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Population assessment and species distribution modeling of *Paris polyphylla* in Sikkim Himalaya, India

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Abstract. *Lepcha DL, Pradhan A, Chhetri DJ. 2019. Population assessment and species distribution modeling of* Paris polyphylla *in Sikkim Himalaya, India. Biodiversitas 20: 1299-1305.* *Paris polyphylla* Smith is an important therapeutic plant that grows in the Indian Himalayan region. In Sikkim, the survival of the species is threatened by illegal extraction of its rhizome. Therefore, immediate conservation initiative is required to conserve the existing species population in the wild. Population assessment through field survey followed by ENM revealed a positive correlation between predicted suitable habitats with the actual sites of its occurrence, except in disturbed habitats. Precipitation of driest month (Bio14) and slope were the most influential factors that contributed 41.9 % and 30 % respectively to the MaxEnt model. Field survey revealed that the density of the plants varied between 0.45 (pl/m^2) and 3.89 (pl/m^2) and the frequency varied from 36% to 76%. The IVI for *P. polyphylla* ranged between 2.68 to 8.66 based on locations. On the other hand, the IVI of associated species varied from 3.57 to 18.14 based on species. *P. polyphylla* is a vulnerable plant in Sikkim Himalaya and it is facing an imminent threat of extinction. Under this situation, it is imperative that works on predictive modeling will help conserve the species. This study identified the potential habitats for *P. polyphylla* in the higher elevations of Sikkim Himalaya where it could be reintroduced.

Keywords: Ecological niche modeling, habitat, Himalaya, *Paris polyphylla,* Sikkim

INTRODUCTION

Paris polyphylla Smith commonly known as Love apple belongs to the Family Melanthiaceae (earlier Trilliaceae or Liliaceae) (Figure 1), and is mostly found in India, China, Bhutan, Laos, Myanmar, Nepal, Sikkim, Thailand and Vietnam (Sharma et al. 2014). In India the species have been recorded from the Himalayan states like Arunachal Pradesh, Himachal Pradesh, Jammu and Kashmir, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Uttarakhand (Paul et al. 2015).

In traditional medicine, the roots are used as analgesic, antiphlogistic, antipyretic, antispasmodic, antitussive, depurative, febrifuge and narcotic (Duke and Ayensu 1984) Furthermore, it has been used to treat liver cancer in China for several decades (Lee et al. 2005; Shoemaker et al. 2005). In Nepal, the rhizome is indigenously used against snake bites, insect bites, alleviate narcotic effects, internal wounds, external wounds, fever, food poisoning and are fed to cattle during diarrhea and dysentery (Dutta 2007; Baral and Kurmi 2006). It is also used to treat headache, vomiting, and worms (Uprety et al. 2010). In the Indian Himalayan Region, *P. polyphylla*, used against burn, cut or injury, diarrhea, dysentery, fever, gastritis, skin diseases, stomach pain and wounds (Farooquee et al. 2004; Maity et al. 2004; Tiwari et al. 2010; Jamir et al. 2012; Lalsangluaii et al. 2013; Pfoze et al. 2013; Sharma and Samant 2014).

