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Species Distribution Modelling of *Rhododendron arboreum* Sm. – A Keystone Species, in India and Adjoining Region

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ABSTRACT

Rapid global climate change is threatening the species for their healthy survival. The increase in mean surface temperature is particularly evident in mountain areas where there has been increase in winter temperature, less snowfall and more rainfall. In this study, we have modeled the species distribution of *Rhododendron arboreum* Sm., which is an ecological and economically important forest tree species in entire Himalayan mountain range, using three future climate scenarios of three global climate models. We have used species location data of Uttarakhand state to model species distribution in the Himalayan region and adjoining areas, where species has been reported. New region (Philippines and Taiwan) where species has its potential habitat and thus, could be introduced has been proposed. Most areas where species is found are biodiversity hotspot areas. All future models suggest that the species would suffer from range contraction and population localization and ultimately extinction in low altitude (<3000 m) areas, whereas, species would be able to expand its range in areas of high altitudes (>4000 m) where there is possibility to move upwards. The range expansion of species will be under check by environmental and anthropogenic factors. The populations in different region will exhibit variation in survival behaviour based on local environmental conditions. However, species being a tree would survive in scattered refugia habitat leading to range disjunction and will be able to spread to other areas through forest corridors when favourable environment appears. Key environment variables which will affect future distribution of *R. arboreum* are temperature and precipitation. Altitude and slope govern species distribution of mountain plants like *R. arboreum*. The species will struggle to survive (or get extinct) in low (1400-1700 m) and lower-middle (1800-2000 m) altitude zones. The factors responsible for *R. arboreum* forest destruction and conservation measures have been suggested. Management actions should be taken quickly to ensure a healthy species distribution in future environment.

Key Words: Anthropogenic Pressure; Biodiversity Hotspot; Climate Change; Conservation; Himalaya; MaxEnt; Uttarakhand.

Abbreviation and Symbols: a.m.s.l. (above mean sea level), °C (degree Celsius), FAO (Food and Agriculture Organization), FSI (Forest Survey of India), ha (hectare), km^2 (square kilometres), m (metre), m^3 (cubic metres), mm (millimetres), % (percent).

INTRODUCTION

The Himalayan mountain chain is a global biodiversity hotspot (Mittermeier et al. 2004, Convention on Biological Diversity India 2009) and extends from North-Western (NW) Indian state of Jammu and Kashmir (J&K) to North-Eastern (NE) state of Arunachal Pradesh. The mountainous region of Indian Himalaya harbours wide diversity of flora and fauna (Badola and Aitken 2003, Nandy et al. 2006). According to an estimate, the Indian Himalayan region (IHR) harbours around 18,440 plant species [~8000 species of angiosperms (40% endemic)] (Singh and Hajra 1996, Samant et al. 1998) of which 1,748 species have medicinal value (Samant et al. 1998) and 675 species are used as wild edibles (Samant and Dhar 1997). Out of these 121 plant species are characterized as rare, endangered and threatened (RET) species in the Red Data book of Indian plants (Nayar and Shastri 1987-90).

Due to climate change, earth's global mean surface temperature had quickly risen in past decade (Hansen et al. 2010) breaching the mark of 1°C in year 2015 (Hawkins et al. 2017). However, temperature change in the Himalayan region is quite significant e.g. in NW Himalayan region annual temperature has increased by 1.6 °C (Bhutiyani et al. 2007). Similarly, temperature in southern slope of central Himalayan region is increasing at a rate of 0.65°C/decade (maximum) and 0.11°C/decade (minimum) (Kattel and Yao, 2013). Main causal agents responsible for increasing temperature are anthropogenic factors such as greenhouse gases (Tett et al. 1999, Crowley 2000, Hughes 2000, Huber and Knutti 2011) and sulphate aerosols (Tett et al. 1999, Huber and Knutti 2011).

Most of the brunt of changing climate is borne by plant species because unlike animals, they are immobile and are adapted to local climatic conditions. Most pronounced effect of global warming is on land plants particularly trees as they form major component of a forest ecosystem and serve as foundation and keystone species (Aitken et al. 2008). The mountainous forests (sub-alpine, alpine, Himalayan dry temperate and Himalayan moist temperate forests) are the most susceptible sites to climate change because of greater altitude of these regions and thus, will receive more warming in the coming years (Chaturevdi et al. 2011, Gopalakrishnan et al. 2011). Satellite image analysis has shown that by year 2100 only 10% of the dense forest will be left in the IHR (Pandit et al. 2007). In the IHR, some species are expanding their range upward and thus intruding in habitat of other species (Dubey et al. 2003), whereas some are moving towards higher altitudes due to development of unfavourable climatic conditions at lower altitudes (Singh et al. 2012, Telwala et al. 2013). Other changes brought about by global climate change in the Himalayan mountain ecosystem are: precocious flowering (Ranjitkar et al. 2013, Rawat, 2013), altered leaf phenology (Singh et al. 2010), melting and receding of glaciers (Hasnain 2002, Mehta et al. 2011, Pandey et al. 2011) causing increased river flow and drainage.

Forests are important ecosystems because they provide countless ecosystem services. In the Himalayan mountain there are different climatic conditions according to the altitude and thus the forest structure changes with increase or decrease in elevation. The forests are named on the basis of dominant tree species present in them e.g. the Himalayan mountain range exhibits, pine-oak, oak-rhododendron and birch-rhododendron forest etc. (Singh and Singh 1987). Generally, dominant plant species present in the forest ecosystem are Keystone species (Paine 1969). One such keystone species is *Rhododendron arboreum* Sm. (Tree Rhododendron) which is present in the entire Himalayan region from western to easternmost part, providing stabilization to mountain slopes. It gives refuge to lichens, orchids, bryophytes, pteridophytes, and provide food source for insect, birds, animal including human beings. The plant has ethno-medicinal value as it is used to treat throat pain, diarrhoea, burns and scalds (Kunwar et al. 2006, Bhattacharya et al. 2015). Different parts such as flowers possess antihyperglycemic, antihyperlipidemic (Verma et al. 2012) and anti-inflammatory activity (Agrawal and Sharma 1988), bark has antifungal, antinociceptive, anti-inflammatory activity (Nisar et al. 2013, 2016) and leaves have immunosuppressive (Sonar et al. 2013), anti-inflammatory, anti-oxidative and membrane stabilizing activity (Kumar et al. 2014). It is an important agro-forestry species, wood used for fuel, making furniture (Turin 2003) agricultural implements (Arya 2014) etc., flowers being used for making juice, squash, offered to the temple for religious purpose, provide aesthetic beauty etc., and leaves used as fodder (Turin 2003) and manure (Arya 2013). It can also be regarded as a cultural keystone species, which serve as an indicator for the society or cultural group, besides providing innumerable essential ecosystem services (Garibaldi and Turner 2004, Cristancho and Vining 2004). Here in this study, we have used *R. arboreum* as a model species to study the impact of global warming on the Himalayan and mountain forest ecosystem.

Species distribution models (SDMs) are experimental models associating species occurrence data to environmental predictor variables, based on statistically or theoretically derived response surfaces, used to assess the suitable conditions for species persistence (Guisan and Zimmermann 2000, Araújo and Peterson 2012). Less work had been conducted in area of distribution extent of Rhododendrons in the Himalayan region (Vetaas 2000, 2002, Kumar 2012, Menon et al. 2012, Ranjitkar et al. 2014) and very few particularly in *R. arboreum* (Vetaas 2000, 2002, Ranjitkar et al. 2014, Mamgain et al. 2017). The study was conducted to answer these questions: i) to estimate the distribution of *R. arboreum* in the present environmental conditions, ii) to use species location data of *R. arboreum* in Uttarakhand in order to predict the distribution extent of *R. arboreum* under future climate scenarios using three climate models, iii) to determine novel potential habitat sites of species outside its distributional range.

MATERIAL AND METHODS

Site Selection

The location of species under investigation was accessed by visiting different herbaria [(University of Delhi (code DUH), National of Bureau of Plant Genetic Resources, New Delhi (NHCP), Botanical Survey of India, Northern Circle Dehradun (BSD), Forest Research Institute, Dehradun (DD) and Botanical Survey of India, Kolkatta (CAL)]. The selection of sites to be surveyed were made by using the data from herbaria, earlier published reports, on altitude basis, information provided by local people and online database (GBIF) (GBIF 2016).

Study Area

The Uttarakhand state (28° 44' & 31° 28' N Latitude and 77° 35' & 81° 01' East longitude) lies in the central IHR and comprises of 13 districts grouped into two administrative divisions: Garhwal (North-West) and Kumaon (Kumaun) (South-East) region (Uttaranchal SoE 2004, UKSAPCC 2012). Total geographic area is 53,484 km^2 out of which 37,999.53 km^2 (71.04%) is forest area (UK Forest Statistics 2012-13), 93% (46035 km^2) is hill area and only 7% (7448 km^2) being plane area (UK at a Glance 2013-14) with altitude varying from 210-7817 m above mean sea level (a.m.s.l.) (UKSAPCC 2012).

Average annual rainfall is 1631 mm (year 2012) and average summer and winter temperature is 30°C and 18°C (UK at a Glance 2013-14). Five climatic zones are classified according to altitude viz. warm temperate (900-1800 m), cool temperate (1800-2400 m), cold zones (2400-3000 m), alpine zone (3000-4000 m), glacier zone (4000-4800 m), and perpetually frozen zone (>4800 m) (UK Forest Statistics 2012-13). Physiographic zones are characterized into two broad types: i) non-montane zone (consist of bhabhar and tarai areas) and ii) montane zone consisting of sub-Himalayas, mid-Himalayas, greater-Himalayas and trans-Himalayas (Uttaranchal SoE 2004). Eight major forest types found in the state are: tropical moist deciduous, tropical dry deciduous, subtropical pine, Himalayan moist temperate, Himalayan dry temperate, subalpine, moist alpine scrub and dry alpine scrub forests (FSI 2011). There are also present pastures (2400-2800 m) and alpine meadows (>3000 m). The total flowering plant species found in the state are ~4,700 (Uniyal et al. 2007).

In this study, locations of *R. arboreum* present in Uttarakhand were used as training and test data to model the species distribution in India and adjoining region [(because i) Himalayas and South-East (SE) Asia are centre of diversity for Rhododendrons (Gibbs et al. 2011), and ii) *R. arboreum* subspecies are present in other Indian states and adjoining areas of China and SE Asia (Black 1966, Mei and Pei-Gen 1992, Vetaas 2002, Kress et al. 2003, Gibbs et al. 2011, Ranjitkar et al. 2014) (Table 1) Figure 1] under three global climate models.

Study Species

R. arboreum (Ericaceae, subgenus Hymenanthes, section Pontica, subsection Arborea) [vernacular name 'Buransh' (Hindi) or 'Guransh'/'Lali Guransh' (Nepali)] is an evergreen medium sized tree (5-12 m, maximum 15 m), present throughout the IHR. It is an important component of montane forest ecosystem with Oak (*Quercus* species) and shows scattered presence in Pine (*Pinus*) forest. Altitudinal range of occurrence is from warm temperate (1500 m) to subalpine zone (3300 m).

