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Research

Rhododendron species richness patterns and impacts of global warming on its distribution in Central Himalayas, Nepal

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Abstract

Global warming and climate change have caused devastating impacts on biological diversity especially in northern latitude and altitude. Evaluation of species richness patterns and range size distribution is crucial for the conservation and management of biological diversity. As *Rhododendron* species generally grow in the higher latitude and altitude their study on range size distribution may help to predict the future fate of species against presumed global warming in the Himalayas. This study relates the distribution range of *Rhododendron* species and the potential impacts of global warming and climate change on it. The distribution range varied from 100 to 2600 m along the Himalayan elevation gradient. Generally, species found at the higher elevation have longer range compared to the species found at lower elevation. Among the *Rhododendron* species found in Nepal Himalayas, *R. epapillatum, R. trichocladum* and *R. virgatum* have only 100 m distribution range, which are therefore most vulnerable to the shift in vegetation zones as a result of future projection of temperature rise. Other species having 300 m range of distribution are also vulnerable to different levels of temperature rise as predicted by various sources. These findings can generate hypothesis that species with shorter distribution rage are more vulnerable to climate change which can be tested quantitatively. This in turn will establish a relationship between distribution ranges of species and shift in vegetation zones, and rising temperatures in the Himalayan region due to global warming.

Key-words: Distribution range, global warming, unimodal, vegetation, vulnerable.

Introduction

Recent phenomena of global warming and climate change may cause devastating impacts on vegetation belt (Sanz-Foreza *et al*. 2003). The volume of CO_2 released into the atmosphere undergoes biogeochemical processes, thereby affecting natural ecosystems on land and as well aquatic vegetation of oceans (Botkin 1989; Cubasch and Meehl 2001). Of the various predictions on future rise in temperature caused by excess emissions of greenhouse gases in the atmosphere, Intergovernmental Panel on Climate Change (IPCC) predictions is believed to be the most reliable one. By the end of the 21st century temperature could rise between 1.1°C-6.4°C (IPPC 2005). Several current trends clearly demonstrate that global warming is directly impacting the rise of sea level; the melting of icecaps, migration of vegetation belts and significant worldwide climatic changes and thus causing extinction of plant and animal species (Emanuel *et al*. 1985). The Himalayan

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region has experienced higher level of temperature rise, and thereby affecting the distribution of flora and fauna in this fragile ecosystem (MOE 2010). In this context, assessment of potential impacts of climate change on the richness pattern of plant species is an important first step to understanding the future climate change impacts on vegetation in the Himalayas.

One way to examine the consequences of the global warming and climate change in vegetation is to compare current and likely future ranges of species (Odland and Birks 1999). Based on the projected mean warming of 3°C by the middle of the next century, it is predicted that vegetation belts on mountain slopes will show an upward migration trend of 150-200 m (Ozenda and Borel 1990). Thus, in high mountain areas an extensive reduction in biodiver-sity may occur. In danger of extinction are alpine tundra on moderately high mountains due to the encroach-ment of today's sub-alpine forests (Sanz-Foreza *et al*. 2003). Seeds would be dispersed beyond the species' current marginal distributions. As a result, migrated species would face a serious risk of extinction.

Upper limit of distribution of species is determined by climatic factors while the lower limit of distribution is controlled by a combination of climatic and biotic interactions (MacArthur 1972). Absence of alpine vascular plant species in lowlands is explained by the facts that their ability to compete is relatively small in comparison to that of other species to be found in lowlands and they cannot survive in natural vegetation under the given climatic factors (Dahl 1990). The processes of competition and upward migration depend on the potential expansion rates of particular species of specific plant populations, which is unknown for the vast majority of plants found in the Himalaya (Körner and Spehn 2002). Further, adaptation or migration is a rather slow process and, therefore, this will not be enough to cope with the impacts on vegetation distribution due to rapidly changing environmental factors caused by climate change. Evidently, the species that cannot cope with the changing environmental conditions will face a risk of extinction.