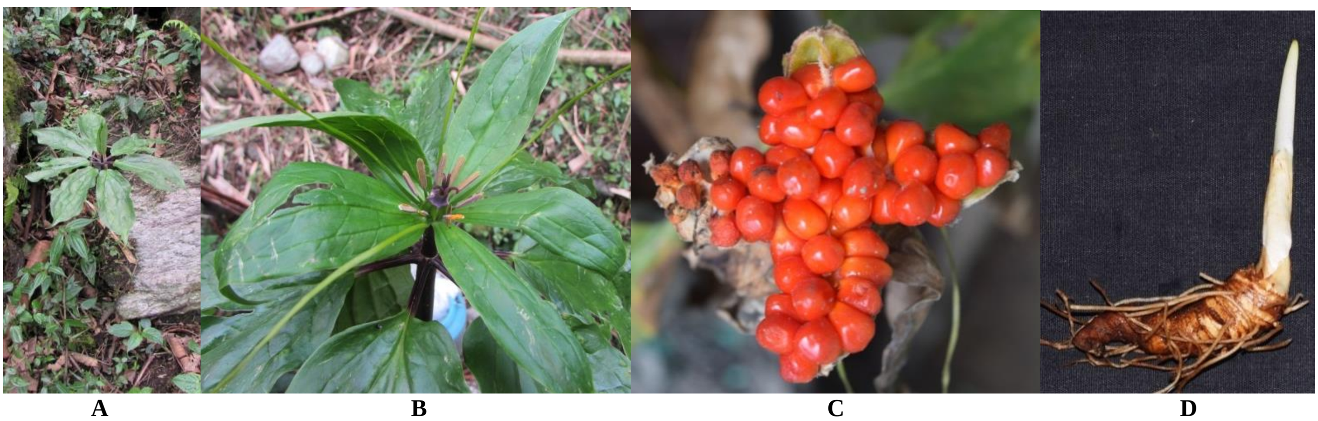


Figure 1. A. Pictorial representation *P. polyphylla* from Sikkim, Himalaya, India. A. Whole plant; B. Plant with flower; C. Mature fruits with exploded pod; D. Sprouting rhizome

The rhizome is the primary mode of regeneration, although it regenerates from seeds. Because of the commercial demand of the rhizome, the population of the species may entirely be wiped out if proper conservation initiatives have not been taken. To consider the importance, illegal harvesting, seed dormancy and slow-growing nature of the plant, there is an immediate need to develop the conservation methods (Chandra et al. 2015).

Understanding the ecology of individual species is important for conservation and for cultivation purposes. Effective conservation strategies may help to protect the species from its extinction (Paul et al. 2015). Such strategies for conservation and protection of threatened species depend on identification of habitat types. Ecological niche modeling (ENM) is a technique which uses computer algorithms to generate predictive maps of species distribution in a geographic space by correlating the point distributional data with a set of environmental raster data. ENM facilitates interpolation as well as extrapolation of species distributions in geographical space across different time periods. This makes it possible to prepare species distribution maps with high levels of accuracy and identify areas suitable for reintroduction of the threatened species (Kumar and Stohlgren 2009). Predicting and mapping the suitable habitat for threatened and endangered species is critical for monitoring and restoration of their declining native populations (Kumar and Stohlgren 2009). Detailed knowledge of its potential habitats is essential, to rehabilitate a threatened species. Development of species-specific conservation strategies, threat assessment of rare and threatened species and identification of suitable habitats for reintroduction may be aided by ENM (Chettri et al. 2018; Adhikari et al. 2018).

One way to identify forest habitats where rare plant species are found is through the use of species distribution models that relate field habitat observations to environmental predictor variables to quantify species-environment relationship (Guisan and Thuiller 2005). Models subsequently predict suitable potential habitats where certain species are likely to occur based on the data of their real occurrence, making the models useful for conservation projects (Hawk 2017). Maxent is a general purpose, machine learning probability model that searches for predicted occurrence based on a set of variables. It is interesting to note that it can also perform to maximum accuracy despite incomplete data sets which are quite common in rare species (Hernandez et al. 2006).

