories, called Representative Concentration Pathways (RCP) i.e., RCP 4.5 and RCP 8.5 for the periods 2050 and 2070. The RCP 4.5 ("intermediate stabilization pathways") was developed by Pacific Northwest National Laboratory's in the United States. It is relatively stable scenario in which total radiative forcing reaches 4.5 W/m<sup>2</sup> and stabilized shortly after 2100, without overshooting the long-run radiative forcing target level (Clarke et al., 2007; Smith and Wigley, 2006; Wise et al., 2009). The RCP 8.5 was developed by the International Institute for Applied System Analysis in Austria. It is characterized by increasing greenhouse gas emissions throughout the 21<sup>st</sup> century and radioactive forcing is predicted to reach up to 8.5 W/m<sup>2</sup> by 2100 (Riahi et al., 2007; Riahi et al., 2011). These two scenarios are being used by various workers to analyze impacts of climate change on predictive species

distribution modeling (Monahan et al., 2013; Shrestha and Bawa, 2014; Li et al., 2015; Kang et al., 2016; Soheli et al., 2016; York et al., 2016). For future potential distribution predictions of *P. pseudoginseng*, we ran separate models (*Appendix*) and also by averaging the results (ensemble approach) from the CGCM3, CSIRO-MK3 and HadGEM2-CC future climate models (Araujo and New, 2007).

**Table 1.** Percentage contribution (average of over twenty replicate runs) and permutation importance of the climatic variables in the Maxent models for *Panax pseudoginseng*

Climatic variable	Code	Unit	Percentage contribution	Permutation importance
Annual mean temperature [AMT]	Bio1	°C	-	-
Mean diurnal range temperature {Mean of monthly (max temp - min temp)}[MDRT]	Bio2	°C	-	-
Isothermality (Bio2/Bio7) (* 100) [ISO]	<b>Bio3</b>		0.1	0.3
Temperature seasonality (Standard deviation *100) [TS]	Bio4		-	-
Maximum temperature of warmest month [MTWM]	Bio5	°C	-	-
Minimum temperature of coldest month [MTCM]	Bio6	°C	-	-
Temperature annual range (Bio5-Bio6) [TAR]	<b>Bio7</b>	°C	0.8	0.0
Mean temperature of wettest quarter [MTWQ]	Bio8	°C	-	-
Mean temperature of driest quarter [MTDQ]	Bio9	°C	-	-
Mean temperature of warmest quarter [MTWAQ]	<b>Bio10</b>	°C	8.5	21.9
Mean temperature of coldest quarter [MTCQ]	<b>Bio11</b>	°C	25.6	76.6
Annual precipitation [AP]	Bio12	mm	-	-
Precipitation of wettest month [PWM]	Bio13	mm	-	-
Precipitation of driest month [PDM]	Bio14	mm	-	-
Precipitation seasonality (Coefficient of variation) [PS]	<b>Bio15</b>		60.2	0.7
Precipitation of wettest quarter [PWQ]	Bio16	mm	-	-
Precipitation of driest quarter [PDQ]	Bio17	mm	-	-
Precipitation of warmest quarter [PWAQ]	<b>Bio18</b>	mm	4.8	0.6
Precipitation of coldest quarter [PCQ]	Bio19	mm	-	-

### **Predictive Maxent modeling**

For the prediction modelling, maximum entropy based technique i.e., Maxent ver. 3.3.3k (<http://www.cs.princeton.edu/~schapire/Maxent/>) was chosen due to its better performance with small sample sizes relative to other modelling algorithms (Elith et al., 2006). This programme attempts to estimate a species distribution by finding the probability distribution of species occurrence i.e., closest to uniform subject to the constraint that the mean environmental conditions by the model should be close to the empirical average of the conditions at the presence localities (Phillips et al., 2006; Phillips and Dudik, 2008; Elith et al., 2011).

A total of twenty replicate runs were set for model building and averaged the result. In the replicated runs the cross validation technique was used, where samples divided into replicate folds and each fold was used for test data. Jackknife test and percent variable contributions were used to estimate the relative influence of different predictor variables, which estimate the training gain of every variable and recommend the best interpreter for the prediction of distribution of species. The AUC (area under curve), area under the ROC (Receiver Operating Characteristics) curve, was used to evaluate model performance. However, ROC AUC provides a threshold-independent measure of model performance compared to that of null expectations, such should provides an overall picture of the predictive nature of models (Stockwell and Peterson, 2002;

Fawcett, 2006). An AUC statistic closer to 0.5, indicates that model did not perform better than random whereas closer to 1.0, indicates perfect discrimination (Swets, 1988). Araujo et al. (2005) recommended the following interpretation of AUC for the models generated, viz., excellent if  $AUC > 0.90$ ; Good if  $0.80 > AUC < 0.90$ ; Acceptable if  $0.70 > AUC < 0.80$ ; Bad if  $0.60 > AUC < 0.70$ ; Invalid if  $0.50 > AUC < 0.60$ .

