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Distribution pattern and species richness of Liliaceae in the Nepal Himalaya

Hum Kala Rana[1], Santosh Kumar Rana[1,2,3*] and Suresh Kumar Ghimire[1]

[1]*Central Department of Botany, Tribhuvan University, Kirtipur, Kathmandu, Nepal*
[2]*Key Laboratory of Plant Diversity and Biogeography of east Asia, Kunming Institute of Botany, Chinese Academy of Sciences, Kunming, Yunnan 650204, China*
[3]*University of Chinese Academy of Sciences, Beijing 100049, China*
[*]*E-mail: rana.1.santosh@gmail.com*

Abstract
The most important aspect of plant conservation is to predict the potential distribution and its richness in response to climate change. Contributing to the management program, this study aimed to predict the distribution and richness pattern of Liliaceae in Nepal. The BIOCLIM in DIVA GIS 7.5 model based on distribution records of 19 species belonging to three subfamilies of Liliaceae (Lilioideae, Streptopoideae and Calochortoideae) and 19 climatic variables (derived from Worldclim), revealed that Lilioideae and Streptopoideae are potentially distributed in most of the hilly and mountainous regions of Nepal; whereas Calochortoideae mostly in Eastern and very scanty in Central Nepal. Lilioideae is projected to have high species richness in Central and Western Nepal as compared to other subfamilies.

Key words: Conservation, DIVA GIS, Lily, Modelling

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Introduction
The family is named after *Lilium*, the type genus (Simpson, 2006). *Lilium* is Latin for 'lily' and which came from the Greek word *leírion* (lily flower "a classic symbol of purity"). Liliaceae are generally bulbous geophytes (but also possess other forms of enlarged underground stem). This family contains many members with economic importance. Notable among them are species of *Fritillaria, Lilium, Tulipa* and *Tricyrtis*. Particularly, *Fritillaria cirrhosa*,

Lilium nepalense and *L. wallichianum* are also valued in Nepal as medicine and food (Ghimire *et al.,* 2008; Kunwar *et al.,* 2006). *F. cirrhosa* and *L. nepalense* are traded from Nepal to overseas herbal market. Considering their increasing exploitation for trade, Conservation Assessment Management Prioritization Workshop (CAMP) held in Nepal has listed *F. cirrhosa* and *L. nepalense* as threatened medicinal plants under threat categories 'Vulnerable' and 'Data Deficient', respectively (Tandon *et al*. 2001). Both of these species are also included in National Register of Medicinal Plants (IUCN, 2004) and these medicinal plants are important components in the flora of Nepal (Rana *et al*., 2015).

The members of the family are widespread throughout the world, but most common in temperate to subtropical regions, especially East Asia and North America in the Northern hemisphere. They occur mostly in the steppes and mountain meadows. The centre of diversity is considered as S.W. Asia to China (Simpson, 2006).

It is a well known fact that plant species are not homogenously distributed, each species depends on the existence of a specific set of environmental conditions for its long-term survival (Gaston and Blackburn, 2000). Detailed knowledge of species ecological and geographic distribution is fundamental for conservation planning and forecasting (Ferrier, 2002; Funk and Richardson, 2002; Rushton *et al*., 2004), and for understanding ecological and evolutionary determinants of spatial patterns of biodiversity (Rosenzweig, 1995; Brown and Lomolino, 1998; Ricklefs, 2004).

To predict species potential geographic distribution and its richness, a range of models have been developed. Many scientists have used BIOCLIM model of DIVA-GIS to predict the species current distribution (Guisan and Zimmerman, 2000; Hijmans and Graham, 2006; Parthasarathy *et al*., 2006; Rajbhandary *et al*., 2010; Barman *et al*., 2011; Babar *et al.,* 2012), taking one or few genera and even a whole family. But, no work has focused on the family Liliaceae. However, very less work has been done on species distribution modeling for Nepal. Although distribution modeling cannot be treated as substitute for detailed empirical field data, including data on demography, abundance and species-environment interactions, its prediction accuracy can be judged based on available information. In case of Liliaceae, the collection of occurrence records is limited mostly to the sites where field excursions have been made in the past, which may result in the perception that they grow under certain conditions when other areas were simply not examined. Selected parameters may not be sufficient to describe the species habitat requirements. Certain species have specific ecological limitations governing where they are known to occur, which may result in over-prediction of suitable habitat by the model. Distribution model (BIOCLIM) predicts suitability areas only in the neighbourhood of occurrence records. Thus, the present work also aims, 1) to predict the current potential geographic distribution of three subfamilies of Liliaceae: Lilioideae, Streptopoideae and Calochortoideae; 2) to generate the overall species richness pattern for the family Liliaceae in Nepal.