The Himalayan region has been regarded as home to many valuable medicinal and aromatic plant species, but rapid loss of genetic resources due to anthropogenic activities affects the regional biodiversity. *Taxus baccata* Zucc., the Himalayan Yew plant has already become threatened due to its unsustainable extraction (Paul et al. 2013) and the history is again repeating for other species including *Paris polyphylla* Smith due to its commercial demands (Paul et al. 2015). In Sikkim Himalaya, *Paris polyphylla* is found only in some restricted high altitude areas of North, East, West and South districts. This species was categorized as vulnerable in 2014 (Ved et al. 2017), but continuous anthropogenic activities within the past four years have drastically decreased the population. The threat of extinction is imminent, especially in consideration that the species has already vanished from the nearby Darjeeling Himalaya within the past 8-10 years. Many studies on ecology, pharmacology, and conservation of *Paris polyphylla* have been carried out so far. In India, such studies have been done with respect to species from other parts of Himalaya, but there is dearth of information for the same from Sikkim Himalaya. Therefore, the present work was undertaken to determine the potential habitat range of *Paris polyphylla*; to identify the major factors that determine its distribution in the potential habitats and ultimately to contribute towards the conservation of the species and saving it from extinction. Identification of suitable habitats for the reintroduction of the species are the essential steps in the species conservation efforts. Therefore, in this study, ENM of *Paris polyphylla* has been undertaken to assess the spatial scale of proposed distribution of the species in Sikkim Himalaya and to test the potential distribution in conjunction with actual field data to determine the suitable sites for future reintroduction of the species.

MATERIALS AND METHODS

Species data and environmental variable

The occurrence data for *Paris polyphylla* Smith *(P. polyphylla)* were collected from the field using Garmin GPS 78s. The environmental variables used in the study were downloaded from the Worldclim database (http://www.worldclim.org) (Hijmans et al. 2005). In order to remove the highly correlated variable (r>0.9) we performed multicollinearity using ENM Tools 1.3 (Warren et al. 2010). Thus out of 19 bioclimatic variable, six were selected for modeling.

MaxEnt modeling and model validation

Maxent software (MaxEnt version 3.3.3k, http://www.cs.princeton.edu/~schapire/maxent/) (Philips et al. 2006) were used to model the distribution of *P. polyphylla* in Sikkim. We executed 10 replicated model runs for the species to validate the model robustness with 10 percentile training presence logistic threshold. Other parameters were set default as the program is already calibrated on a wide range of species datasets (Phillips and Dudik 2008). From the replicated runs, average, maximum, minimum, median and standard deviation were generated. The quality of the model was evaluated based on AUC value, a value below 0.5 can be interpreted as a random prediction; 0.5-0.7 indicates poor model performance; 0.7-0.9 indicates moderate performance; and a value above 0.9 is considered to have ``good" discrimination abilities (Peterson et al. 2011). Further, the potential area of distribution was categorized into five classes based on 10 percentile training presence logistic threshold i.e. very-high (0.717-1), high (0.550-0.717), medium (0.385-0.550), low (0.218-0.385) and very low (0-0.218).

Population assessment in relation to model threshold

Thirty random quadrates of 1 m x 1 m were laid in each study sites (viz. Tholung, Lachung, Lingthem, Chungthang (North Sikkim), Barsey, Uttray (West Sikkim), Pangthang, Zuluk (East Sikkim) and Ravangla (South Sikkim) to study community characteristics using quantitative analytical methods. During survey, much care was taken to reflect different vegetation types, landform, elevation, and other important ecological characteristics so as to provide data of the species found in both the altitudinal range (Bhadra et al. 2016). During the study period, average temperature ranged from 10-22°C, and annual rainfall was between 2000-2650mm (Meteorological Station Gangtok, Sikkim). The density, frequency and other values of these parameters were calculated and Importance Value Index (IVI) following (Curtis 1959 and Mishra 1968). The formula used was;

Relative frequency = (Frequency of a species / Sum of frequency of all species) × 100

Relative density = (Density of a species / Sum of density of all species) × 100

Importance Value Index (IVI) for Herb = Relative Frequency + Relative Density.

The population status of *P. polyphylla* determined through quadrate studies were then correlated with model threshold to ascertain whether the region covered in the very high and high suitability thresholds of the model maintain higher populations or not and vice-versa.