The Himalayas has high degree of altitudinal variation from tropical to snow-capped mountains within 150-200 km in north-south direction, so it could be an ideal experimental site to study the impact of global warming and climate change on plant species, and predict their fate in the future. Generally woody species are more influenced by variation in climatic factors than herbaceous flora (Bhattarai and Vetaas 2005). We have selected *Rhododendron* species as all species are woody perennial and are found at higher altitude and higher latitude (Dulal 2008). This study, therefore, aims at analysing the species richness patterns of *Rhododendron*, its future trajectory against changing climate. The study also tries to relate the distribution range of *Rhododendron* species and the potential impacts of climate change on it by generating some useful hypothesis, which can be tested by further studies.

Materials and Method

STUDY AREA AND VEGETATION

This study focuses on central Himalaya, Nepal that lies between 80^0 04'- $88^0$12' E longitudes and 26^0 22'- 30^0 27' N latitudes. The topography of the country shows altitudinal variations and represents all types of climatic zones from tropical to alpine (Hagen 1969). There is a tropical forest below 1000 m, dominated by *Shorea robusta*, *Adina cordifolia*, *Dalbergia sissoo* and species of *Terminalia*. In this range *Rhododendron* species are not found. In the subtropical (1000-2000 m), the forest is dominated by a mixture of *Schima wallichii, Castanopsis indica* and *Pinus roxburghii*. The species of *Rhododendron* are found between 1500 m to 5600 m asl. In the cool temperate zone (2000-3000 m), the forest is dominated by laurel, oak and *Rhododendron*. This elevation range consists of 16 species of *Rhododendron*. The subalpine zone (3000-4000 m) is dominated by *Betula utilis* and coniferous forest. *Pinus wallichiana* is an aggressive coloniser and can be found throughout Nepal at these elevations. Generally, *Rhododendron* *lepidotum* and *Rhododendron anthopogon* bush are found in this range.

DATA SOURCE AND INTERPOLATION

All the data of *Rhododendron* species were collected from DPR (2001), Dulal (2008) and verified from Rajbhandari and Watson (2005). To examine the relationship between *Rhododendron* species richness and elevation, total elevation gradient between 1500 and 5600 m was divided into 41 bands with 100 m elevation intervals (vertical elevation bands). A species was defined as being present in every 100 m interval between its upper and lower elevation limits. For example, a species with its elevation limit between 2050 and 2550 m is then present in the 2100, 2200, 2300, 2400, 2500 and 2600 m elevation bands (see Vetaas and Grytnes 2002; Grytnes and Vetaas 2002, Bhattarai *et al*. 2004). The elevation range of each *Rhododendron* species was estimated as the difference between the maximum and minimum elevations, where a species was found within the range of study site, rounded off to the nearest 100 m. Species reported from single site were given an elevational range of 100 m and were included in the analysis. In this study, species richness is defined as the number of *Rhododendron* species occurring within each 100 m band (Vetaas and Grytnes 2002).

DATA ANALYSIS

The relationship between species richness and elevation was evaluated by generalized linear models (GLM; McCullagh and Nelder 1989). The relationship between mid-elevation and elevation was checked by generalized additive models (GAM; Hastie and Tibshirani 1990). Number of species of *Rhododendron* is used as the response variable and elevation as the explanatory variable. The response variable, species richness, is discrete data (counts) with a Poisson distribution (assumed), and a logarithmic link was used in the GLM (Crawley 1993). These assumptions were evaluated by comparing the residuals of the analysis with the residuals from models by using an identity link function. The Poisson models seemed reasonable when examining the residuals with diagnostic plots (McCullagh and Nelder 1989). Unimodality was evaluated by testing the significance of the model including a second order polynomial term against a linear model. The explanatory variable was tested until the third order polynomial. An *F*-test was used, as most of the deviance was under-dispersed (McCullagh and Nelder 1989). We used S-plus (version 4.5) for regression analysis and graphical representation.