The multi-collinearity test was conducted using pairwise Pearson's correlation coefficient ( $r$ ) to examine the cross-correlation among the climatic variables using the ENM tool (Warren et al., 2010). The variables with cross-correlation coefficient value of  $\geq +0.90$  were excluded from the analysis (see *Table A1* in the *Appendix*). Based on such criterion, 13 bioclimatic variables were excluded and only 6 bioclimatic variables were used in the final model to predict the effect of climate change on the future distribution of *P. pseudoginseng*. For validating the model robustness a 10 percentile training presence threshold rule was executed over a twenty replicated model runs (Pearson et al., 2004). Other parameters were set to default as the program is already calibrated on a wide range of species datasets as suggested by Phillips and Dudik (2008). To avoid erroneous predictions of suitable habitat under future climate scenarios for 2050 and 2070 'fade by clamping' option was used in Maxent, which removes heavily clamped pixels from the final predictions (Fielding and Bell, 1997; Phillips et al., 2006). For each of the three habitat models, including the current *P. pseudoginseng* potential distribution and the two future predictions under the RCP scenarios (2050 and 2070), we calculated the total area of habitats, and amounts of stable/no change (areas of the current potential range predicted to remain suitable), unsuitable, lost (areas not predicted to remain suitable in future), and gained habitats (areas that are predicted to be suitable future that are not currently suitable) areas for each of the two future models under 2050 and 2070 years.

## Results

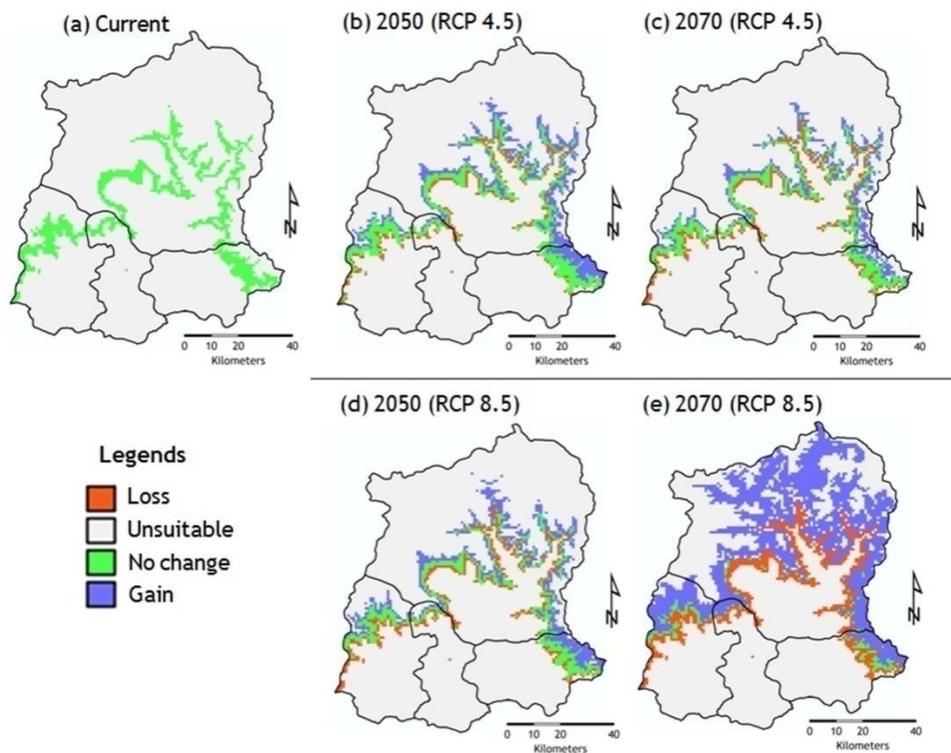
The selected climatic variables, 6 in number, provided a satisfactory prediction of the potential current distribution of species (*P. pseudoginseng*) evident by mean test AUC value of  $0.927 \pm 0.043$ , and considered excellent (Araujo et al., 2005). Amongst these climatic variables, precipitation seasonality (PS) and mean temperature of coldest quarter (MTCQ) appeared significant for the occurrence of the species (collectively contributed to 85.8% of the model's variance; *Table 1*) indicating role of moisture and cold environment as apparent by contribution of Mean temperature of warmest quarter (MTWAQ) and precipitation of warmest quarter (PWAQ). Temperature annual range (TAR) and isothermality (ISO) made the lowest contribution to the predictive model. Considering the permutation importance, MTCQ had the maximum influence on model and contributed to 76.6%, followed by mean temperature of warmest quarter (MTWAQ), i.e., 21.9% (*Table 1*). Climatic profiles (based on the occurrence records; minimum, maximum and mean value of nineteen current climatic variables) for the species under investigation are presented in *Table 2*.