Soil property analyses

Fresh soil samples from each study site (0-15cm depth) were collected with soil corer (Diameter-5.5cm). Different soil parameters such as soil moisture by gravimetric oven dried method (105°C for 24 hours), soil temperature by soil thermometer, soil pH by digital pH meter (Cos-Lab), etc were analyzed. Further soil samples were air dried, crushed and passed through a sieve (1mm) to separate out coarse material and gravel and live roots. The sieved soil samples were used to determine soil organic carbon (SOC) by colorimetric methods (Anderson and Ingram 1993). Total nitrogen was determined by using Kjeltec 8500 (FOSS), and available phosphorus was determined by ammonium molybdate-stannous chloride method (Devi and Yadava 2006) (Table 1).

RESULTS AND DISCUSSION

Species distribution modeling

The potential distribution map for *P. polyphylla* is shown in Figure 2.

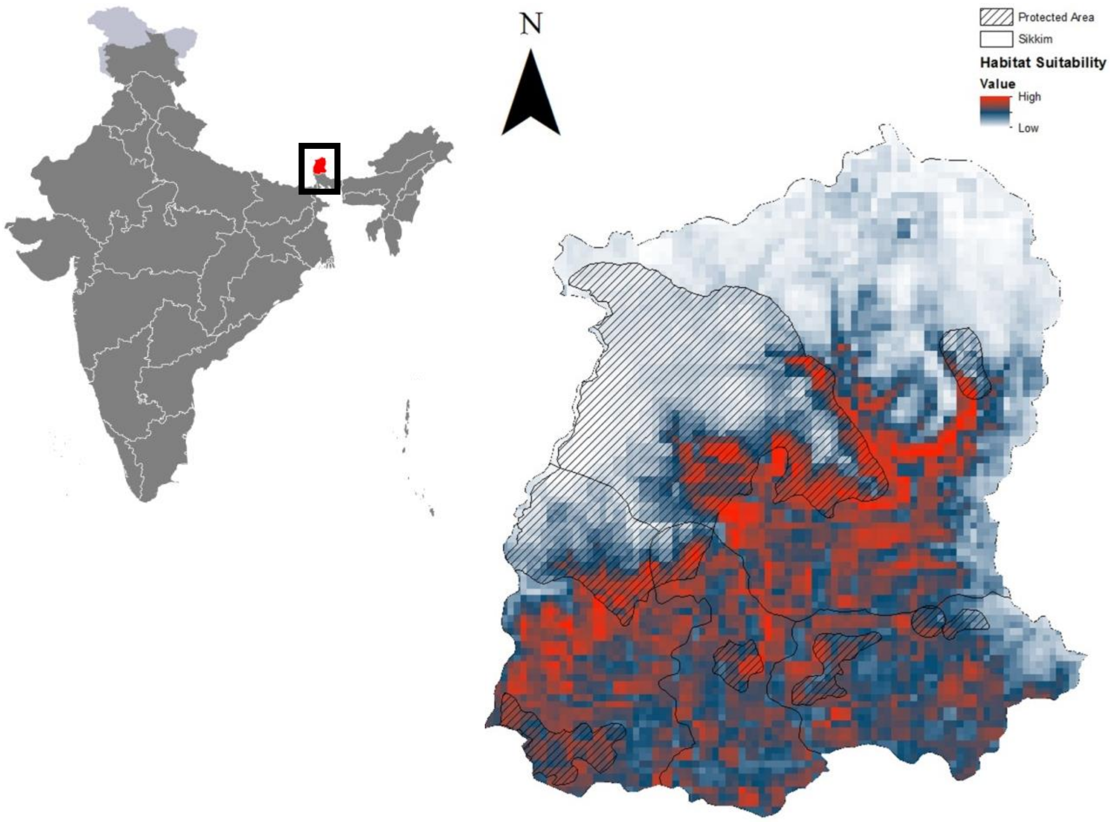


Figure 2. Study site in Sikkim, India (in rectangle, *left*) and distribution mapping of *Paris polyphylla* in Sikkim, India (*right*)