Climate Data

A total of 26 environment variables were selected for species distribution modelling of *R. arboreum*. For the environmental data 19 bioclimatic (BIOCLIM) variables were downloaded from the Worldclim database version 1.4 (Hijmans et al. 2005, WorldClim 2016) at a 2.5 arc minute spatial resolution (~4.5 km at the equator) for the period 1950-2000. These bioclimatic variables correspond to the annual variation (trend), seasonality and extremes of environmental feature (temperature and precipitation) (Hijmans et al. 2005). The reason behind selecting 2.5 arc minute spatial resolution were: i) study species is a tree and therefore unlike herbs is not distributed sparsely or in patches, whereas it forms forest in mountain like Rhododendron-Oak forest, ii) it is a widespread species, iii) selected resolution is close to fine resolution of 30 second spatial resolution, iv) coarser resolution is easy to handle because of small file size. Altitude was available from DIVA GIS database (DIVA-GIS, Free Spatial Data 2016) and other geographical variables were accessible from the US Geological Survey's Earth Explorer (2016), which included drainage directions, slope aspect, digital elevation model, slope inclination, topographic index and flow accumulation (Table 2).

Table 1. Reported distribution of *R. arboreum* and its subspecies (ssp.) in India and other countries. (Abbreviation: AP - Arunachal Pradesh, EN - endemic, HP - Himachal Pradesh, J&K - Jammu and Kashmir, MG - Meghalaya, MN - Manipur, MZ - Mizoram, NG - Nagaland, SK - Sikkim, SW Ghats - South-western Ghats, TN - Tamil Nadu, UK - Uttarakhand, VU - vulnerable, WB - West Bengal, syn. - synonym)

Species	India		Other Countries
	Location	Status	
1) *Rhododendron arboreum* Smith var. *arboreum* (C.B. Clarke) Ridley [syn. *R. arboreum* Smith subsp. *arboreum*]	AP (Kalita & Khan 2013); HP (Sharma et al. 2004, Uniyal et al. 2006); J&K (Dangwal et al. 2014; Khan & Hussain 2014); MG (Yumnam 2008); MN, MZ, NG (Sekar & Srivastava 2010); SK (Singh et al. 2003; Tiwari & Chauhan 2006; Singh et al. 2009; Mao 2010); UK (Dangwal & Sharma 2011; Ballabha et al. 2013; this study); WB (Bhattacharya & Sanjappa 2008; Bhattacharya et al. 2015)	VU [SK (Tiwari & Chauhan 2006; Singh et al. 2009)]	Bhutan (Mao 2010); China (Mei & Pei-Gen 1992); Nepal (Vetaas 2000, 2002; Mao 2010; Ranjitkar et al. 2014); Pakistan (Haq et al. 2011; Ali et al. 2015)
2) *R. arboreum* Sm. subsp. *cinnamomeum* (Wall. ex G.Don) Tagg [syn. *R. arboreum* Sm. var. *cinnamomeum* (Wall. ex G.Don) Lindley]	AP (Mao 2010); SK (Mao 2010); UK (this study)		Bhutan (*R. arboreum* subsp. *campbelliae*, Wangda & Ohsawa 2006); Nepal (Vetaas 2000, 2002; Mao 2010)
3) *R. arboreum* Sm. var. *roseum* Lindley [syn. *R. arboreum* Sm. var. *album* Wallich]	AP (Mao 2010); SK (Mao 2010); UK (this study)		Bhutan (Mao 2010); China (Mao 2010); Nepal (Vetaas 2000, 2002; Mao 2010); Tibet (Wang et al. 2014)
4) *R. arboreum* Sm. subsp. *delavayi* (Franchet) Chamberlain [syn. *R. arboreum* Sm. var. *delavayi* (C.B. Clarke) Ridley]	AP (Mao 2010); MG (Yumnam 2008; Mao 2010); MN, NG (Mao 2010; Mao & Gogoi 2012); MZ (Mao 2010)		China (Hemsely & Wilson 1910; Berg 1986; Mei & Pei-Gen 1992; Ma et al. 2010; Ranjitkar et al. 2014); Myanmar (Valder 1983; Kress et al. 2003; Mao 2010); Thailand (Valder 1983; Khamyong et al. 2004; Mao 2010); Vietnam (Valder 1983)
5) *R. delavayi* Franchet var. *adenostylum* Xiang Chen & X. Chen			China (Chen et al. 2010)
6) *R. delavayi* Franchet var. *peramoenum* (I. B. Balfour & Forrest) T. L. Ming	AP (Paul et al. 2005; Mao 2010; Paul et al. 2010; Menon et al. 2012)	EN [AP (Paul et al. 2005; Paul et al. 2010; Sekar & Srivastava 2010; Menon et al. 2012)]	China (Valder 1983); Myanmar (Kress et al. 2003); Vietnam (Valder 1983); Tibet (Wang et al. 2014)
7) *R. arboreum* Sm. ssp. *niligaricum* (Zenker) Tagg	SW Ghats [KL (Giriraj et al. 2008); TN (Valder 1983; Jain et al. 2000; Paul et al. 2005; Giriraj et al. 2008; Kuttapetty et al. 2014)]	EN (Paul et al. 2005; Giriraj et al. 2008; Kuttapetty et al. 2014)	---
8) *R. arboreum* Sm. ssp. *zeylanicum* (T.J.Booth) Tagg		VU (MOE 2012)	Sri Lanka (Valder 1983; Justice 1990; Jain et al. 2000; Kuttapetty et al. 2014)
9) *R. arboreum* Sm. (hybrid)			New Guinea (Black 1966)
10) *R. arboreum* Sm. (subspecies not given)			Bhutan (Wangda & Ohsawa 2006; Moktan et al. 2009); Myanmar (Kress et al. 2003); Thailand (Frahm et al. 2009); Vietnam (Nguyen & Nguyen 2012),

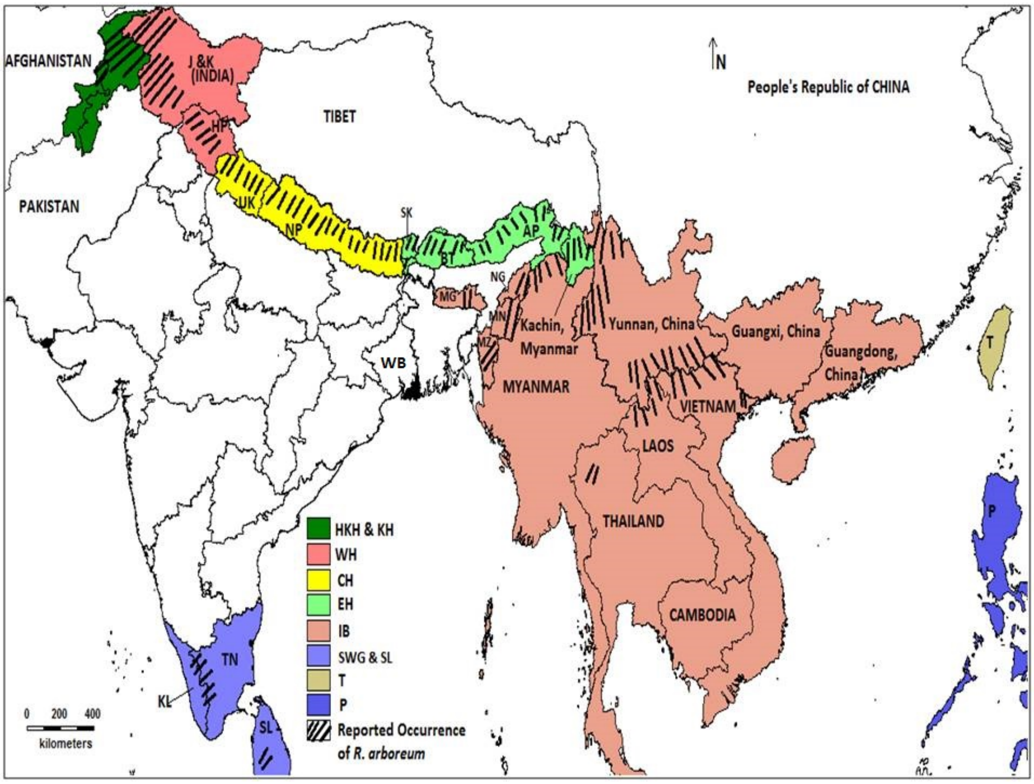

Figure 1. Map showing locations (bars) of reported occurrence of *R. arboreum* and its subspecies in five biodiversity hotspots (Himalaya, SWG & SL, IB, T and P).

Abbreviations: J&K - Jammu & Kashmir, HP - Himachal Pradesh, UK - Uttarakhand, NP - Nepal, SK - Sikkim, WB - West Bengal, BT - Bhutan, AP - Arunachal Pradesh, MG - Meghalaya, MN - Manipur, NG - Nagaland, MZ - Mizoram, KL - Kerala, TN - Tamil Nadu, SL - Sri Lanka, HKH & KH - Hindu Kush Himalaya & Karakorum Himalaya, WH - Western Himalaya, CH - Central Himalaya, EH - Eastern Himalaya, IB - Indo Burma, SWG & SL - South-western Ghats and Sri Lanka, T - Taiwan, P - Philippines

Future Climate Scenarios

To predict species distribution in future climatic condition three global climate models (GCMs) were used. The data for these GCMs were downloaded from WorldClim 1.4 downscaled [Coupled Model Inter-comparison Project Phase 5 (CMIP5)] data (WorldClim 2016) database. These GCMs has data under heading of representative concentration pathways (RCPs), which represent the amount of different concentration of green-house gases and pollutants. RCPs were proposed during the IPCC (Intergovernmental Panel on Climate Change) Fifth Assessment Report (AR5) 2013 (Collins et al. 2013) and were part of CMIP5 having a radiative forcing levels of 2.6, 4.5, 6.0 and 8.5 watts/m^2 by the year 2100 (Meinshausen et al. 2011, Van Vuuren et al. 2011). The three GCMs used were: Community Climate System Model Version 4 (CCSM4) (Gent et al. 2011), Hadley Centre Global Environmental Model version 2- Earth System (HadGEM2-ES) (Jones et al. 2011, Martin et al. 2011) and Model for Interdisciplinary Research on Climate-Earth System Model (MIROC-ESM) (Watanabe et al. 2011) each having three RCPs of 2.6, 6.0 and 8.5 representing low, medium and high emission scenarios of the year 2050 (average 2041-2060) and 2070 (average 2061-2080) respectively.