The current suitable habitats for *P. pseudoginseng*, covering 14.4% of the total geographical area, are confined to mainly in central part of North Sikkim district, north-eastern part of East Sikkim district, north-western part of West Sikkim district, with some patches in northern part of South Sikkim district (*Fig. 2a*). The Jackknife test estimated the training gains of each predictor variable, when a variable is used in separation, when it is excluded, and when all variables are utilized. The graph of

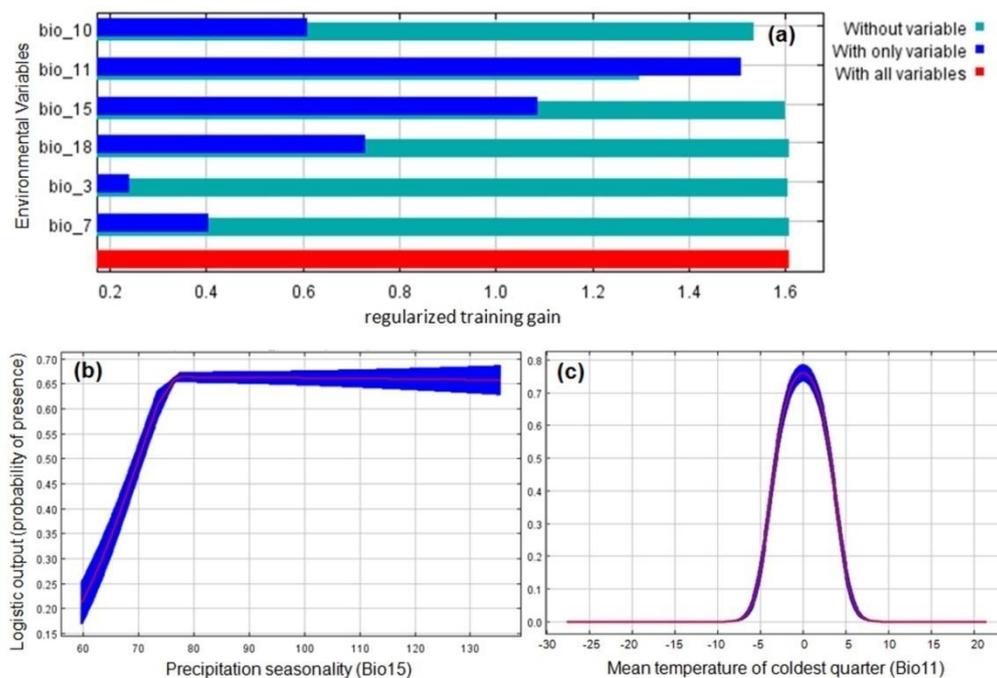
Jackknife predictor test indicates that the MTCQ and PS as main factors influencing the distribution pattern and has highest training gain (Fig. 3a). The response curve of *P. pseudoginseng* showed that the predicted habitat suitability area was initially increased sharply with increasing PS and was bell shaped with MTCQ (Fig. 3b, c). Areas with suitable climatic conditions for *P. pseudoginseng* are predicted to decline by the 2050s and the 2070s under both RCP scenarios. Averaged future predictions from three climatic models under an intermediate scenario (RCP 4.5) of 2050 showed loss of suitable area (190.88 km<sup>2</sup>; 2.69%); while further losing the suitable habitat area over the year 2070 (266.1 km<sup>2</sup>; 3.75%) (Fig. 2b, c; Table 3). The loss of suitable habitat area in average model of RCP 4.5 scenario was predicted mainly in patches form of northern part of West Sikkim and central parts of North Sikkim districts for year 2050, whereas in 2070 the loss predicted continuously over the north-western part of West Sikkim, northern part of South Sikkim, north-eastern part of East Sikkim and, central and north-eastern part of North Sikkim districts (Fig. 2b, c). Conversely, in higher scenario (RCP 8.5) the loss of suitable habitat areas was predicted continuously in northern part of West and South Sikkim districts, and in patches form of north-eastern parts of North and East Sikkim districts for year 2050, whereas in 2070 the loss predicted continuously over the entire four districts of Sikkim (Fig. 2d, e). However, the loss of suitable area predicted under a RCP 8.5 was more than RCP 4.5 for 2050 (307.26 km<sup>2</sup>; 4.3%), which further continuously lost predicted suitable habitat over the year of 2070 (63,509 km<sup>2</sup>; 8.95%) (Fig. 2d, e; Table 3). Those scenarios also decreased the number of suitable patches (i.e. no change/stable) in RCPs 4.5 by 8.21% to 7.51% and RCP 8.5 by 6.57% to 1.95%, over the years 2050 to 2070 respectively. Another common feature for projected distribution in future climate models under the both RCPs scenarios (4.5 and 8.5), was the upward shift of species (i.e., gain in suitable habitat area) in high elevation area over the years of 2050 and 2070.