Table 1. Physiochemical properties of soil collected from different sites of *Paris polyphylla* occurrence in Sikkim Himalaya, India

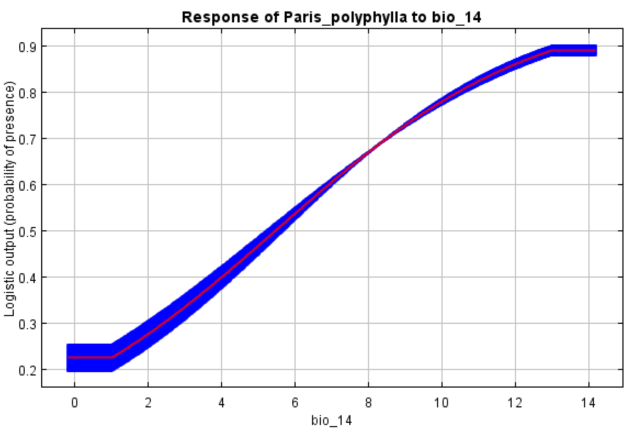
Locality	Altitude(m)	Soil pH	Soil moisture (%)	Soil temperature (^{0}C)	Organic carbon (%)	Total nitrogen (%)	Available phosphorous (%)
Chungthang	1800-1900	4.83± 0.58	30.79± 1.91	13.96± 0.54	3.30± 0.30	0.31± 0.08	0.04± 0.01
Lingthem	1500-1700	5.00± 0.94	30.40± 3.37	15.76± 3.06	3.55± 0.31	0.49± 0.13	0.06± 0.04
Tholung Forest Area	2500-2900	4.48± 0.14	40.40± 5.42	11.77± 1.20	4.26± 0.29	0.51± 0.23	0.05± 0.02
Lachung	2800-3100	5.00± 0.16	28.68± 5.89	10.29± 0.19	4.08± 0.49	0.58± 0.13	0.04± 0.02
Pangthang Area	1800-1900	5.70± 0.58	33.87 ± 3.25	14.21± 0.81	3.79± 0.11	0.34± 0.12	0.04± 0.04
Zuluk valley	2500-2600	4.38± 0.50	30.91± 2.88	10.84± 0.35	3.05± 0.34	0.51± 0.10	0.03± 0.02
Ravangla Forest Area	1800-1900	5.26± 0.24	42.35± 1.27	13.02± 0.73	3.40± 0.60	0.31± 0.10	0.05± 0.02
Uttray	1800-2000	5.51± 0.55	32.8± 4.93	14.70± 0.05	2.86± 0.31	0.37± 0.09	0.06± 0.02
Barsey Rhododendr-on Sanctuary	1800-1900	4.99± 0.42	31.37± 3.17	13.04± 0.73	3.18± 0.06	0.46± 0.13	0.05± 0.03

The MaxEnt model performance for *P. polyphylla* provided satisfactory result with mean AUC value of 0.809 (±0.140) which was higher than a random model. The AUC of Maxent model performance for *Trillium simile* Gleason, a plant belonging to the same family Melantiaceae was found to be good at 0.839 (Hawk 2017). Almost similar values had been obtained for *P. polyphylla* during the present study. However, Maxent predictive performance for another rare medicinal plant from Himalayan foothills, *Justicia adhatoda* L. was much higher (AUC= 0.923). The Maxent model uses presence-only data which is preferable since this model tends to overestimate the areas of potentially elevated biodiversity which is more suitable for conservation of endangered species (Zaniewski et al. 2002).