Materials and methods

Climatic and species data

Locality records (in total, 218) for 19 enumerated species (classified into 3 subfamilies *viz*., Lilioideae, Streptopoideae, Calochortoideae) of family Liliaceae were used for distribution modeling. These locality records were obtained from the herbarium specimens housed at different herbaria National Herbarium and Plant Laboratories (KATH), Tribhuvan University Central Herbarium (TUCH), University of Tokyo (TI) and Royal Botanic Garden Edinburgh (RBGE). A set of 19 climatic variables for Nepal (Tab. 1) were extracted from WORLDCLIM (http//www.worldclim .org) (Hijmans *et al.,* 2005). WORLDCLIM contains climatic data at a spatial resolution of 2.5 arc sec (~5 Km^2) obtained by interpolation of climatic station records from 1950-2000. The variables were derived from monthly precipitation and maximum and minimum temperature.

Table 1. List of 19 bioclimatic variables used for predicting the species distribution.

BIO1	Annual Mean Temperature	Derived from max and min temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp –min temp))	
BIO3	Isothermality (BIO2/BIO7) (* 100)	
BIO4	Temperature Seasonality (standard deviation *100)	
BIO5	Max Temperature of Warmest Month	
BIO6	Min Temperature of Coldest Month	
BIO7	Temperature Annual Range (BIO5–BIO6)	
BIO8	Mean Temperature of Wettest Quarter	
BIO9	Mean Temperature of Driest Quarter	
BIO10	Mean Temperature of Warmest Quarter	
BIO11	Mean Temperature of Coldest Quarter	
BIO12	Annual Precipitation	Derived from precipitation
BIO13	Precipitation of Wettest Month	
BIO14	Precipitation of Driest Month	
BIO15	Precipitation Seasonality (Coefficient of Variation)	
BIO16	Precipitation of Wettest Quarter	
BIO17	Precipitation of Driest Quarter	
BIO18	Precipitation of Warmest Quarter	
BIO19	Precipitation of Coldest Quarter	

Data cleaning

The initial record of presence points were 355, after removing the multiple collection records. The presence points were georeferenced using ArcGIS 9.3 and duplicate records were removed within each 2 min grid cell (separately for species of 3 subfamilies) to obtain least spatial autocorrelation. Finally, 164 collection points for subfamily Lilioideae (16 species), 42 for Streptopoideae (2 species) and 12 for Calochortoideae (1 species) were obtained.

Distribution modeling

In ecological and biogeographical studies, the present distribution of organism is analyzed with regard to the characteristics of the physical environment, involving modeling. Prediction of distributions have been carried out for many types of organism, especially with the application of DIVA-GIS (Guisan and Zimmerman, 2000; Delanoy and Damme, 2006; Hijmans and Graham, 2006; Parthasarathy *et al.,* 2006; Zafra-Calvo *et al.,* 2010; Hou *et al.,* 2010; Rajbhandary *et al.,* 2010; Barman *et al.*, 2011; Babar *et al.*, 2012). The environmental suitability for each species was ranked under five classes (Tab. 2). The places not suitable for the species were displayed in white. Areas with various classes of suitability for the species were shown from dark green to red color. The dark green color means lower suitability (0-2.5 percentile) while red (20-30 percentile) indicates place with higher suitability for species present occurrence. For each grid cell of the map, percentile value is assigned, which range from zero (low) to the theoretical maximum of 50 (very high). Locations where the values lie within the 2.5-30 percentile of the climate envelope are traditionally classified as 'core' regions of species occurrence. Excellent distribution of species belonging to subfamilies is shown by the region with 20-30 percentiles.

Species richness

Richness gradient in Nepal for the family Liliaceae was estimated by overlaying the overall potential range map predicted by BIOCLIM in DIVA-GIS 7.5. For this purpose, neighborhood option with 9 × 9 neighborhood size was selected. Estimated richness of species was then interpreted on the basis of vegetation type in Nepal. Number of species occurring in any habitat not only depends on the climatic variables, but also on local ecological conditions as defined by the composition of dominant vegetation.

Table 2. Species richness classes with suitability value.