**Table 2.** Climatic profile of *Panax pseudoginseng* based on herbarium and presence records

Climatic variable	Code	Unit	Min.	Max.	Mean	SD
Annual mean temperature [AMT]	Bio1	°C	3.1	8.2	4.9	1.6
Mean diurnal range temperature {Mean of monthly (max temp - min temp)}[MDRT]	Bio2	°C	9.6	13.0	12.1	1.0
Isothermality (Bio2/Bio7) (* 100) [ISO]	Bio3		45.0	47.0	45.8	0.6
Temperature seasonality (Standard deviation *100) [TS]	Bio4		4271.0	5561.0	5167.5	380.2
Maximum temperature of warmest month [MTWM]	Bio5	°C	14.3	18.3	15.8	1.3
Minimum temperature of coldest month [MTCM]	Bio6	°C	-13.1	-4.0	-10.3	2.5
Temperature annual range (Bio5-Bio6) [TAR]	Bio7	°C	21.1	28.2	26.2	2.1
Mean temperature of wettest quarter [MTWQ]	Bio8	°C	9.4	13.3	11.0	1.3
Mean temperature of driest quarter [MTDQ]	Bio9	°C	-3.2	3.2	-1.1	1.8
Mean temperature of warmest quarter [MTWAQ]	Bio10	°C	9.4	13.3	11.0	1.3
Mean temperature of coldest quarter [MTCQ]	Bio11	°C	-4.2	2.2	-2.1	1.9
Annual precipitation [AP]	Bio12	mm	626.0	1400.0	806.0	211.7
Precipitation of wettest month [PWM]	Bio13	mm	126.0	319.0	168.6	51.9
Precipitation of driest month [PDM]	Bio14	mm	3.0	9.0	5.3	1.7
Precipitation seasonality (Coefficient of variation) [PS]	Bio15		73.0	90.0	81.4	5.8
Precipitation of wettest quarter [PWQ]	Bio16	mm	340.0	818.0	449.8	132.0
Precipitation of driest quarter [PDQ]	Bio17	mm	20.0	49.0	28.1	8.7
Precipitation of warmest quarter [PWAQ]	Bio18	mm	340.0	818.0	449.8	132.0
Precipitation of coldest quarter [PCQ]	Bio19	mm	30.0	62.0	40.1	9.7



**Figure 2.** Predicted (a) current and (b-e) future (Suitable/no change, loss, gain and unsuitable) habitats of *P. pseudoginseng* for the years 2050 and 2070, under RCP 4.5 and RCP 8.5 climate change scenarios



**Figure 3.** (a) Jackknife regularized training gain, showing the relative predictive power of bioclimatic variable; and (b) response curves showing the relationships between probability of presence of a species and climatic variables. (Values shown are average of twenty replicate run)

**Table 3.** Predicted suitable habitat areas for *P. pseudoginseng* under each climate change scenarios

Classes	Area (km <sup>2</sup> )					Area (%)				
	Current	RCP 4.5		RCP 8.5		Current	RCP 4.5		RCP 8.5	
		2050	2070	2050	2070		2050	2080	2050	2070
Suitable/No change	1,025	582.58	507.36	466.21	138.37	14.44	8.21	7.15	6.57	1.95
Loss		190.88	266.10	307.26	635.09		2.69	3.75	4.33	8.95
Gain		491.04	374.67	510.91	1871.92		6.92	5.28	7.20	26.38
Unsuitable		5,831.49	5,947.87	5,811.62	4,450.61		82.18	83.82	81.90	62.72

## Discussion

The modelling result suggests that the suitable habitat area for *Panax pseudoginseng* (*Himalayan Ginseng*) would shrink under the predicted levels of climate change in future. The Maxent model performed better than random, with satisfactory mean test AUC value. Maxent predicted the upward shifts of (i.e., more than 4000 m high elevated zones) *P. pseudoginseng* suitable area under the both intermediate and high scenarios, with greater risk of habitat loss from current suitable predicted areas in Sikkim Himalaya. Field observation suggest the *Himalayan Ginseng* is highly dependent on local climates, the plant thrives only when there is moist soil humus content at places ranging between 3000-4000 m elevations, due to this the species has confined distribution in eastern Himalayan region of India. Maxent model result shows, predicted suitable habitat area under the current climatic condition would become unsuitable in predicted future climate change scenarios, resulting in local extinction of the species.