Amongst all the six variables used precipitation of driest month (Bio 14) (41.9 %) and slope (30 %) had the highest contribution to the model (Figure 3.A and 3.B). These two variables collectively contributed 71.9 % to the model output (Table 2). Present results are in consonance with earlier reports whereby the Maxent model performed with high discriminatory ability due to variables related to temperature and precipitation (Bradie and Leung 2016). It was also found that terrain attributes such as aspect and slope are highly significant in the modeling (Lecours et al. 2016). It is important to mention here that the predicted distribution of suitable habitat does not actually represent the true distribution of the species, but represents the prediction of distribution of suitable habitats (Setyawan et al. 2018).

Table 2. Percentage contributions of the predictor environmental variables to the MaxEnt model of *Paris polyphylla* habitats in Sikkim Himalaya, India

Environmental variables	% Contribution
Annual mean temperature (^{0}C, Bio1)	6.6
Mean diurnal temperature range [mean of monthly (max temp - min temp)] (^{0}C, Bio2)	17.1
Precipitation of driest month (mm, Bio14)	41.9
Precipitation seasonality (CV) (Bio15)	4.2
Slope (%)	30
Aspect (^{0})	0.2



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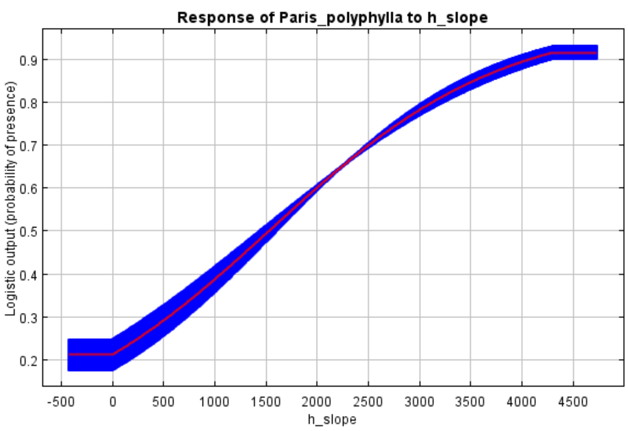

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Figure 3.A. Response curves showing the relationships between the probability of presence and Precipitation of driest month (Bio 14) (values shown are average over 10 replicate runs: blue margins show SD calculated over 10 replicate run). B. Response curves showing the relationships between the probability of presence and Slope (values shown are average over 10 replicate runs: blue margins show SD calculated over 10 replicate run).

Table 3. Ecological details of different *Paris polyphylla* habitats in Sikkim Himalaya, India

Place of collection/ locality	Geographical coordinates	Probability value (0-1)	Habitat suitability	Quadrates of occurrence	Frequency %	Relative frequency	Density (pl/m^2)	IVI
Chungthang (North Sikkim)	27°37´131´´N 88°40´017´´E	0.60	High	17	56	3.44	1.76	5.21
Lingthem(North Sikkim)	27°31´515´´N 88°29´542´´E	0.46	Medium	19	63	3.80	2.38	6.19
Tholung Forest Area (North Sikkim)	27°39´218´´N 88°27´435´´E	0.62	High	23	76	4.85	3.81	8.66
Lachung(North Sikkim)	27°42´450´´N 88°44´573´´E	0.72	Very High	14	46	3.57	1.67	5.24
Pangthang Area (East Sikkim)	27°22´222´´N 88°36´201´´E	0.54	Medium	11	36	2.14	0.69	2.83
Zuluk valley(East Sikkim)	27°15´153´´N 88°46´367´´E	0.47	Medium	13	43	3.18	1.51	4.69
Ravangla Forest Area(South Sikkim)	27°18´410´´N 88°21´508´´E	0.73	Very High	16	53	3.22	1.48	4.71
Uttray (West Sikkim)	27°16´115´´N 88°08´306´´E	0.64	High	11	36	2.22	0.45	2.68
Barsey Rhododendron Sanctuary (West Sikkim)	27°12´625´´N 88° 08´470´´E	0.62	High	22	73	4.36	2.16	6.53

Soil nutrients like organic carbon, total nitrogen and available phosphorous of soil of *P. polyphylla*'s habitat were analyzed. In terms of organic carbon, the amount was found slightly higher in Tholung and Lachung forest area as compared to the other sites. Earlier study reported that the study sites where the *Paris* plant grows have higher nutrient content than the soil devoid of the plant (Madhu et al. 2010). In general, in all the Paris habitats the soil was characterized by acidic pH (4.48- 5.70), high organic carbon (2.86-4.26%) and low soil temperature (10.29-15.76 °C). Moreover, the available phosphorous was uniformly low in all the sites (Table 3).