Color	Class	Suitability (Percentile)
	Not suitable	> 0
	Low	0 - 2.5
	Medium	2.5 - 10
	High	10 - 20
	Very high	20 - 30
	Excellent	20 - 30

Results and discussion

Species Distribution Modeling

Among the members of the family Liliaceae, taxa belonging to the subfamily Lilioideae are distributed throughout the Northern part of Nepal (Fig. 1). But the model predicted greater concentration of the subfamily Lilioideae in North-Central and North-Western region than in North-Eastern region of Nepal (Fig. 2). The best region for Lilioideae is explained by 20-30 percentile value for North-Central Nepal. For the members of the subfamily Streptopoideae North-Western region seems to be less favourable than the North-Eastern region (Fig. 3). North-Eastern region is with maximum parts of excellent distribution (20-30 percentiles). In the case of the subfamily Calochortoideae, mostly the North-Eastern region and very less parts of the North-Central region seems to be favourable for species occurrence (Fig. 4). Present distribution of *Tricyrtis maculata* (the only member of the subfamily Calochortoideae) is restricted only to these regions.

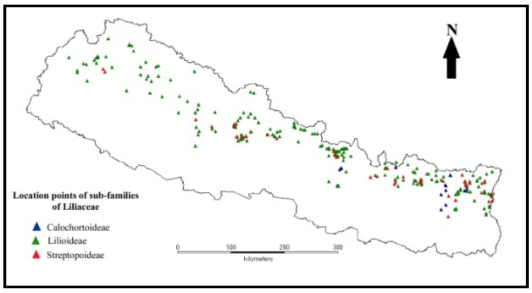

Figure 1. Overall distribution of Liliaceae in Nepal based on herbarium records of species occurrence points.

Members of three subfamilies within Liliaceae differed in distribution pattern. The adaptation to seasonal habitats limits the distribution of species in different regions (West-East) of Nepal (Rajbhandary *et al.*, 2010). The suitability value for potential distribution varies for members of three subfamilies. Some of the areas shows very high suitability and are interesting for future plant collections. One of the reasons for this is that the areas with high suitability were mostly covered by field trips. Some areas with low suitability, however, were not explored. Guarino *et al.* (2002) stated that even limited information can be used to identify areas where a species has not been previously recorded but where it might be expected to occur.

The suitability percentile values ranged 0-30; where 20-30 percentiles measured excellent distribution. The climatic factors where suitability percentile values are highest (20-30) matches with the climatic conditions of actually occurring data points; but, the areas with less than zero percentile values indicates that climatic factors of actual distribution (based on collection records) do not match with mapping site.

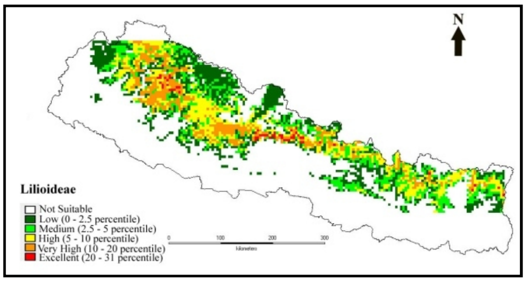

Figure 2. Current potential distribution of subfamily Lilioideae in Nepal.

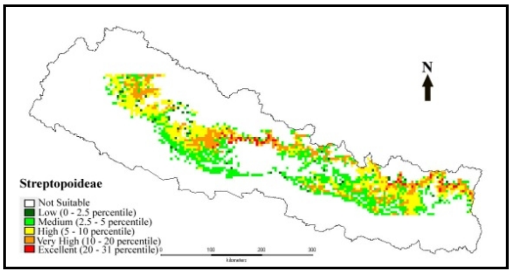

Figure 3. Current potential distribution of subfamily Streptopoideae in Nepal.

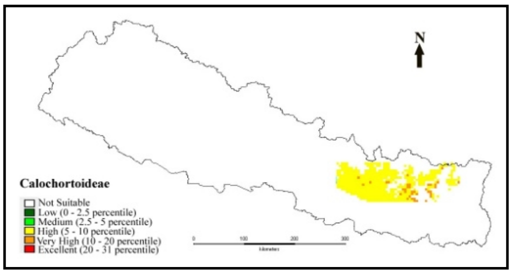

Figure 4. Current potential distribution of subfamily Calochortoideae in Nepal.