Considering climate sensitive plants, the seasonality (such as temperature, rainfall, humidity, soil temperature, soil moisture content and day length) expose them to regular periodic changes in the quality and abundance of resources (Franklin et al., 1992). All of these factors are known to play a role, only or in combination with, in triggering the phenological or physiological changes. Some species may be capable of adapting to future climatic condition through phenological changes (such as early or late flowering/fruitletting) or through adaptation towards microclimate conditions responsible for survival of its natural population. In this investigation, *Himalayan Ginseng* showed the range expansions of suitable habitat towards higher elevated zones in future climate change scenarios, which may be to make possible through adaptation towards the changes in local climatic condition. Khanum et al. (2013) showed similar results of adaptation and range expansion of species for predicting the impact of climate change of three important medicinal asclepiads in Pakistan. Midgley et al. (2006) suggested that, in predicting the impact of climate changes on plant species the dispersal of seed is also a regulating factor for adaptation of species. A study across twenty-six mountains in Switzerland demonstrated that, the alpine flora expanded their ranges upward towards the peaks (Grabherr et al., 1994; Pauli et al., 1996) and a similar study by Moiseev and Shiyatov (2003) showed the upward movement of treelines in Siberia.

While generalizing the ecosystem responses towards the rapid warming in the Himalayan region, Singh et al. (2010) have reported that the woody species of higher elevated zones have began to invade the alpine meadows, and result in a complex series of changes in ecosystem functioning process with involvement of the soil subsystems. Another hypothesis is the future exploitations pressure on this plant species will make coping difficult against the climate changes and this could cause the extinction of this species despite good showing in the current and future climate suitable habitats (Svenning et al.,

2009). The present study shows that *Himalayan Ginseng* is threatened under the predicting climate change scenarios in Sikkim, Himalaya; a similar kind of results have been reported from another studies for economically important species, viz., studies on Baobab trees by Sanchez et al. (2011); on medicinal Asclepiads in Pakistan by Khanum et al. (2013); on Caterpillar fungus in Nepal by Shrestha and Bawa (2014) and on *Dysoxylum binectariferum* by Soheli et al. (2016) in northeastern part of Bangladesh. Another parameter such as soil and land transformations would also become the contributing factor for predicting the species response in climate change (Pearson and Dawson, 2005), but the present study did not incorporate these parameters, due to unavailability of datasets.

Species with known economic importance value experiences pressures, (i.e., loss of natural habitats from climate change events, changes in land use and land cover patterns, and overexploitation) because of their known utility (Pandit et al., 2007). These threats adversely affect natural plant resources in Himalayan region of India. The high medicinal important is responsible for their extraction from the wild which has already reduced the population sizes of *Himalayan Ginseng* in the natural population (Pandit and Babu, 1998). Loss of natural habitats due to deforestation, developmental works and expansion of agricultural practices have driven many of the endemic and medicinally important plant species to the brink of extinction in Himalaya region (Pandit et al., 2007). The *Himalayan Ginseng* is already listed as threatened taxa in the Red Data Book of India (Nayar and Sastry, 1990). On regional scale the climate change is one of the greatest challenges for conserving the biodiversity and forests ecosystems. Changes have already reported in different region, including impact of change on plant biodiversity in Europe (Thuiller et al., 2005), plant species vulnerability to climate change in Peninsular Thailand (Trisurat et al., 2011), declines of woody plant species ranges under climate change in Yunnan, China (Zhang et al., 2014) and extinction of freshwater swamp forest trees (*Pongamia pinnata* and *Barringtonia acutangula*) of Bangladesh in climate change scenarios (Deb et al., 2016).

Conservation of natural plant resources at species level has often failed owing to lack of proper knowledge of the target species in term of habitat suitability. The application of Ecological Niche Models (ENMs) to extract simple inventory data (such as presence records of species) may provide predictions of species under changing climates at both regional and local scale, and the models may be used to make recommendations for policymakers and conservationists in dealing with potential climate change (Sanchez et al., 2011). Here, we used the maximum entropy based modelling techniques, as implemented in the ENM software Maxent (Phillips et al., 2006; Elith et al., 2006, 2011), to summarize the climatic niche of the *Himalayan Ginseng* to predict changes in climate change emission scenarios. Maxent accounts for some consequences, for example, it does not estimate the probability of occurrence directly, but rather the environmental suitability for the species that can be mapped in a geographic space (Royle et al., 2012). Considerably, it is the most widely used and has good predictive power capabilities (Elith et al., 2006). Maxent have been used extensively for investigating plant and animal responses to climate change (Trisurat et al., 2011; Chitale and Behera, 2012; Khanum et al., 2013; Kumar, 2013; Shrestha and Bawa, 2014; Alamgir et al., 2015; Cuyckens et al., 2016; Soheli et al., 2016).