Population assessment

The IVI value for *P. polyphylla* was positively correlated with higher model thresholds. The IVI analysis of *P. polyphylla* and 30 other closely associated plants was carried during the survey. Among all these species the top three dominant associated species with maximum IVI. includes *Fragaria nubicola*, *Pteris* sp. and *Sarcococca coriaceae.* Other associated plant species were: *Aconogonum molle, Arisaema griffithii, Arisema ciliatum, Aresima costatum, Artemisia vulgaris, Cantella* sp., *Commelina* sp., *Crassocephalum crepidioides*, *Cyperus cyperoides, Deparia boryana, Drymeria cordata, Elatostema umbellatum, Girardinia diversifolia, Impatiens* sp., *Panax bipinnatifidus, Plantago asiatica, Polygonatum varticillutum, Polygonum hydropiper, Pouzolzia hirta, Rubia manjith, Rubus ellipticus, Rumex nepalensis, Selaginella* sp., *Trillium govanianum, Trillium tschonoskii, Urtica dioica, Viburnum erubescens and Viola* sp. (Table 4).

Density, frequency of occurrence and Importance Value Index (IVI) of the study species is presented in Table 2. The observation revealed that in Uttaray the mean density of *P. polyphylla* was lowest at 0.45 (pl/m^2) with an IVI of 2.68. In contrast, the Tholung forest area recorded the highest density of the plant at 3.81 (pl/m^2) and the highest IVI (8.66). This IVI was followed by that in Barsey (6.53) which may be because both of those locations falls under protected areas. Despite showing the Medium and High ‘Habitat Suitability’ by the MaxEnt model run, the two lowest IVI recorded were by Uttray (2.68) followed by Pangthang (2.83). This may be because Uttray was the first place from Sikkim where illegal trade of *P. polyphylla* started since it is near the international boundary of Nepal and Pangthang is located near to the capital city, Gangtok. Present average population density of *P. polyphylla* was found similar to the reported density (1.78 individual m^{-2}) from Nepal (Madhu et al. 2010) and higher than the population density reported from Arunachal Pradesh (1.07 individuals m^{-2}) (Paul et al. 2015). The report shown here regarding population density was according to the survey conducted during the period of 2014-15, but more importantly as we revisited this area (2017-18) to take stock of the present scenario, it was observed that the wild population of *P. polyphylla* has further declined and from some areas it has become completely obliterated, except a few small pockets and protected areas (National parks and wildlife sanctuaries). All other areas where the plant was once available has significantly degraded.

The protected areas in Sikkim where *P. polyphylla* suitably thrives are Khangchendzonga National Park, Barsey Rhododendron Sanctuary, Maenam Wildlife Sanctuary, Pangolakha Wildlife Sanctuary, Fambonglho Wildlife Sanctuary, Kyongnosla Alpine Sanctuary, and Singba Rhododendron Sanctuary. These protected areas proved to be an important habitat for the *in-situ* conservation of *P. polyphylla* germplasm. Apart from these few patches, majority of the area where *P. polyphylla* was once abundant, have recently become bereft of the species due to illegal extraction. Just in the span of 8-10 years, the population of *P.polyphylla* in Sikkim Himalaya has drastically reduced in the natural habitat, but it could be rehabilitated as the present study suggests.