Results

DIVERSITY PATTERNS OF *RHODODENDRON* SPECIES

Altogether 31 species of *Rhododendron* were found growing from 1500 to 5600 m. The number of species of *Rhododendron* increased with increasing elevation up to 3300 m, then species richness decreased with increasing elevation; thus, unimodel type of relationship observed. The maximum numbers of *Rhododendron* species were found at 3300 m elevation (Figure 1), which was indicated by statistically significant in the second order term in GLM. When species found in east, central and west were separated and regressed against the elevation, similar unimodel pattern was found. This unimodel pattern observed in whole datasheet was statistically significant in GLM second order (Table 1). The model could explain 97% of variation on data set. There was also a trend between elevation range and elevation midpoint. Species distribution range increased with increasing elevation (Figure 2). The species found at the higher elevation had longer range compared to the species found at lower elevation.

RANGE SIZE OF *RHODODENDRON* SPECIES

The lower limit of *Rhododendron* species was 1500 m and uppermost limit was 5600 m asl along the elevation gradient. The range of distribution of *Rhododendron* species varies from 100 to 2600 m (Table 2). *R. papillatum*, *R. trichocladum* and *R. virgatum* had only 100 m range of their distribution along the elevation gradient. Similarly, *R. barbatum*, *R. ciliatum* and *R. falconeri* were limited to 300 m elevation range. *R. griffithianum* had 400 m range of distribution along

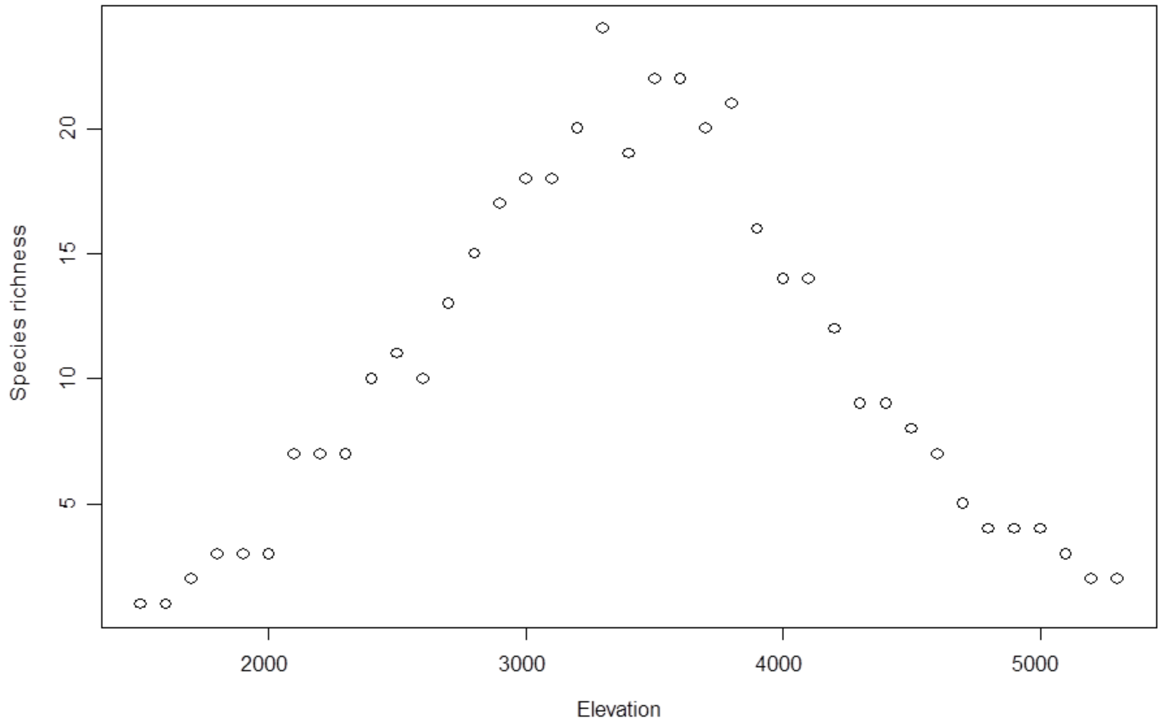

Figure 1. Species richness patterns of *Rhododendron* spp. along the elevation gradient of central Himalayas.