Model Construction

Ninety four species location points of *R. arboreum* in Uttarakhand were collected of which 47 primary points were obtained through field surveys and the rest were obtained through herbaria and research papers and verified using Google Earth (version 7.1) (Google Earth 2016) (Figure 2). The climate data (GeoTiff format) was converted into ASCII raster grids using Quantum GIS (Q-GIS version 2.14.1 -Essen) (Quantum GIS Development Team, 2012) and these ASCII raster grids were converted into Arc/Info II Binary Grid using ARC View 3.3 (ESRI 2002). These arc/info binary grid files

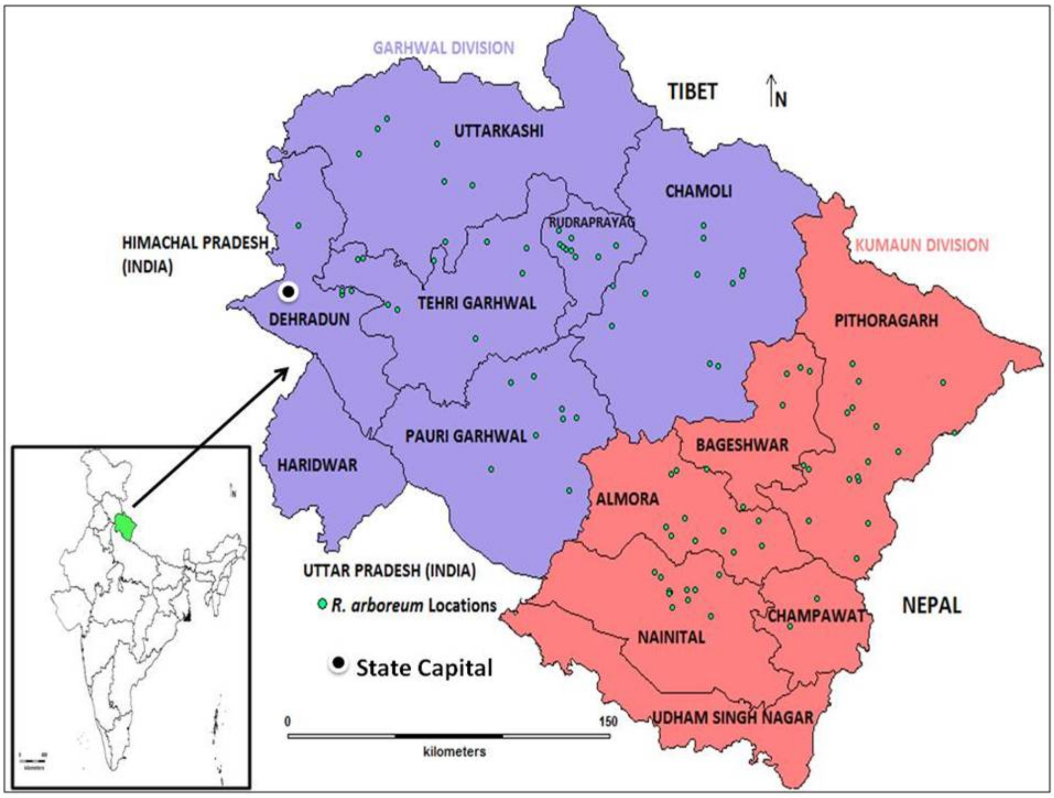

Figure 2. Study area showing locations (green circles) of *R. arboreum* in Uttarakhand state, used in construction of species distribution models. Inset shows India with Uttarakhand state in green colour.

were used to clip the bioclimatic variables to the study area of India and adjoining countries at a spatial resolution of 11.25 km in ARC View 3.3. A total of 26 environmental variables were used to model the species distribution (Table 2). ASCII grid files obtained after MaxEnt analysis were analysed for calculating the area. The extent of area in each modelling scenario was determined by cell analysis in ARC View 3.3 and verified by Q-GIS. Thus, total mean area (land and sea) covered during analysis is 24,260,951.95 ± 133,973.79 (standard error) km^2 of which total mean land area amounts to 14,904,644.68 ± 82,311.87 (standard error) km^2. The species distribution area (under future climate scenario) is given in percentage of the total land area because there still can be measurement discrepancy in accuracy of total mean land area because it is measured using a GIS software in contrast to the area measured during land survey (Table 3). The species distribution model maps for present and future scenarios were compared with each other to ascertain the future status of the species in different regions: Himalayan region, South-Western (SW) Ghats and Sri Lanka (S.L.), Indo-Burma and new region.

Model Robustness

Species distribution model was developed using maximum entropy modelling (MaxEnt version 3.3.3k) (Phillips et al. 2004, Phillips et al. 2006, Phillips et al. Internet). Presently, maxent features among the most widely used programs for SDM. This program identifies the target distribution of species by calculating probability of maximum entropy from the set of conditions which have features close to target species distribution (Philips et al. 2006). Some quality features of this program are: a) only presence data of the species is needed along with environmental data, b) can operate on both continuous and categorical environmental data and also include relations between different environmental variables, c) has brief mathematical definition and thus can be analysed, d) results are continuous so that separate areas can be identified based on model suitability, e) can handle small sample size, f) the logistics output predicts probability distribution of the species close to the surroundings and help in model calibration, g) based on the number of samples, the program has different features like linear, quadratic,

Table 2. Table shows the different environment variables used in the present study of species distribution modelling.

Category	Variable	Abbreviation	Unit
Climate	Annual mean temperature	bio1	°C
	Mean diurnal range	bio2	°C
	Isothermality	bio3	-
	Temperature seasonality	bio4	°C
	Max. temperature of warmest month	bio5	°C
	Min temperature of coldest month	bio6	°C
	Temperature annual range	bio7	°C
	Mean temperature of wettest quarter	bio8	°C
	Mean temperature of driest quarter	bio9	°C
	Mean temperature of warmest quarter	bio10	°C
	Mean temperature of coldest quarter	bio11	°C
	Annual precipitation	bio12	mm
	Precipitation of wettest month	bio13	mm
	Precipitation of driest month	bio14	mm
	Precipitation seasonality	bio15	-
	Precipitation of wettest quarter	bio16	mm
	Precipitation of driest quarter	bio17	mm
	Precipitation of warmest quarter	bio18	mm
	Precipitation of coldest quarter	bio19	mm
Topography			
	Altitude	alt	m
Hydro-1K			
	Drainage directions	fl_dir	
	Slope Aspect	h_aspect	°
	Digital elevation model	h_dem	m
	Slope inclination (angle)	h_slope	°
	Topographic Index	h_topoind	-
	Flow accumulation	wt_flacc	-

Table 3. Table shows distribution percentage of *R. arboreum* with AUC values in present and future climate scenario.

Model	Year	RCP	Distribution (%)	AUC Training	AUC Test
Present		-	10.64	0.995	0.995
CCSM4	2050	2.6	16.57	0.994	0.995
		6.0	11.37	0.996	0.98
		8.5	12.42	0.996	0.993
	2070	2.6	17.60	0.994	0.995
		6.0	20.09	0.994	0.992
		8.5	25.62	0.993	0.994
HadGEM2-ES	2050	2.6	8.46	0.995	0.995
		6.0	7.59	0.996	0.995
		8.5	3.94	0.996	0.997
	2070	2.6	8.11	0.995	0.994
		6.0	6.14	0.996	0.996
		8.5	2.89	0.996	0.996
MIROC-ESM	2050	2.6	15.21	0.996	0.994
		6.0	15.49	0.994	0.994
		8.5	12.69	0.996	0.995
	2070	2.6	17.47	0.993	0.993
		6.0	16.69	0.996	0.997
		8.5	17.53	0.997	0.994

hinge, threshold and product, h) regularization (L1-regularization) is a consistent and modern method and makes the distribution smooth, thus helping in model selection, i) "target-group" background sampling increases analytical capacity while random background sampling decreases model running time (Phillips et al. 2006, Pearson et al. 2007, Phillips and Dudík 2008, Elith et al. 2011).

The 94 occurrence records of the species were divided into training (70%) and testing (30%) the model. A regularization multiplier of 30 was used to reduce model over-fitting and make the smooth and widespread species distribution because *R. arboreum* is a widespread species. Maximum iterations used were 10000 to have the model sufficient time for convergence and replicated run type of subsample was selected, where sample sets replicate were selected by removing random test percentage without substitution to be used for estimation. Other parameters settings were default. The Area Under Curve (AUC) value of the receiver-operating characteristic (ROC) plot was used to evaluate the model as suggested by Thuiller et al. (2005), null model (AUC <0.8), fair (0.8 < AUC < 0.9), good (0.9 < AUC < 0.95), very good (0.95 < AUC < 1).

In a receiver operating characteristic curve (ROC), a relationship is plotted between true positive ratio (TPR) (sensitivity) on y-axis and false positive ratio (FPR) (1-specificity) on x-axis as one varies the definition of positivity (Centor 1991). Sensitivity is the proportion of true positives correctly predicted, whereas, specificity is the proportion of true negatives correctly predicted (Thuiller et al. 2005). In assessment of performance of machine learning algorithm the area under the ROC curve (AUC) is used (Bradley 1997).

AUC can vary between 0.5-1.0 (Swets 1988). High performance models generally have large areas under the ROC curves [i.e. high AUC] (Manel et al. 2001). Some advantages of ROC curve analysis are: i) increased sensitivity in Analysis of Variance (ANOVA) tests, ii) decision is threshold independent, iii) gives an indication of how well separated the negative and positive classes are for the decision index, iv) it is invariant to a-priori class probabilities (Bradley 1997).

RESULTS

Model Calibration

The model performance for *R. arboreum* gave acceptable results in terms for AUC values (AUC_{train} = 0.993-0.997 and AUC_{test} = 0.992-0.997) (Table 3). Out of the 26 environment variables 19 variables contributed to the model development and the remaining seven contributed scarcely. Of the 19 variables the most significant were bio4 (contribution 18.5-32.1%), bio6 (11.5-40.6%), bio14 (0.8-22.9%), bio17 (7.6-33.6%), bio19 (0.6-19.4%), altitude (0.1-9.2%) and slope (0.8-5.5%). The altitude was found to be important variable for CCSM4 (Figure 3a) and MIROC-ESM model (Figure 3c), while slope was found to be important for HadGEM2-ES (Figure 3b) and MIROC-ESM model. Topographic index was important for MIROC-ESM model.

Evaluation of Current Species Distribution

Our models correctly predicted the distribution of *R. arboreum* in J&K, Himachal Pradesh (H.P.), Sikkim, Arunachal Pradesh (A.P.), Meghalaya, Manipur, Nagaland, Mizoram, West- Bengal (W.B.), SW Ghats and S.L., even though we have not supplied the occurrence data of *R. arboreum* to the algorithm (Table 1) (Figure 4). Similarly, present distribution was also found in Myanmar, Vietnam. This shows that the modelling results were accurate and close to present occurrence. Climatic conditions suitable for species growth were also found in Laos, Taiwan and Philippines.

Area Evaluation of Future Species Distribution

We have predicted the future distribution extent of the species by counting the number of cells containing the data in each scenario. The distributional extent of *R. arboreum* in the present climate is 10.64 % of the total land area (Table 3) (Figure 4).