## Conservation strategies

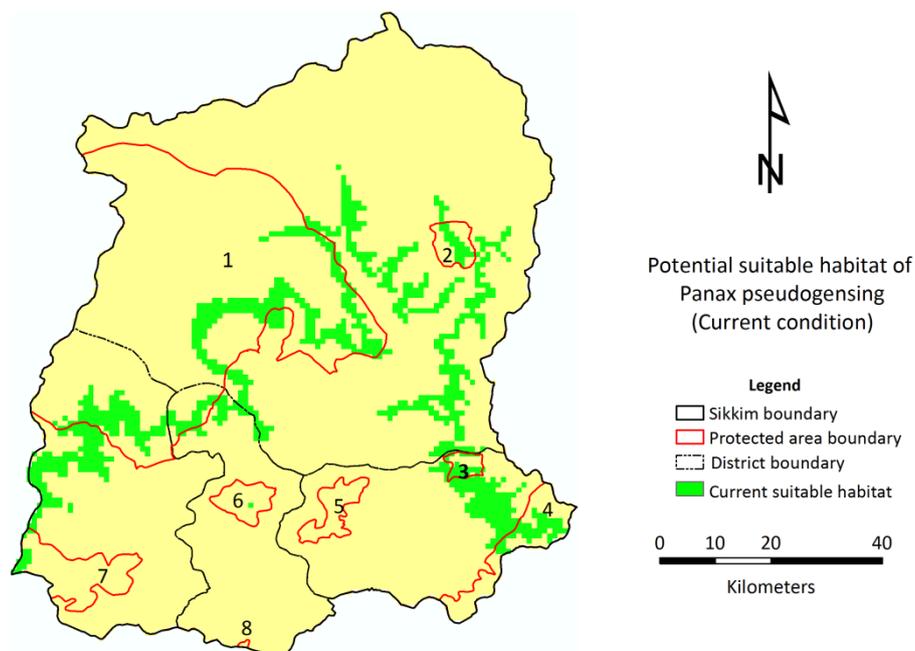
Considering the results in this study by predictive Maxent modelling on distribution of *Himalayan Ginseng* in Sikkim Himalaya, there will be moderate to high impacts under the future climate change scenarios. The most of suitable habitat area predicted for this plant

species might already be devoid of populations due to transformation of landuse, and overexploitations by local people for economic gain. A recent investigation on predicting the impact of climate change on a tree species (*Dysoxylum binectariferum*) in north-eastern part of Bangladesh by Soheli et al. (2016) suggested that the combined effect of human induced anthropogenic factors and change in climate condition in future will increase the extent of unsuitable habitat for the plant. Therefore, successful management plan for conserving the natural population in human dominated landscape is needed which can be used to address the issues and generate connectivity across protected areas (Urbina-Cardona and Flores-Villela, 2010). Besides designating a new protected area, the existing protected areas should have successful management plan for conservation and restoration of key species. These management plans should consider ecotourism, restriction of grazing, firewood collection and forest fire, involving the field researchers, NGOs and local communities. The subtropical to temperate and alpine areas of Sikkim is of special conservation interest as it is also suitable area for the conservation of key species such as the Snow Leopard (Sathyakumar et al., 2011b; Forrest et al., 2012), Red Panda (Ghose et al., 2011), Rhododendrons (Kumar, 2012) and for Galliformes (Sathyakumar et al., 2011a) in different protected area of Sikkim. This is also the area where *Himalayan Ginseng* exhibits the highest generic diversity (Sharma and Pandit, 2011).

Another possible conservation strategy for *Himalayan Ginseng*, especially for areas at high risk of habitat loss, e.g., in Pangolakha Wildlife Sanctuary and Barsey Rhododendron Sanctuary (Fig. 2), could be compensated by ex situ germplasm collection and micropropagation techniques, as suggested by Sanchez et al. (2011) for Baobab trees in Africa. Moreover, results of habitat loss do not necessarily suggest extinction but certainly increase the local extinction risk (Alarcón and Cavieres, 2015). The Convention on Biodiversity (CBD) suggested that a minimum representation of species habitat at ecosystem level should be under protection between 10-12% (Burgess et al., 2005; Tear et al., 2005), or 17% for terrestrial ecosystems (Moilanen et al., 2013). In this study, the current network of PAs accomplishes and even surpasses this suggestion area (at 30.8%) where, most of the natural population of *Himalayan Ginseng* are growing (Fig. 4). Table 4 showed the area statistics of predicted potential habitats for *Himalayan Ginseng* in current climatic condition under different PAs network of Sikkim. The most effective strategy for protecting the *Himalayan Ginseng* viable populations in the areas of suitable future habitat is through conservation or sustainable utilization (Sanchez et al., 2011). For example, if local peoples are made aware that they may reap higher economic benefits from this plant left in their natural habitat than if grown as a crop this change in priority of action would yield better conservation outcome for the *Himalayan Ginseng*.