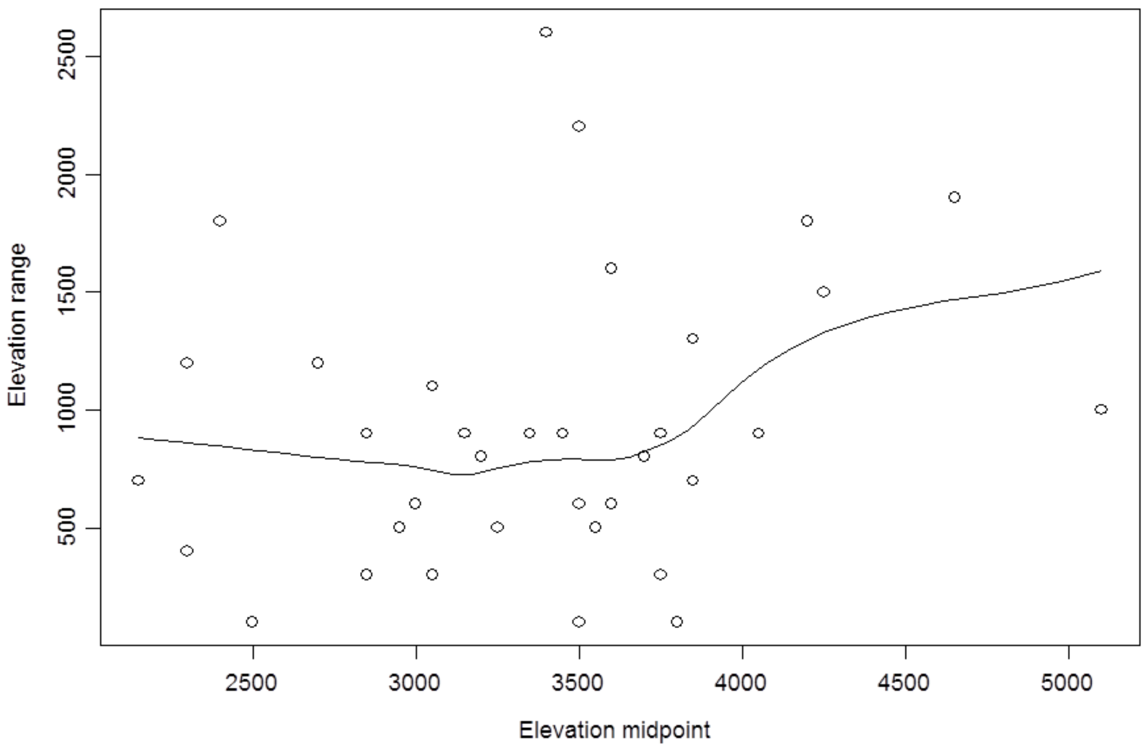

Figure 2. Relationship between elevation mid-point and elevation range along the elevation gradient in Central Himalayas. The solid line is fitted by GAM smoother.

Table 1. Summary of regression statistics for the species richness along the whole Himalayan gradient.

Response variable	Predictor Variable	Range	GLM order	d.f.	%-Deviance Explained	P-value
Species	Elevation	Whole range	2	36	97.19	<0.001

Table 2. The distribution range and their corresponding number of species. The number of species includes varieties.

SN	Distribution range in meter	Number of species
1	<200	3
2	300	3
3	400	1
4	500	3
5	600	2
6	700	2
7	800	4
8	900	6
9	1000	1
10	1100	1
11	1200	3
12	1300	1
13	1500	1
14	1600	1
15	1800	2
16	1900	1
17	2200	2
18	2600	1

elevation gradient. Similarly, *R. camelliiflorum*, *R. hodgsonii* and *R. pendulum* were limited within 500 m range of elevation.