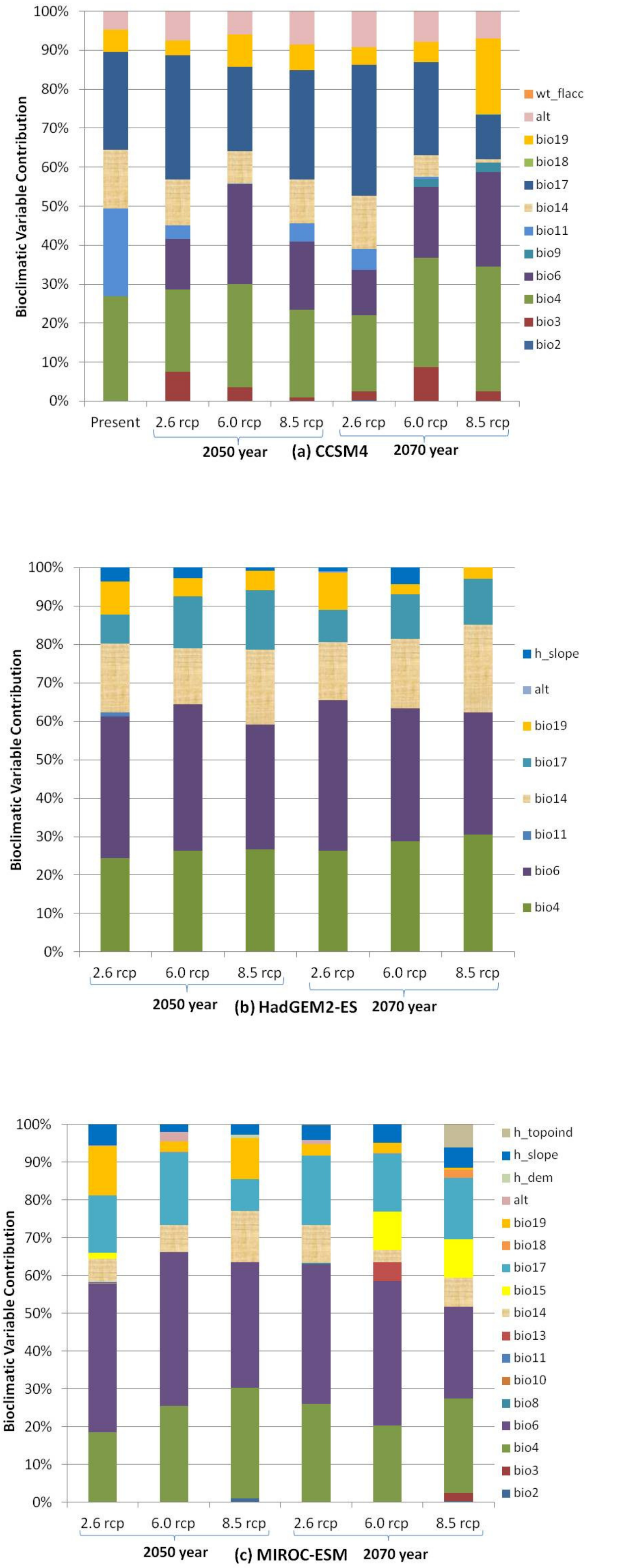

Figure 3. Contributions of bioclimatic variables to: a) present model (year 1950-2000) and future model scenarios of CCSM4 GCM, b) HadGEM2-ES GCM and c) MIROC-ESM GCM.

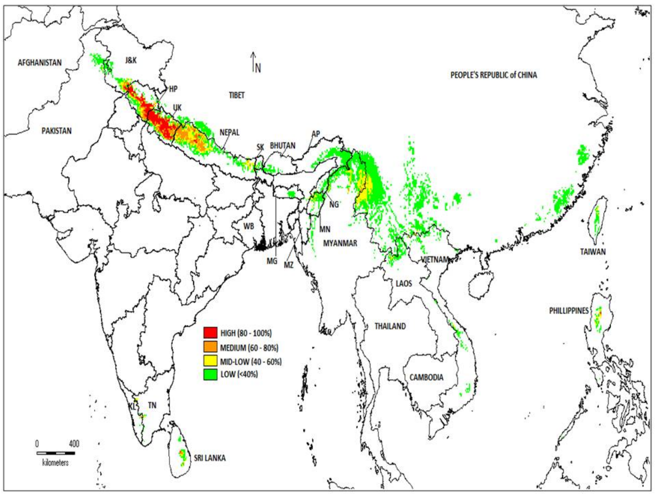

Figure 4. Habitat suitability map of *R. arboreum* in present scenario (year 1950-2000)

1) RCP 2.6

According to CCSM4 model, area distribution percentage will increase to 16.57% and 17.60 % for the period 2050 (Figure 5a) and 2070 (Figure 6a) respectively. HadGEM2-ES model predicts that the distribution percentage will decrease to 8.46% (period 2050) (Figure 7a) and 8.11% (period 2070) (Figure 8a). MIROC-ESM model predicts increase in distribution percentage to 15.21% (period 2050) (Figure 9a) and 17.47% (period 2070) (Figure 10a).

2) RCP 6.0

CCSM4 model predicts that the distribution percentage will increase to 11.37% for the period 2050 (Figure 5b) and 20.09% for period 2070 (Figure 6b). However, the HadGEM2-ES model predicts decrease in distribution percentage to 7.59% (period 2050) (Figure 7b) and 6.14% (period 2070) (Figure 8b). MIROC-ESM predicts increase in distribution percentage to 15.49% (period 2050) (Figure 9b) and 16.69% (period 2070) (Figure 10b).

3) RCP 8.5

CCSM4 model predicts that the distribution percentage will increase to 12.42% for the period 2050 (Figure 5c) and 25.62% for period 2070 (Figure 6c). However, the HadGEM2-ES model predicts drastic decrease in distribution percentage to 3.94% (period 2050) (Figure 7c) and 2.89% (period 2070) (Figure 8c). MIROC-ESM predicts increase in distribution percentage to 12.69 % (period 2050) (Figure 9c) and 17.53 % (period 2070) (Figure 10c).

Future Prediction on *R. arboreum* in Different Regions under Diverse Modelling Scenarios

1) Himalayan Region

In the Himalayan region, NW Himalayas include Indian states of J&K, and H.P., Khyber-Pakhtunkhwa and FATA (Federally Administered Tribal Areas) province of Pakistan. The central Himalayan region includes Uttarkhand (India), Nepal and west Tibet, and NE Himalayan region includes A.P. (India), Bhutan, Sikkim (India), W.B. (India), east Tibet and northern Myanmar. According to CCSM4 and MIROC-ESM model, there would be range expansion with decrease in distribution area, along with population localization (isolation) at some places in NW and central Himalayan region. In NE Himalayan region there would be range expansion and increase in distribution area, along with decrease and population localization at some places. According to HadGEM2-ES model, there would be decrease in distribution area and population localization in entire Himalayan region. (Table 4).

2) SW Ghats and Sri Lanka

According to CCSM4 and MIROC-ESM model, there would be decrease in distribution area and population localization in SW Ghats and S.L. Some areas in SW Ghats will show range expansion and in S.L. under worst circumstances species will show extinction. According to HadGEM2-ES model, there would be decrease in distribution area and population localization in both SW Ghats and S.L. (Table 4).

3) Indo-Burma

Indo-Burma region includes Indian states of Meghalaya, Manipur, Mizoram and Nagaland and countries of Laos, Myanmar, Thailand, Vietnam and Yunnan (South China). Although we have not found any report for *R. arboreum* occurring in Laos however, our results showed that northern Laos has suitable climatic conditions for species growth. However, other species of Rhododendrons have been reported from Laos (Valder 1983). According to CCSM4 and MIROC-ESM model, there would be range expansion and increase in distribution area, along with some parts experiencing population

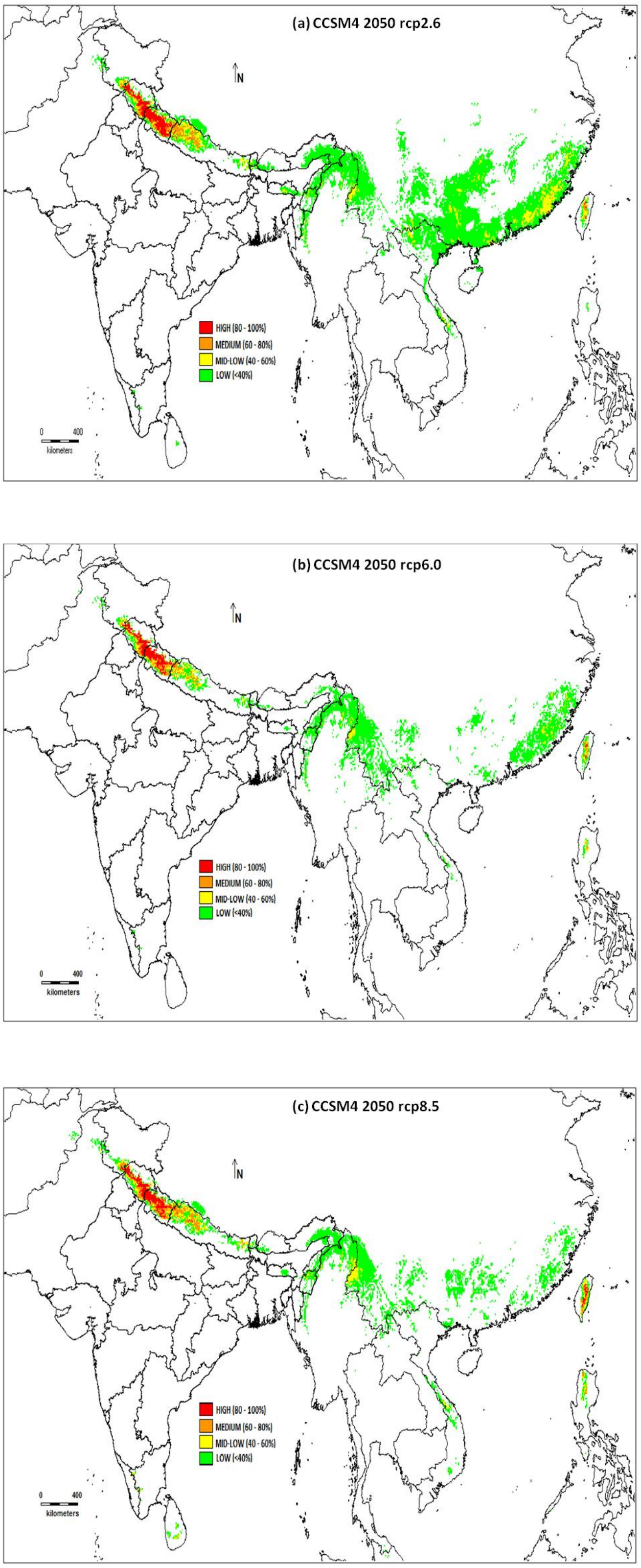

Figure 5. Habitat suitability maps for *R*. *arboreum* show predicted distribution of the species under different modelling scenarios of CCSM4 GCM (year 2050). a) rcp 2.6, b) rcp 6.0 and c) rcp 8.5.