Table 4. List of associated species with their ecological parameters that were encountered during the sampling

Associate species	Quadrates of occurrence	Frequency%	Relative frequency	Density (pl/m²)	IVI
Aconogonum molle	13	45	2.89	2.47	5.37
Arisaema griffithii	13	45	2.89	2.47	5.37
Arisema ciliatum	17	58	3.72	1.44	5.17
Aresima costatum	24	80	4.80	3.43	8.24
Artemisia vulgaris	13	43	2.68	0.88	3.57
Cantella sp.	19	65	4.02	8.97	12.99
Commelina sp.	19	66	4.13	2.88	7.01
Crassocephalum crepidioides	19	65	3.90	1.70	5.60
Cyperus cyperoides	20	68	4.13	1.86	6.02
Deparia boryana	19	65	4.02	2.63	6.66
Drymeria cordata	19	65	4.14	8.33	12.47
Elatostema umbellatum	19	64	4.12	5.34	9.46
Fragaria nubicola	21	72	4.59	13.54	18.14
Girardinia diversifolia	20	67	4.19	2.18	6.38
Impatiens sp.	22	73	4.67	3.11	7.79
Panax bipinnatifidus	13	43	3.02	1.67	4.70
Plantago asiatica	15	51	3.63	1.88	5.52
Polygonatum varticillutum	14	47	3.40	2.79	6.20
Polygonum hydropiper	19	63	4.04	8.09	12.14
Pouzolzia hirta	20	69	4.36	3.30	7.66
Pteris sp.	19	63	4.02	4.44	8.45
Rubia manjith	19	65	4.14	1.86	6.12
Rubus ellipticus	16	56	3.62	1.19	4.82
Rumex nepalensis	18	60	4.27	3.15	7.42
Sarcococca coriaceae	17	58	4.17	10.03	14.21
Selaginella sp.	21	71	4.58	10.01	14.60
Trillium govanianum	19	63	4.10	1.81	5.81
Trillium tschonoskiin	15	51	3.68	1.88	5.57
Urtica dioica	16	53	3.64	3.11	6.75
Viburnum erubescens	15	50	3.17	0.73	3.90
Viola sp.	15	52	3.24	1.17	4.41

In conclusion, the present study demonstrated that the population of *P. polyphylla* is rather low in its natural habitats in Sikkim Himalaya. Habitat destruction for developmental activities like road construction, hydel power projects, tourism development and illegal extraction of rhizomes before the plant matures and sets the seeds are the main reason for its population decline. Like any other ENM, the Maxent model of *P. polyphylla* predicted the distribution of suitable habitats based on the available predictors. The Maxent model performance provided satisfactory result for *P. polyphylla* Smith. The model output was at accurate level with high AUC values. Of all the environmental variables, precipitation in the driest month and the slope exhibited highest contributions to the model. Field validation of the habitat vindicated similarities between habitat characteristics at predicted habitats *vis-à-vis* extant *P. polyphylla* population encountered during the fieldwork except in some locations heavily influenced by anthropogenic disturbances. *Fragaria nubicola*, *Sarcococca coriaceae* and *Pteris* sp. were the most dominant species associated with *P. polyphylla.* The model showed that the habitat suitability thresholds are the highest for Lachung and Ravangla forests. However, physical counts revealed that the actual population is moderate in those two sites. It should be mentioned here that there is a heavy influx of tourists in these areas. On the other hand, it was found that the population of the plant was highest in Lingthem, Tholung, and Barsey which are all protected areas and least susceptible to anthropogenic disturbances. Clearly, anthropogenic activities are the main cause of their population decline. Development of agrotechnology, transfer of technology from the lab to the land, reintroduction of the species in the suitable protected areas and sensitization of cultivators for harvesting the rhizomes only after seed set may be the right steps for conserving the species in Sikkim Himalaya. Our studies may be used for prioritizing areas for introduction of the species for cultivation and for management of the same for conservation.

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