Discussion

SPECIES RICHNESS PATTERNS

Himalaya possesses the highest bio-climatic gradient in the world (Bhattarai 2003). Interpolation method can be better option to study species richness in such a macroscale as it might takes several years to collect primary data (Grytnes and Vetaas 2002; Bhattarai and Vetaas 2003, 2006). In the present study, species richness of *Rhododendron* increased with increasing elevation until the middle of the gradient and decreased afterwards (Figure 2). Thus, a statistically significant hump-shaped pattern was observed between species richness and elevation. This is a common pattern and it is also reported for different groups of organisms from several regions (e.g., Parris *et al*. 1992; Grytnes and Vetaas 2002; Bhattarai *et al*. 2004; Carpenter 2005; Bhattarai and Vetaas 2006). The optimum species richness was found approximately in the middle of the gradient (i.e., 3300 m elevation), which was the highest optimum elevation ever recorded as compared to the optimum richness found for the other vascular plants. In the Nepal Himalayas, the maximum diversity is observed at 900-1000 m for trees, at 2000 m for fern, and at 2700 m for bryophytes (Bhattarai and Vetaas 2003; Bhattarai *et al*. 2004; Grau *et al*. 2007).

Distribution pattern of *Rhododendron* from 1500 m to 5600 m with optimum elevation at 3300 m is a local mid-elevation peak (Rahbek 1995). This could be a result of the intermediate location between the subtropical and alpine flora in high mountains, which increase the chances for immigration from both directions, i.e. a mass effect (Grytnes and Vetaas 2002). Further, the decline in *Rhododendron* species richness above 3300 m could be due to harsh climatic conditions related to dryness, high radiation, low temperature, low precipitation, and high snow cover (Körner 2000). Therefore, the hard boundary effects could also influence the species richness at high elevation (Grytnes and Vetaas 2002). There is a reduction in the channels available for immigration resulting in the reduction of the number of species that occupy high elevation sites. The limited species pool of vascular plants in high elevation also affects the total species richness (Körner 2000).

The elevation represents a complex gradient. Many environmental variables co-vary with elevation (Austin *et al*. 1996). The environmental factors which may vary with elevation are temperature, potential evapo-transpiration, length of growing season, humidity, air pressure, nutrient availability, ultraviolet radiation, moisture index and rainfall (Graber *et al*. 1995). The observed species richness pattern might be due to combination of all. But, the effect of each variable could be difficult to separate. Therefore, the present study does not include a specific test with specific climatic factors. The distribution pattern of *Rhododendron* along the elevation is observed and actual pattern is evaluated. It is assumed that woody species are more influenced by climatic factors than herbaceous species (Woodward 1987). The upper elevation range for woody is lower than herbaceous species. This might be due to factors that woody species are most susceptive to climatic changes (Bhattarai and Vetaas 2006). But, *Rhododendron* is reported up to 5600 m on elevation, which indicates that *Rhododendron* appears different then other woody species.

IMPACT OF CLIMATE CHANGE ON *RHODODENDRON*

Rhododendron species are found in the higher altitude (http://folk.uib.no/nboov/erica.gif). Environmentalist and ecologists have claimed that alpine plant community is most vulnerable to global warming (Graber *et al*. 1994). IPCC has predicted that by the end of the 21st century climate change could result in a probable temperature rise between 1.8°C and 4°C, with a possible temperature rise between 1.1°C and 6.4°C. Here, we relate the impacts of these rises in temperatures on *Rhododendron* species patterns qualitatively, which can form a sound basis for formulating hypotheses of this relationships for further studies in this area.

Along the Himalayan elevation gradient, there is a lapse rate 0.53^{0}C per 100 m elevation increase (Bhattarai and Vetaas 2003). Since global warming is a process of gradual rise in temperature, the vulnerability of global warming upon species depends on distribution range with respect to temporal scale. Taking into consideration of maximum temperature rise by 4°C by the end of this century, there may be a possibility of shift in the present vegetation belt more than 800 m upwards. Thus, *Rhododendron* species which have less than 800 m range of distribution might be influenced by climate change. Species with shorter range of distribution would be influenced more by global warming. Plant species might cope with the influence of global warming by two means: either they migrate upward along the elevation gradient to find suitable environment or they adapt to the changing environment (Körner and Spehn 2002).