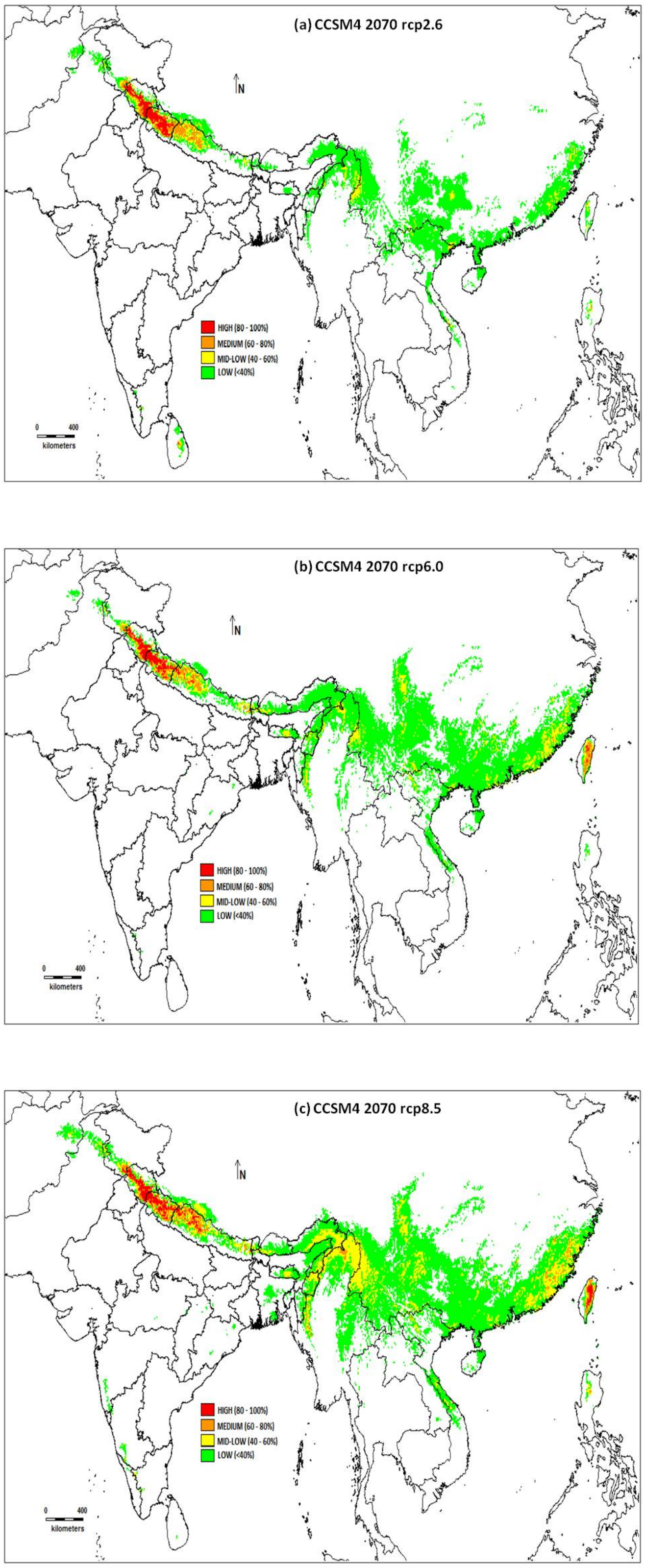

Figure 6. Habitat suitability maps for *R*. *arboreum* show predicted distribution of the species under different modelling scenarios of CCSM4 GCM (year 2070). a) rcp 2.6, b) rcp 6.0 and c) rcp 8.5.

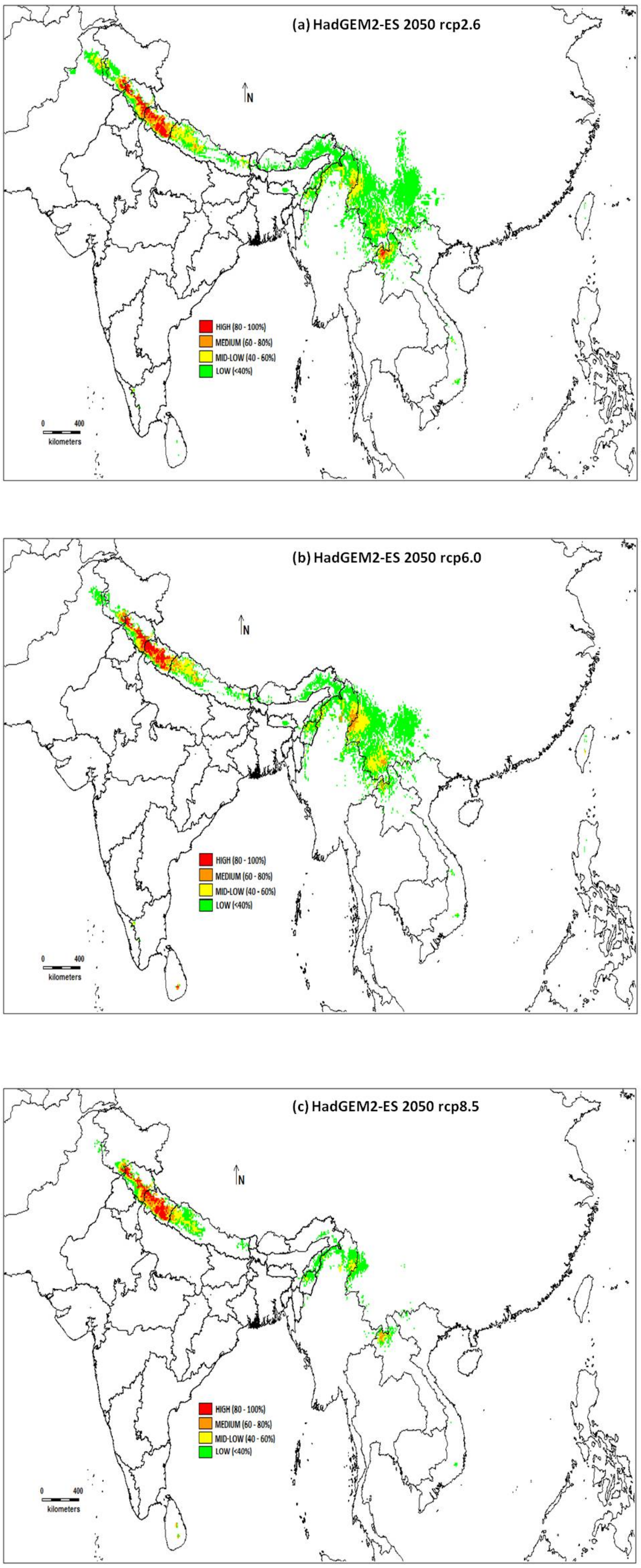

Figure 7. Habitat suitability maps for *R. arboreum* show predicted distribution of the species under different modelling scenarios of HadGEM2-ES GCM (year 2050). a) rcp 2.6, b) rcp 6.0 and c) rcp 8.5.

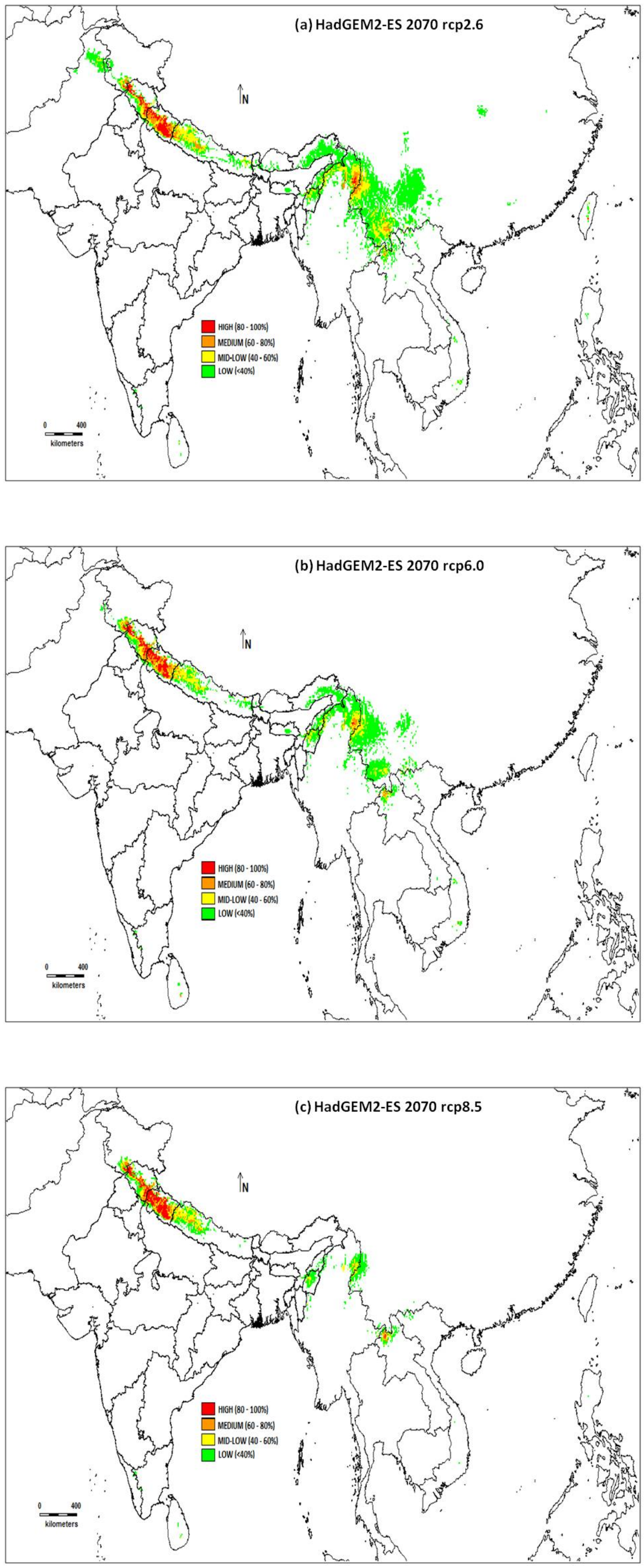

Figure 8. Habitat suitability maps for *R. arboreum* show predicted distribution of the species under different modelling scenarios of HadGEM2-ES GCM (year 2070). a) rcp 2.6, b) rcp 6.0 and c) rcp 8.5