North-Central region of the Nepal seems to be most suitable region for species distribution of the subfamilies Lilioideae and Streptopoideae, as they have highest parts with 20-30 percentile of suitability. Rainfall in Nepal is mostly monsoonal, which occur during June to August, and this rainfall decreases sharply from Eastern to western Nepal. This creates fairly moderate rainfall in the North-Central region of Nepal. The occurrence of several species of subfamily Lilioideae and Streptopoideae in the North-western and North-far-western regions of Nepal is because of the ability of those species to cope with marked seasonality in precipitation and prolonged periods of drought. But, there seems overlapping distribution of species belonging to three subfamilies in the North-Eastern region of Nepal. Species of subfamily Calochortoideae do not occur in North-western region. It is because they prefer wetter habitats with high humidity even during the drier months.

Most parts of the middle and upper belts of Nepal are climatically suitable for species of these 3 subfamilies, where they are widely distributed. For subfamily Lilioideae, excellent suitability percentile is represented by North-Central region followed by North-western region and very less by North-Eastern region. This result indicates that Lilioideae species favoured relatively drier habitat in North-Central and North-western region than wetter habitat in North-Eastern region. In contrast, predicted potential distribution map of subfamily Streptopoideae shows almost equal parts of North-Central and North-Eastern regions with 20-30 percentile value. These results indicate that species of subfamily Streptopoideae prefer relatively moist habitat than the species of Lilioideae. Although these two subfamilies show overlapping pattern of distribution from North-western to North-Eastern regions, there occurs variation in suitability percentile for species occurrence in these regions.

There is no any region with excellent (20-30) percentile value in predicted potential distribution map of subfamily Calochortoideae. The percentile value lies within 2-20, for all the predicted regions. The reason behind this is lesser number, as well as larger distance between collections records used for modeling.

Species Richness

Richness value ranges between 1-50. The richness value 50 indicates that all the 19 species occur in a particular locality, and the value below 1 indicates species does not occur. The results showed maximum species richness (represented by richness value 50) in large part of the North-Central and North-western regions as compared to the North-Eastern region of Nepal (Fig. 5).

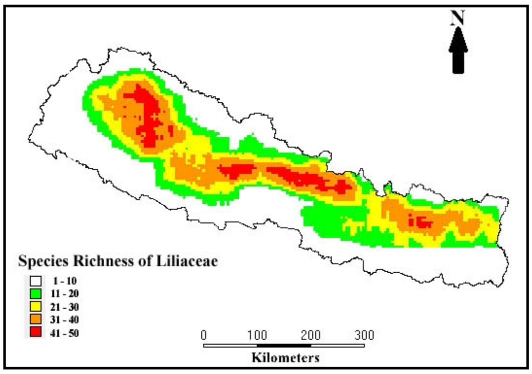

Figure 5. Species richness pattern of the family Liliaceae in Nepal**.**

Pattern of species richness was analyzed in 9 x 9 neighborhood grid size for the family. The results showed that species richness value was highest in North-Central and North-western regions than in the North-Eastern region of Nepal. Their occurrence in these regions indicates that the species requires a relatively small amount of water to establish. Except for the similarities in climatic factors of actually recorded data points and the modeled sites of potential distribution, other reasons for occurrence of such pattern are: firstly, species richness is based solely on specimen data and hence missing data for locality will be interpreted as zero species leaving many areas for which there are no collections; secondly, only species which have a fairly wide modeled distribution will have an impact on the overall modeled species richness. A better analysis of species richness will be obtained if relating it with factors other than the climatic factors (Terribile *et al.*, 2009).

Conclusion

Use of geographic location of the collection sites in combination with the relatively simple GIS software (i.e. DIVA-GIS) allowed prediction on distribution and estimation of species richness for the family Liliaceae. Species distribution models can provide valuable information about where species are likely to be found. As well as being important tool for conservation, they can help to determine the aspects of species' environment that are important in determining its distribution and thus advance our understanding of ecological niches. Species distribution modeling can also be useful tool for data exploration to provide direction for fieldwork design. Current potential distribution of species enumerated in the family Liliaceae has provided new localities for future expeditions and explorations. Species distribution modelling can be a valuable and cost-effective tool for understanding a species occurrence probability with given environmental data, especially in poorly-surveyed regions of the least known species (Guisan *et al.*, 2006).

Furthermore, this work will be crucial in understanding spatial dynamics of the species in the sub-family in socially and environmentally changing condition. Local and national government authority can use results of this study to devise the conservation, sustainable harvest, and farming plan to protect the important species of the sub families in wild and to get economic benefit. It can be further useful in assessing threats and evaluating gaps in protected areas in order to conserve these medicinally and economically important sub families of Liliaceae. Moreover, evaluating the distribution pattern and species richness will be important in devising adaptive responses and baseline data for the sustainable management of the species of subfamilies in natural habitat.

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