**Table 4.** Present projection of suitable habitat area of *P. pseudoginseng* in different PAs of Sikkim

Protected area		Predicted potential area habitat for <i>P. pseudoginseng</i>	
Name	Area (km <sup>2</sup> )	km <sup>2</sup>	%
Khangchendzonga National Park	1784.00	290.46	16.28
Shingba Rhododendron Sanctuary	43.00	18.77	43.65
Kyangnosla Alpine Sanctuary	31.00	18.71	60.35
Pangolakha Wildlife Sanctuary	128.00	36.55	28.55
Maenam Wildlife Sanctuary	35.34	0.56	1.58
Barsey Rhododendron Sanctuary	104.00	8.60	8.27
<b>Total</b>	<b>2125.34</b>	<b>373.65</b>	<b>17.58</b>



**Figure 4.** Predicted current potential habitat of *P. pseudoginseng* overlaid on existed protected areas (red color lines) networks of Sikkim Himalaya. (1: Khangchendzonga National Park; 2: Shingba Rhododendron Sanctuary; 3: Kyangnosla Alpine Sanctuary; 4: Pangolakha Wildlife Sanctuary; 5: Fambunglho Wildlife Sanctuary; 6: Maenam Wildlife Sanctuary; 7: Barsey Rhododendron Sanctuary; 8: Kitam Bird Sanctuary)

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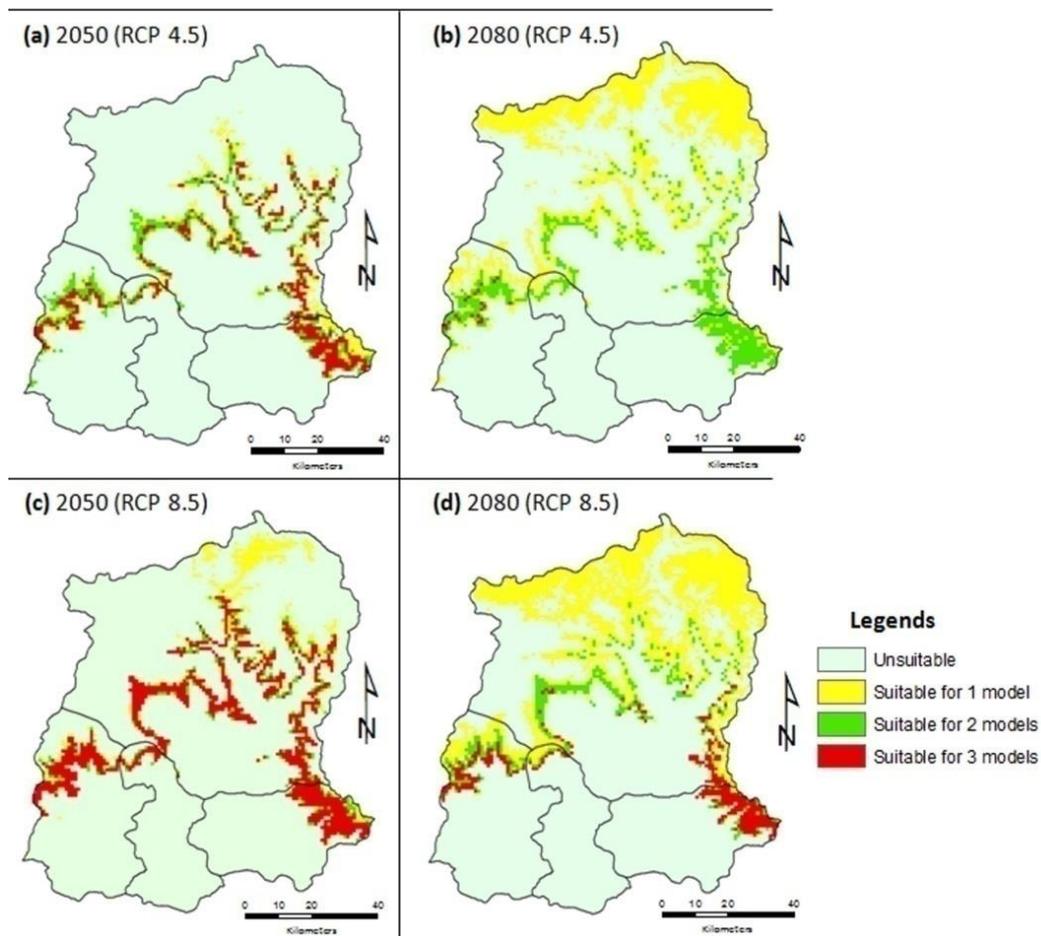
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## APPENDIX

### Uncertainty among model predictions

It should be noted that only three global circulation models (GCMs; MRI-CGCM3, CSIRO-MK3.6 and HadGEM2-CC) under two future climate scenarios (RCP 4.5 and 8.5) were used in this study (Fig. A1).