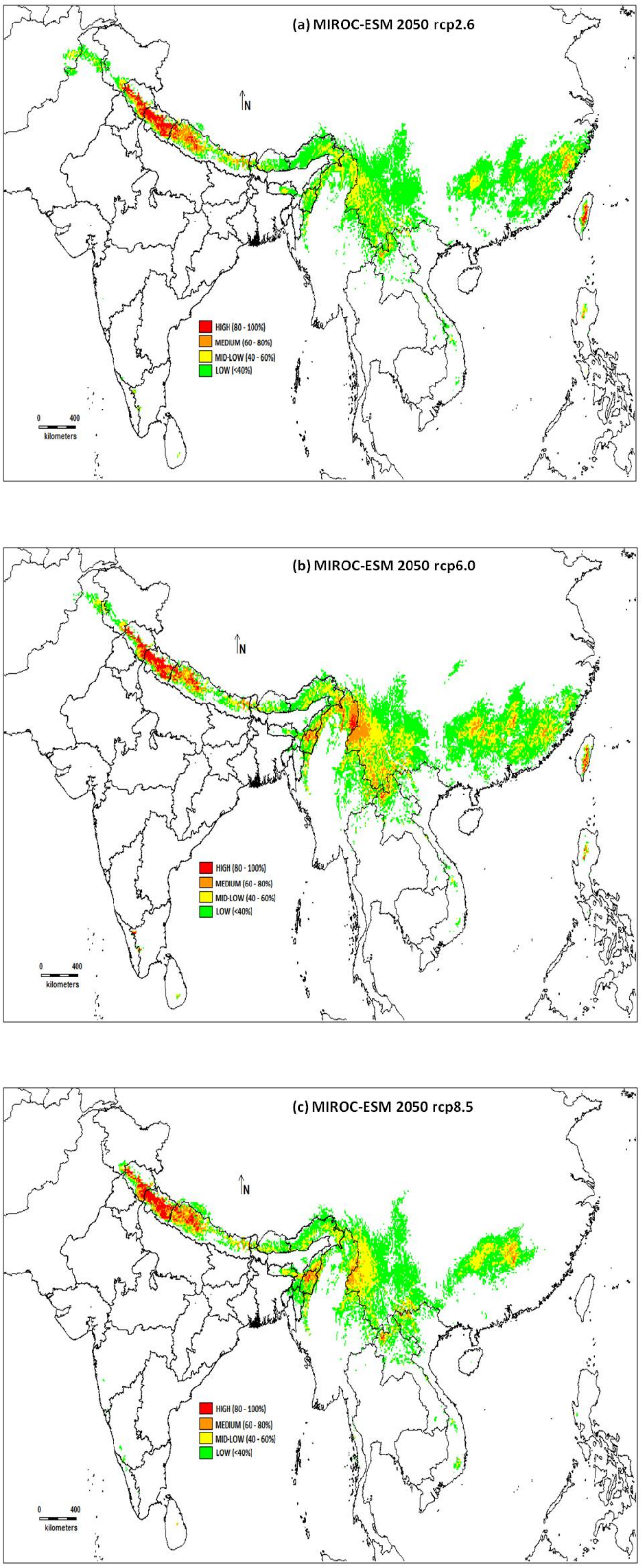

Figure 9. Habitat suitability maps for *R*. *arboreum* show predicted distribution of the species under different modelling scenarios of MIROC-ESM GCM (year 2050). a) rcp 2.6, b) rcp 6.0 and c) rcp 8.5.

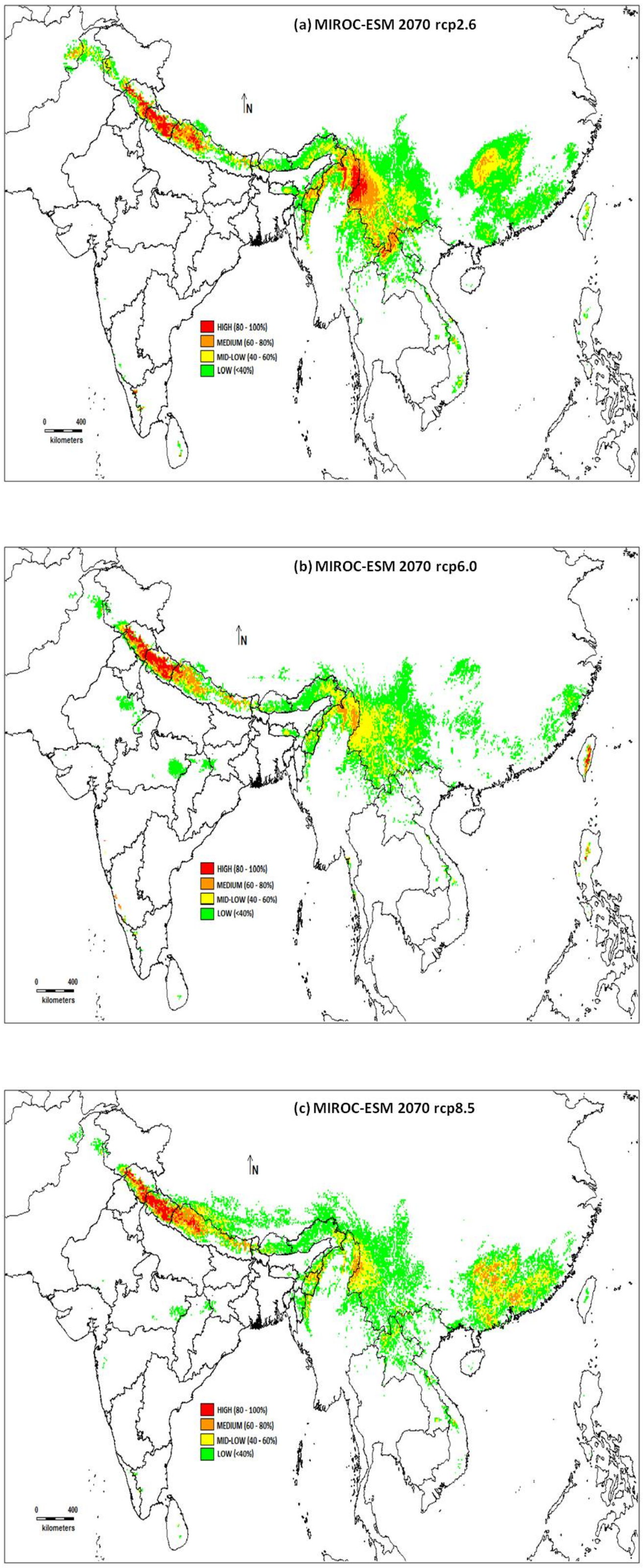

Figure 10. Habitat suitability maps for *R*. *arboreum* show predicted distribution of the species under different modelling scenarios of MIROC-ESM GCM (year 2070). a) rcp 2.6, b) rcp 6.0 and c) rcp 8.5.

Table 4. Table shows the future distribution prediction for *R. arboreum* in different regions under different modelling scenarios. (Abbreviation and symbols: C - central, D - decrease, E -extinction, I - increase, PL - population localization, NE - north-eastern, NW - north-western, RE - range expansion, S - south, SW - south-western).

Model	Year	RCP	Future Prediction					
			Himalayan NW & C	Region NE	SW Ghats	Sri Lanka	Indo-Burma	New Region
CCSM4	2050	2.6	I, RE	I, RE	D, PL	D, PL	I, RE	I, RE
		6	D, PL	D, PL	D, PL	E	D, PL	I, RE
		8.5	D, RE	D, PL	I, RE	I, RE	D, PL	I, RE
	2070	2.6	I, RE	I, RE	D, PL	I, RE	I, RE	D, PL
		6	D, RE	I, RE	D, PL	E	I, RE	I, RE
		8.5	I, RE	I, RE	I, RE	D, PL	I, RE	I, RE
HadGEM2-ES	2050	2.6	D, PL	D, RE	D, PL	D, PL	D, PL	D, PL
		6	D, PL	D, PL	D, PL	D, PL	D, PL	I, RE
		8.5	D, PL	D, PL	E	D, PL	D, PL	E
	2070	2.6	D, PL	D, PL	D, PL	D, PL	D, PL	D, PL
		6	D, PL	D, PL	D, PL	D, PL	D, PL	E
		8.5	D, PL	D, PL	D, PL	D, PL	D, PL	E
MIROC-ESM	2050	2.6	D, RE	I, RE	D, PL	D, PL	I, RE	D, PL
		6	D, PL	I, RE	D, PL	D, PL	I, RE	I, RE
		8.5	D, PL	I, RE	D, RE	D, PL	I, RE	E
	2070	2.6	I, RE	I, RE	D, RE	D, PL	I, RE	D, PL
		6	D, RE	D, RE	D, RE	D, PL	D, RE	I, RE
		8.5	D, RE	D, RE	D, PL	D, PL	D, RE	D, PL

decline and localization. HadGEM2-ES model predicts that there would be decrease in distribution area and population localization in entire region (Table 4).

4) New Region

Presently, there is no report of *R. arboreum* occurring in Philippines and Taiwan, however, our results showed suitable climatic conditions in these new areas where the species can sustain itself. These new areas could come under the potential habitat (or distribution) of the species. CCSM4 model predicted range expansion and increase in distribution area of the species. According to HadGEM2-ES model, there would be decrease in distribution area and population localization, along with some parts undergoing species extinction. MIROC-ESM model predicted decrease in distribution area with population localization whereas, few parts will show increase in distribution area and range expansion (Table 4).

Environmental Requirements of *R. arboreum*

The environmental factors which are required for healthy growth of *R. arboreum* on the basis of present field study are: i) altitude (average 1800 m), ii) mean annual maximum temperature 21°C (range 17-25°C), iii) minimum temperature 10°C, iv) well drained soil thus the area should have adequate rainfall (mean annual precipitation 500-2500 mm), v) prefers well lighted area (facultative sciophyte), vi) prefers acidic soil (low pH 4-6) and vii) soils of sandy loam, brown and red to dark black clayey soils. In India all these conditions are met in Himalayan region and therefore, species is distributed in all the Himalayan states, besides also being present in biodiversity hotspot of SW Ghats, where the conditions are suitable. One hybrid specimen of *R. arboreum* was also reported from New Guinea (Black 1966) (Table 1).

From species distribution model of present condition, the environment variables required for good growth of *R. arboreum* are: i) altitude average 2070 m,

ii) average annual precipitation of 1550 mm, iii) mean minimum precipitation of driest quarter 107 mm, iv) average minimum temperature of coldest quarter 9°C, v) average maximum temperature of 24°C (range 18-30°C). Moreover, it can tolerate minimum temperature of -5 °C (range -5 – -10°C) and maximum of 35°C requiring that other conditions should be favourable, but it will show reduced growth.

DISCUSSION

Global Climate Change and Impact on Plants

The phenomenon of global climate change is responsible for increase in global temperature. In the last 20th century, there is increase in frequency of warm nights and decrease in cold nights annually in 70% of the total land area of earth, with minimum temperature exhibiting significant increase (Alexander et al. 2006). Annual precipitation range has increased globally and there is greater likelihood for rainier regions to get more wetter in rainy season and drier regions will get more drier in dry season (Chou et al. 2013). At global level average temperature will show an increase of 1.4-5.8°C (year 2100) because of increase in carbon dioxide concentration (Bajracharya et al. 2006).

The increase in global temperature is causing plants to: i) species specific increase (Morin and Chuine, 2014) or decrease (Lutze et al. 1998) in frost resistance, ii) increase in number of plant growth days (Walther 2003, Khanduri et al. 2008), iii) migration and range shift (Hansen et al. 2001, Bakkenes et al. 2002, Hamman and Wang 2006, Hickler et al. 2012), iv) change in phenology (advancement of flowering, bud-burst and green-up) (Badeck et al. 2004, Cleland et al. 2007), v) increase in photosynthetic rates (Saxe et al. 2001, Lloyd and Farquhar 2008), vi) increase in net primary productivity (NPP) (Saxe et al. 2001), vii) increase or decrease in plant species richness (Sommer et al. 2010) and viii) increase in timber line elevation (Schickhoff 2005).