Among the *Rhododendron* species found in Nepal, *Rhododendron epapillatum*, *Rhododendron trichocladum* and *Rhododendron virgatum* have <200 m range of distribution. This is relatively shorter range of distribution. Thus, relatively these three species may have highest risk of extinction if they could not shift to upper vegetation belt or adapt to the changing temperature. The species *Rhododendron barbatum*, *Rhododendron ciliatum* and *Rhododendron falconeri* are found distributed along 300 m range along the elevation gradient. The 300 m range is also shorter range. Within this range, there may be temperature difference of 1.5°C. These species would be second most vulnerable against global warming. The species found at 400 m range comprise *Rhododendron griffithianum* and the species distributed along 500 m range are *Rhododendron camelliiflorum*, *Rhododendron hodgsonii* and *Rhododendron pendulum*. In these ranges, there could be a temperature difference of about 2-2.5°C between upper and lower end. This rise of temperature also lies within the predicted probable rise of temperature by the end of this century. Therefore, these species are also vulnerable against global warming. The species having distribution range of 600 m are *Rhododendron campylocarpum* and *Rhododendron cinnabarinum.* Similarly, *Rhododendron glaucophyllum* and *Rhododendron dalhousiae* have 700 m distribution range. All of these species may not be safe under global warming with 4^{o}C^{--} temperature rise.

Considering the lowest probable value of temperature rise by 1.8°C by the next century, there would be shift of vegetation belt by 340 m. In such a case, the species having distribution range *ca*. up to 400 m could be affected. In this scenario, *Rhododendron epapillatum*, *Rhododendron trichocladum*, *Rhododendron virgatum*, *Rhododendron barbatum* f. *imberbe*, *Rhododendron ciliatum*, *Rhododendron falconeri* and *Rhododendron griffithianum* could be affected even in the lowest probable case.

Considering IPCC's highest possible rise in temperature by 6.4°C, there is a possibility of a shift in vegetation belt by 1200 m upwards along the elevation gradient. In such scenario, the species having below 1200 m distribution range would be affected. This indicates the devastating impacts of all *Rhododendron* species in the Himalaya.

The possible lowest value of temperature rise as predicted by IPCC is 1.1°C, which means that there is a probability of *ca*. 200 m shift in vegetation zone along the elevation gradient. In this scenario, *Rhododendron papillatum*, *Rhododendron trichocladum* and *Rhododendron virgatum*, having distribution range of <200 m along the elevation gradient, would be affected by global warming by the end of this century.

The mid-point value (2.9°C) of probable rise in temperature by the next century could lead to a *ca*. 550 m shift of vegetation zone along the elevation gradient. In this scenario, the species distributed at the range of 100 to 600 m would be vulnerable. Similarly, considering the mid-point of possible temperature rise, there would be an increase in temperature by 3.75 °C temperature by the next century. This magnitude of temperature rise means that there would be 700 m shift in vegetation belt. Thus, in this condition *Rhododendron* species distributed below 700 m could be affected against global warming by the next century. However, the degree of vulnerability increases gradually from 700 m to 100 m.

This study related the distribution range of Rhododendron species and the potential impacts of climate change on it, which generated some useful hypotheses that species with shorter elevation range are more prone against the global warming. Among the *Rhododendron* species found in Nepal, *Rhododendron papillatum*, *Rhododendron trichocladum* and *Rhododendron virgatum* have only <200 m altitudinal range of distribution. Thus, relatively these three species may have highest risk of extinction if they could not shift to upper vegetation belt or adapt to the rising temperature. Other three species having 300 m distribution range are also in danger but with varying degrees depending upon their distribution range and levels of shift in vegetation zone as a result of projected temperature rise at the end of this century. These hypotheses need to be tested quantitatively by the future research in this area as we have just related the distribution range with the potential shift in vegetation zones due to the temperature rise in the future.

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