**Figure A1.** Differences in future potential predictions, among three different Global Circulation Models (GCMs) viz.; CGCM3, CSIRO-MK3 and HadGEM2-CC for *Panax pseudoginseng*. Where cyan color shows unsuitable prediction, yellow color shows predicted suitable habitat area by at least one of the GCMs, green color shows predicted suitable habitat area by two GCMs, and red shows predicted suitable habitat area by all three GCMs



Other scenarios and GCMs could give different results. Buisson et al. (2010) accounted that the Maxent or other modeling algorithms used could yield large variation in projections, followed by GCM, whose contribution increased over time. In order to report for certain future uncertainty Buisson et al. (2010) recommended using several GCMs and scenarios. Model projections also depend on the year. The years 2050 and 2070 are commonly used in studies dealing with the impacts of climate change on biodiversity (Thuiller et al., 2006; Khanum et al., 2013; Dowling, 2015; Hansen and Phillips, 2015; Koo et al., 2015; Al-Qaddi et al., 2016; Deb et al., 2016; Sohel et al., 2016). As expected, projections for 2070 displayed more negative impacts than projections for 2050 (described by Thuiller et al., 2006; York et al. 2014) in RCP 8.5 scenario of climate change. However, in RCP 4.5 scenario projections for 2050 and 2070 displayed less likely to negative impacts.

A pertinent question which arises while studying the potential future distribution of a species is the validity and/or accuracy of the GCM and scenarios commonly used for this purpose, as different GCM from different climatic research centers show different results. However, to date, this is the best data available, and it is still commonly used to study the potential effect of climate change on species' distributions (Buisson et al., 2010; Marini et al., 2010; Khanum et al., 2013; Dowling, 2015; Hansen and Phillips 2015; Koo et al., 2015; Al-Qaddi et al., 2016; Deb et al., 2016; Sohel et al., 2016; Kang et al., 2016). The precautionary principle suggests that the uncertainty about predicted changes in climate does not justify lack of action. It is better to use the data which is available and carry out the studies required to make recommendations for conservation.

**Table A1.** Pairwise correlation matrix (Pearson's correlation coefficients, *r*) between bioclimatic variables. Variables showing (*r*)  $\geq 0.9$  were excluded from the analysis, and only six variables included in this study (i.e., Bio3, Bio7, Bio10, Bio11, Bio15 and Bio18)

Variables	Bio1	Bio2	Bio3	Bio4	Bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18
<b>Bio2</b>	-0.518																	
<b>Bio3</b>	0.319	0.208																
<b>Bio4</b>	-0.592	0.975	0.008															
<b>Bio5</b>	0.850	0.008	0.476	-0.088														
<b>Bio6</b>	0.925	-0.794	0.201	-0.853	0.591													
<b>Bio7</b>	-0.586	0.987	0.063	0.997	-0.075	-0.849												
<b>Bio8</b>	0.957	-0.249	0.401	-0.334	0.966	0.776	-0.326											
<b>Bio9</b>	0.977	-0.678	0.269	-0.748	0.724	0.984	-0.742	0.875										
<b>Bio10</b>	0.957	-0.249	0.401	-0.334	0.966	0.776	-0.326	1.000	0.875									
<b>Bio11</b>	0.980	-0.670	0.269	-0.740	0.732	0.982	-0.734	0.881	1.000	0.881								
<b>Bio12</b>	0.742	-0.955	-0.022	-0.968	0.280	0.936	-0.974	0.515	0.862	0.515	0.856							
<b>Bio13</b>	0.646	-0.970	-0.060	-0.977	0.160	0.879	-0.982	0.401	0.785	0.401	0.778	0.986						
<b>Bio14</b>	0.741	-0.887	0.200	-0.954	0.313	0.928	-0.942	0.528	0.860	0.528	0.852	0.952	0.934					
<b>Bio15</b>	-0.200	-0.573	-0.104	-0.575	-0.588	0.147	-0.567	-0.434	-0.013	-0.434	-0.026	0.413	0.551	0.424				
<b>Bio16</b>	0.657	-0.974	-0.046	-0.984	0.169	0.890	-0.989	0.412	0.796	0.412	0.789	0.990	0.998	0.946	0.532			
<b>Bio17</b>	0.814	-0.897	0.127	-0.946	0.395	0.971	-0.941	0.613	0.917	0.613	0.890	0.979	0.943	0.976	0.316	0.955		
<b>Bio18</b>	0.657	-0.974	-0.046	-0.984	0.169	0.890	-0.989	0.412	0.796	0.412	0.789	0.990	0.998	0.946	0.532	1.000	0.955	
<b>Bio19</b>	0.870	-0.840	0.181	-0.900	0.494	0.984	-0.893	0.696	0.951	0.696	0.856	0.951	0.894	0.953	0.194	0.909	0.990	0.864