Impact of Global Climate Change on *R. arboreum*

We have found seven environment variables which are critical for the growth of *R. arboreum* and will be decisive factors for future status of species. These are i) temperature seasonality (bio4), ii) minimum temperature of coldest month (bio6), iii) precipitation of driest month (bio14), iv) precipitation of driest quarter (bio17), v) precipitation of coldest quarter (bio19), vi) altitude (alt) and vii) slope (h_slope). The temperature and precipitation factor will govern the distribution of *R. arboreum* in future climate, because global warming is causing temperature increase which is most significant in Himalayan region and there is increase in winter temperature leading to warmer days and nights and decrease in winter snowfall and increase in winter rainfall (Dimri and Dash 2012) leading to early spring onset and decrease in monsoon rainfall (Bhutiyani et al. 2010). Further, the annual temperature in NW Himalaya has increased by 2.2°C in past two decades (Bhutiyani et al. 2007).

In India by the year 2080, the annual mean surface temperature is projected to increase by 3.5-5.5°C and winter rainfall decline by 5-25% leading to summer time drought and a slight increase (10-15 %) in summer monsoon rainfall (Lal et al. 2001). Altitude is an important factor affecting *R. arboreum* distribution because with the increase in altitude there is decrease in atmospheric temperature, reduction in land area (Körner 2007) and increase in precipitation (on mountains) (Beniston 2006). Slope factor also accounts for *R. arboreum* distribution because most trees grow and establish themselves on slopes and thus receive water and nutrients through downward flow of water. Secondly, southern slopes (facing equator) receive more direct solar radiation and hence are drier and warmer than northern slopes, which face away from equator (Påhlsson 1974, Radcliffe and Lefever 1981, López-Moreno et al. 2013), thus regulating the vegetation composition. Thirdly, slopes also govern the precipitation, with windward facing slope receiving more precipitation than the leeward slope (Roe 2005). Oke and Thompson (2015) concluded that elevation and slope improves the quality of species distribution modelling (SDM) of mountain plant species. Moreover, importance of slope and altitude is necessary in countries like India, Sri Lanka and SE Asian countries because they are closer to equator and therefore, experience comparatively warmer summer and winter season than European countries, where *R. arboreum* (introduced species) is thriving outside its realized climate niche at a comparatively lower altitude (<500 m) (Vetaas 2002) because they are in northern hemisphere thus, are far from equator. This shows that during cold age, when climate was coldest the species may be present in all the mountains of India and other adjoining region and when the temperature increased it got extinct at lower altitude areas (Pulliam 2000) and survived in present fragmented patches in mountainous (>1500 m) areas of Himalayan region, SW Ghats, S.L. and Indo-Burma. According to Kuttapetty et al. (2014), *R. arboreum* migrated from high altitude areas of Northern India to SW Ghats and S.L. through Satpura and Vindhya Range along river valleys of western and eastern Ghats on the basis of Satpura Hypothesis (Hora 1949).

Future Status of *R. arboreum*

1) Himalayan Region

Our results showed that during 2050s in north western and central Himalayan region there would be decline in population of *R. arboreum* along with range expansion to high altitude areas, while the areas where there is no further area to move upward will suffer from range contraction leading to population localization. However, NE Himalayan region will show a slight increase in population and range expansion along with some areas showing range contraction leading to population localization. During 2070s there would be a severe decline in population in entire Himalayan region and range expansion to upper altitude areas, while some areas will show population localization. The future climate in the Himalayan region also support our results, in NW area the higher altitude regions will experience greater level of warming (3-4°C) (Ravindranath et al. 2006, Chaturvedi et al. 2011, Gopalakrishnan et al. 2011) and the temperature already has risen by 3.2°C (maximum) and 0.8°C (minimum) (Bhutiyani et al. 2007). However, in NE Himalaya there are very few sites being vulnerable because with changing climate wetter areas will receive more rainfall (Chou et al. 2013) and get warmer, which will be favourable for existing tropical type of vegetation (Chaturvedi et al. 2011, Gopalakrishnan et al. 2011). The western Himalayan region will suffer severe loss in both total (30.7%) and dense forest (16.8%), while eastern Himalayan forest will suffer comparatively less in total (70.4%) and dense forest (38.7%) decrease (Pandit et al. 2007)).

Our results are in agreement with Kumar (2012), who showed that because of climate change the area occupied by Rhododendron in Sikkim Himalaya would reduce significantly under future climate circumstances. The distribution of *R. arboreum* is governed by temperature, precipitation (Ranjitkar et al. 2014) and future geographic distribution of rhododendron species will be governed by altitude and seasonal variation (Yu et al. 2016) and this is concordant with our results. According to Vetaas (2002), *R. arboreum* can survive the warm temperate climate but the extreme cold condition act as a boundary for its growth. However, as the future climate warms these cold boundaries will be shifted upwards to more high altitude, so that areas (i.e. above tree line >3600 m) where at present *R. arboreum* is absent will have a healthy growth of species in future. Most studies have pointed out that Himalayan sub-alpine, alpine and temperate forest will be amongst the regions suffering greater damage due to climate change (Pandit et al. 2007, Xu et al. 2009, Singh et al. 2010, Gonzalez et al. 2010, Chaturevdi et al. 2011, Gopalakrishnan et al. 2011)

2) SW Ghats and Sri Lanka

During 2050s there would be a decline and range expansion of population in most areas, along with range contraction and population localization in low altitude areas. During 2070s, the populations will experience a drastic decline and range contraction because mountains in this region are of lower altitude [SW Ghats (<2700 m) (Simon and Mohankumar 2004), S.L. (<2600 m) (von Blanckenburg et al. 2004)] as compared to Himalayan mountains (>6000 m) and most of the region will get occupied during 2050s and very less or few areas will remain where the species could migrate, thus some areas will show species extinction. Our results are supported by future climate of this region which states that Western Ghats in future will get an imperceptible increase in rainfall and temperature will rise by 3°C (Chaturvedi et al. 2011, Gopalakrishnan et al. 2011). In hilly areas of SW Ghats rainfall has decreased in past three decades (Murugan et al. 2008). *R. arboreum* ssp. *nilagiricum* in SW Ghats, which is an endangered plant (Gibbs et al. 2011), is suffering from reduced distribution due to habitat isolation caused by anthropogenic and climatic factors, which checks species migration leading to range contraction (Giriraj et al. 2008). In S.L. annual mean air temperature has increased more than global average (De Costa 2008), whereas rainfall has declined in most parts, significant being high elevation areas (Central Highlands) (Malmgren et al. 2003, Jayawardene et al. 2005, De Costa 2008). This shows that in S.L. *R. arboreum* ssp. *zeylanicum* (vernacular name 'Ma-Ratmal'), which is a vulnerable red-listed plant (MOE 2012), will face severe population decline due to climate change and anthropogenic influences in future, which is consistent with our results. Further, southern population is disconnected from the northern Himalayan population and thus less likely to receive gene flow, which will have an impact on future plant fitness.

3) Indo-Burma

This region includes NE Indian states of Manipur, Meghalaya, Mizoram and Nagaland and countries Laos, Myanmar, Thailand, Vietnam and SW Yunnan (South China) where *R. arboreum* and other rhododendrons have been reported. During 2050s, this region will experience small increase and range expansion in *R. arboreum* population, along with population decline and localization in lower altitude. This is supported by climatic observation, which showed temperature decrease and rainfall decrease in NE Indian states (Jain et al. 2012). Increase in rainfall is also predicted for the future period (Chaturvedi et al. 2011, Gopalakrishnan et al. 2011, Chou et al. 2013). However, during 2070s the region will show population decline and localization in most areas, because mountains are of low elevation [Manipur (<3000 m) (Mao and Gogoi 2012), Meghalaya (<2000 m) (Khan et al. 1997), Mizoram (~2200 m) (ENVIS Centre Mizoram 2017), Nagaland (~3850 m) (ENVIS Centre Nagaland, 2017), Laos (<2900 m) (The World Fact Book, 2017), Thailand (~2565 m) (Khamyong et al. 2004) and Vietnam (<3200 m) (Richardson, 2005)], while high elevation zones [North Myanmar (~5900 m) (Myanmar Tourism 2017) and Yunnan (~6740 m) (Anderson et al. 2005)] will exhibit range expansion to upper altitude.

These results are supported by future climate of this region, (by 2030) Myanmar, Laos, Thailand and Vietnam will show an increase in annual mean temperature (0.68-0.81°C), minor increase in annual mean precipitation (13.5%), decrease in dry season precipitation (Eastham et al. 2008) and an increase in climatic hazards due to climate change (Yusuf and Francisco 2009) thus anthropogenic pressure will increase on mountain areas. In China temperature has increased by 0.5-0.8°C and a projected increase of 2.3-3.3°C (year 2050) and 3.9-6.0°C (year 2100) has been proposed, while precipitation has increased in Northwest, decreased in Northeast region and central region facing drying trend, however, in future, precipitation will show slight increase (10-12%) (Qian and Zhu 2001, Shi et al. 2006, Ding et al. 2007). This shows that in future, the mountain forest of China will show increase in greener areas suggesting range expansion of species, whereas the dry areas will show decrease in vegetation cover and range contraction in some species.

There are three Rhododendron taxa (subgenus *Vireya*) in Myanmar of which two are red listed and one is in data deficient category (Mackay et al. 2016). Although Rhododendron species has been reported from Laos (Valder 1983) but very less work has been done in assessing the impact of environmental change on the flora. By year 2050, forest cover in North Thailand (harbouring rhododendrons) will decrease to 45% (Trisurat et al. 2010), 10 plant species will lose suitable habitat and become near threatened and other species will migrate upwards (Trisurat et al. 2009). Vietnam harbours around 67 species of rhododendron (Vietnam Plant Data Centre 2017). The habitat suitability of tree rhododendrons (*R. arboreum*) in Western Yunnan (China), which has highest number (147) of threatened plant species (Zhang and Ma, 2008), is declining in west to east direction (Ranjitkar et al. 2014). In China, climate change will deeply affect Rhododendron distribution and species with limited geographical or altitudinal range will be at the receiving end (Yu et al. 2016), which is consistent with our results. Some rhododendron species in Yunnan has already reached an altitude of 4000-4100 m (Berg 1986). Ecological niche modelling of *R. simsii* in SW China revealed habitat fragmentation (Li et al. 2012). Similarly, Fir species (*Abies* Mill.) in southern China and North Vietnam are experiencing range expansion to higher altitudes and range contraction in lower altitudes (Shao et al. 2017).

4) New Region

This includes areas of Philippines and Taiwan where *R. arboreum* is not reported but other rhododendron species are present [Philippines (Brown et al. 2006, Mackay et al. 2016), Taiwan (Li et al. 1998, Chung et al. 2007, Huang et al. 2016)] and here, conditions are found to be favourable for *R. arboreum* growth. This region comes under potential habitat (or distribution) of *R. arboreum*. The possible reason behind absence of *R. arboreum* in these areas is due to dispersal limitation and/or local extinctions (Pulliam 2000). During 2050s this region will exhibit minor increase in population and range expansion, along with decline and population localization in some areas. During 2070s there would be a drastic decline in population and range contraction, with some areas showing species extinction. In these areas [Philippines (<3000 m) (Buot and Okitsu 1998), Taiwan (≤3950 m) (Li et al. 1998, Chung et al. 2007, Huang et al. 2016)] mountains are not high as compared to Himalayan region, therefore, the species will have no chance further to move upward when higher altitude areas are occupied. In Philippines there are 32 species of Rhododendron (subgenus *Vireya*) out of which 19 are already under red list (Mackay et al. 2016). Similarly, in future climate seven tree species in Philippines will undergo reduction in suitable habitat (Garcia et al. 2013). Increase in temperature and extreme rainfall event in future will cause decrease water runoff in Philippines (Jose and Cruz 1999) and an increase in climatic danger due to climate change (Yusuf and Francisco 2009) and this will cause people migration to upper altitude areas thus, changing forest structure and plant community.

In Taiwan, the Rhododendron species have low genetic divergence between them (Chung et al. 2007, Huang et al. 2016) and some species are already facing population fragmentation due to warmer climate and experiencing range contraction by inhabiting the last high elevation mountain tops and thus, there can be no further expansion (Chung et al. 2007). Further, plant species in Taiwan montane region (Central Mountain Range) are moving upward at a rate of 3.6 m yr^{-1} (Jump et al. 2012). Climate change is causing increase in summer temperature, decrease in diurnal temperature range, increase in temperature of higher latitudes, increased rainfall in North Taiwan and decrease in South Taiwan and in future the mean temperature will increase by 0.9-2.7 °C (Hsu and Chen 2002).

Limitations of the Study

In this study, anthropogenic factor was not applied, which will cause habitat modification and decrease in population, and will be amongst major decisive factors (with climate), governing future distribution of species. Other environment variables which will have an impact on future species distribution are soil type, plant plasticity, evapo-transpiration, dispersal ability, deforestation event, biotic interactions, vegetation type, habitat fragmentation, land use and land cover change. The species distribution model predictions are subjected to uncertainty, which can occur in three areas: data, model and prediction, thus, dispensing a fake accuracy in forecasting geographical distribution (Beale and Lennon 2012). Increase in global mean temperature by 1-2°C will effect most species and adaptive capacity of ecosystem will be reduced (Leemans and Eickhout 2004), thus it will become difficult for species to maintain a stable reproductive effort, which in turn would affect fitness and number of propagules, the establishment of which in new areas would be limited by dispersal barriers (climate and distance) (Peters 1990). The range expansion of plants in new areas would be a slow process due to low growth rates, long generation times, dispersal and recruitment limitation, difference in regional (local) climatic conditions of present and future areas and interaction (positive or negative) offered by native vegetation of new areas (Dullinger et al. 2004). Further, velocity of plant movement will depend on, number of dispersal events in a time period, distance covered in each event, interaction with other species and human influence (Corlett and Westcott 2013).

Other factors which will also regulate the future distribution of *R. arboreum* are: loss of pollinators and spread of invasive species (Root et al. 2003). In this study, we have not used the species location data outside study area, but still our results are consistent with future observations because higher AUC values (>0.9) of the models strongly suggest that our predictions are good and second we have found presence in those areas where *R. arboreum* is reported to be present. The reason for not choosing presence points outside the study area was to know how much suitable were the environmental conditions of study area for studying this species and second to test whether environmental conditions found in an area where the species is widespread could be used to predict the habitat distribution of species in areas where the species is unknown (not reported).

Factors Threatening *R. arboreum* Distribution

The factors which are responsible for the declining status of *R. arboreum* are ones which are causing decrease in forest area. The forest area of the world has declined by 129 million ha (3.1%) (1990-2015) and now is under 4 billion hectare (ha) (FAO 2016). During the period 2000-2010 there is increase in, forest area lost by 61,865 thousand (K) ha and agricultural area by 77,287 K ha (FAO 2016). Increase in population is leading to expansion of agriculture areas and human settlements, which invade forest areas. Asia is first in terms of highest proportion of agricultural land (52%) but lowest proportion of forest (19%) (FAO 2016). Rapid increase in urbanization and infrastructural developments is putting pressure on forest for resources. Fuel-wood extraction from forest areas is causing decline in tree numbers and thus creating open canopy areas, causing habitat fragmentation. India tops the list of countries where wood is extracted from forest (2011 year) with 434,766 K $metre^3$ of which 88.6% is used as fuel-wood (FAO 2015). Globally, annual wood removal (2011) amounts to 3.0 billion metre^3 of which 49% were fuelwood (FAO 2015).

Livestock overgrazing removes herbaceous ground cover making the soil prone to erosion, which leads to uprooted plants. Some factors cause a large-scale deterioration of forest areas such as dam and road construction and mining, because there construction and operation employs explosives and other harsh methods which drastically transform topography of area causing loss of flora and fauna. Grumbine and Pandit (2013) suggested that dam building in Himalayan region will lead to forest loss due to direct submergence and habitat degradation, causing loss of 22 angiosperms and seven vertebrate taxa by 2025. Moreover, mountains regions are susceptible to natural disaster like landslides and earthquakes etc. and repeated carving and explosion has already made foundation fragile. In Asia, the main drivers for deforestation are local/subsistence agriculture, commercial agriculture, mining, urban expansion, and timber extraction and logging, and fuelwood accounts for forest degradation (Hosonuma et al. 2012).

Implications for Conservation

R. arboreum is a widespread species in the Himalayan mountain region and gives innumerable ecosystem service and thus can aptly be regarded as a keystone species (Paine 1969). However, due to climate and anthropogenic stress, it is declining at lower (1400-1700 m) and low-middle (1800-2000 m) altitude (Mamgain et al. 2017). In order to survive warming climate the species will either migrate to high altitude or adapt to changing environment in the present area. But population adapting to future climate in current areas will not survive anthropogenic pressure (Peters 1990). In future, *R. arboreum* populations at low lying (<3000 m) areas will be at risk and see a population decline and extinction because species will have no further higher altitude to move upwards (Peters 1990) whereas, populations at high altitude areas (>4000 m) will have a chance to move upwards. Due to climate change forest trees (*R. arboreum*) will face any of the three fates i.e. persist by migration to other areas; adapt to the conditions prevailing in the current location and extirpation (Aitken et al. 2008). According to Hughes (2000) change in mean annual temperature by 3 °C characterize a shift in isotherms of around 300-400 km latitude (in the temperate zone) or 500 m in altitude. Therefore, *R. arboreum* would move upward in altitude (alpine plants) in response to changing climatic zones (Hughes 2000, Root et al. 2003), which is concordant with our report. Further, most tree species are displaying range contraction rather than range expansion to northern and southern boundaries (Zhu et al. 2012).

Moreover, areas where *R. arboreum* population grows come under the regions of different global biodiversity hotspots such as Himalayas (Indian Himalayan states, Bhutan, Nepal, North Myanmar, North Pakistan, Tibet), SW Ghats (S. India, S.L.), Indo-Burma [NE Indian states, Myanmar, south and west Yunnan (China), Laos, Vietnam, Thailand], and new region (Philippines and Taiwan) (Mittermeier et al. 2004) and therefore, species in these areas are already in threat. Due to climate change, new 21st century climate will develop in tropical and subtropical regions (eastern India and SE Asia) causing new species associations and ecological shock, whereas present climate will disappear (or become unsuitable) in tropical mountains (portion of Himalaya) leading to species extinctions, narrow geographic or climatic distributions and existing community disruption (Williams et al. 2007). Besides, common plant species (*R. arboreum*) are more susceptible to genetic erosion and loss of genetic diversity arising due to habitat fragmentation (Honnay and Jacquemyn 2007). Habitat fragmentation hampers gene flow from adjacent population leading to reduced plant fitness, causing erratic alteration of species community and decreased resistance to environmental stress (disease epidemic and extreme climate events), thus resulting in plant extinction (Jump and Peñuelas 2005). Further, the rate of adaptive evolutionary response of plants to environmental stress is much slower than rate of climate change (Etterson and Shaw 2001).

Conservation Measures

In addition to conservation methods proposed by Mamgain et al. (2017) other approaches to ensure healthy existence of *R. arboreum* for future period are: i) in-situ conservation– plant protection in native place by creating awareness (economic and environmental benefit of *R. arboreum*) among local people, formation of forest association (‘*Van Panchayat’*) of villagers, ii) ex-situ conservation– species introduction in new areas, iii) plant local economically important adaptable multipurpose plant species in degraded forest areas and wastelands to check soil erosion, slope destabilization and species mono-culture, iv) ban mining from river and forest as it destroys nearby agricultural fields and forest by degrading soil fertility, alters topography of mountain and rivers, make river bed and bank fragile to floods and erosion, pollute downstream river water, cause destruction of local flora and fauna, which ultimately push people to occupy forest area, v) prohibit usage of non-biodegradable products (plastic, styrofoam etc.) because they obstruct ground water recharge, there build up reduce aesthetic appeal of area and release harmful chemicals, thus reducing soil micro-biota, consequently interfering in humification (and/or detritus cycle) and vi) ban construction within 150 m from river periphery (bank) because it make the bank fragile to flood, pollute ecosystem and river water seeping into ground can lead to economic loss in small seismic activity, instead tree plantation should be promoted.

CONCLUSION

The outcome of this study shows that during 2050s the species will exhibit minor cases of population increase, due to changing environment and will seek to expand its range to higher altitude (future potential habitat or distribution), whereas areas where there is no further upward limit for movement (SW Ghats, S.L.) will show range contraction leading to population localization in patches which could lead to species extinction. During 2070s, species will show severe decline in population and range expansion to upper altitude areas (Himalayas, Myanmar, Tibetan Plateau, Yunnan), while low altitude areas (Laos, Vietnam, Philippines, Taiwan) will experience range contraction leading to population localization in patches which could lead to species extinction. Presently, species occupy a broad altitudinal zone (1500-3300 m) but with ongoing rapid environmental change and anthropogenic pressure, in future cold climate boundary will be pushed further to higher altitude areas (~4500 m) and species will be pressed to expand its range, getting close to extinction in low (1400-1700 m) and lower-middle (1800-2000 m) altitudes while some populations will survive in middle (2100-2300 m) altitude and majority will thrive in upper-middle (2400-2600 m), low-high (2700-3300 m) and mid-high (3400-4000 m) altitude zones. Moreover, species may survive effects of climate change in refugia habitats (Keppel et al. 2012) leading to range disjunction and may spread to other areas through forest corridors when favourable environment arrive.

However, range expansion will be possible only in those areas where there is enough altitude to move upward. Further, migration to upper altitude areas will be tested by slow growth rate and dispersal and recruitment limitation (Dullinger et al. 2004). In future, temperature and rainfall will decide species range. Besides, results of this model have some inherent limitations because other factors affecting species distribution are not included, hence, to have a more deeper understanding of ground situation, field surveys along with GIS should be used to ascertain species distribution together with employing other distribution models such as process-based (mechanistic) and demographic models. However, *R. arboreum* is a tree and will resist the climate change to some extent, but together with anthropogenic pressure it will become difficult for the species to sustain itself in a healthy manner. Therefore, to protect species from the global environment change, strict conservation measures should be applied at the earliest otherwise, species will struggle to survive for future period.

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