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COMMUNICATION

POPULATION ASSESSMENT AND HABITAT DISTRIBUTION MODELLING OF THE THREATENED MEDICINAL PLANT *PICRORHIZA KURROA* ROYLE EX BENTH. IN THE KUMAUN HIMALAYA, INDIA

Naveen Chandra, Gajendra Singh, Shashank Lingwal, M.P.S. Bisht & Lalit Mohan Tewari

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COMMUNICATION

Population assessment and habitat distribution modelling of the threatened medicinal plant *Picrorhiza kurroa* Royle ex Benth. in the Kumaun Himalaya, India

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Abstract: Kumaun Himalaya is a home to various threatened medicinal and aromatic plants. *Picrorhiza kurroa* is a threatened medicinal plant useful in curing many diseases in Indian Himalayan region. Due to overharvesting from the wild its population is decreasing at an alarming rate. The present study attempted to assess its availability and predict highly suitable areas for in situ conservation in the alpine region of Kumaun. Availability of *P. kurroa* across various meadows was evaluated through rapid mapping exercise. MaxEnt model was used to predict the geographical distribution of the species using various environmental and physiographic parameters, and 29 primary distribution points. The results reveal that potential habitat of *P. kurroa* is located near forest fringes. Of the 3,828km^2 area (vegetated) of the alpine region of Kumaun, about 202km^2 is recorded highly suitable, 489km^2 less suitable and the rest not suitable for the species. It is also revealed that Napalchu nala, Panchachuli base, Chhipla Kedar, Rongkong, Ralam, Milam, Dwali, and Pindari areas are highly suitable areas for distribution of *P. kurroa*.

Keywords: Distribution, Kumaun Himalaya, medicinal plant, population.

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Author contributions: NC contributed for site selection, field survey, data collection, analysis and finalization of the manuscript. GS has help in the field work, data evaluation, continuous review and finalization of manuscript. SL has participated in field work and compilation of data. MPS has constantly guided the work and provide all the necessary technical support and preparation of manuscript. LM assisted in the field work and analysis of data.

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INTRODUCTION

Picrorhiza kurroa (Scrophulariaceae; vernacular name Kutki) (Image 1) is a perennial herb confined to alpine region of the Himalaya. The species is native to India, Nepal, Bhutan, China, Tibet, and Pakistan. In India, *P. kurroa* is naturally distributed from Kashmir to Sikkim in the subalpine to alpine region between 3,000–5,300 m (Chettri et al. 2005). It prefers rocky crevices and grows on moist, rocky slopes in organic rich soil. It is used either as an adulterant or as a substitute for the Indian Gentian *Gentiana kurroo*. Odour of the stem is slight and unpleasant, taste is very bitter and long lasting, and it has a high demand in the herbal market (Dutt 1928; Ved & Goraya 2008). A drug named picroliv (iridoid glycoside fraction of roots and rhizomes) containing at least 60% of 1:1.5 mixture of picroside-I and kutkoside) has been developed for the treatment of acute and chronic hepatitis, and healthy carriers (Dhawan 1993). In addition, it is used in liver and stomach medicines and prescribed for treatment of respiratory and allergic diseases (Sarin 2008). Consequently, *P. kurroa* is among the top 15 traded plant species in India in terms of economic value (Ved & Goraya 2008).

In recent times exploitation of *P. kurroa* has become a flourishing business for illegal collectors. Uncontrolled exploitation, along with other factors including habitat destruction, overgrazing and increasing tourism activities in habitats, are responsible for the dwindling of wild populations, which provide over 90% of the market demand of *P. kurroa*. Obtaining 1kg of dry weight *P. kurroa* requires uprooting 300 to 400 individual plants (Uniyal et al. 2009). Indiscriminate, unscientific harvesting and lack of organized cultivation of the plant has threatened its status in the wild, and it is listed as an endangered species by IUCN (Nayar & Shastri 1990). The conservation assessment and management prioritization (CAMP 2003) workshop on medicinal plants of northwestern Himalayan states held in Shimla also declared *P. kurroa* as endangered in Jammu & Kashmir and Himachal Pradesh, while its status in Uttarakhand was declared as critically endangered. In the recent past, the consumption of *P. kurroa* in different sectors in India was estimated at 415 metric ton/year (Ved & Goraya 2008). In 1980, 1.47 metric tons of *P. kurroa* were extracted from Himachal Pradesh, and this figure was 10 times higher in 1990 (Sharma 1995). A similar pattern was reported from the Gori Valley, Uttarakhand, where about 5 metric tons of *P. kurroa* was extracted by 12 villages in 2001 (Virdi 2004)

The species is being collected from almost all the alpine meadows of the state for personal and commercial use; however, information concerning species distribution and availability across meadows is limited. Identification of suitable habitats for the reintroduction of species is the next logical step in conservation efforts. Thus the present study was designed to address i) the status of *P. kurroa* natural populations and ii) the distribution of this species in the Kumaun Himalaya.

Image 1. *Picrorhiza kurroa*

MATERIAL AND METHODS

Study area

This study was undertaken in the alpine region of the Kumaun Himalaya, part of the central Indian Himalayan region (IHR), a major habitat of glacial and non-glacial herbs above 3,000m. The area lies between 29.716–30.816N latitude and 79.716–81.083E longitude, and

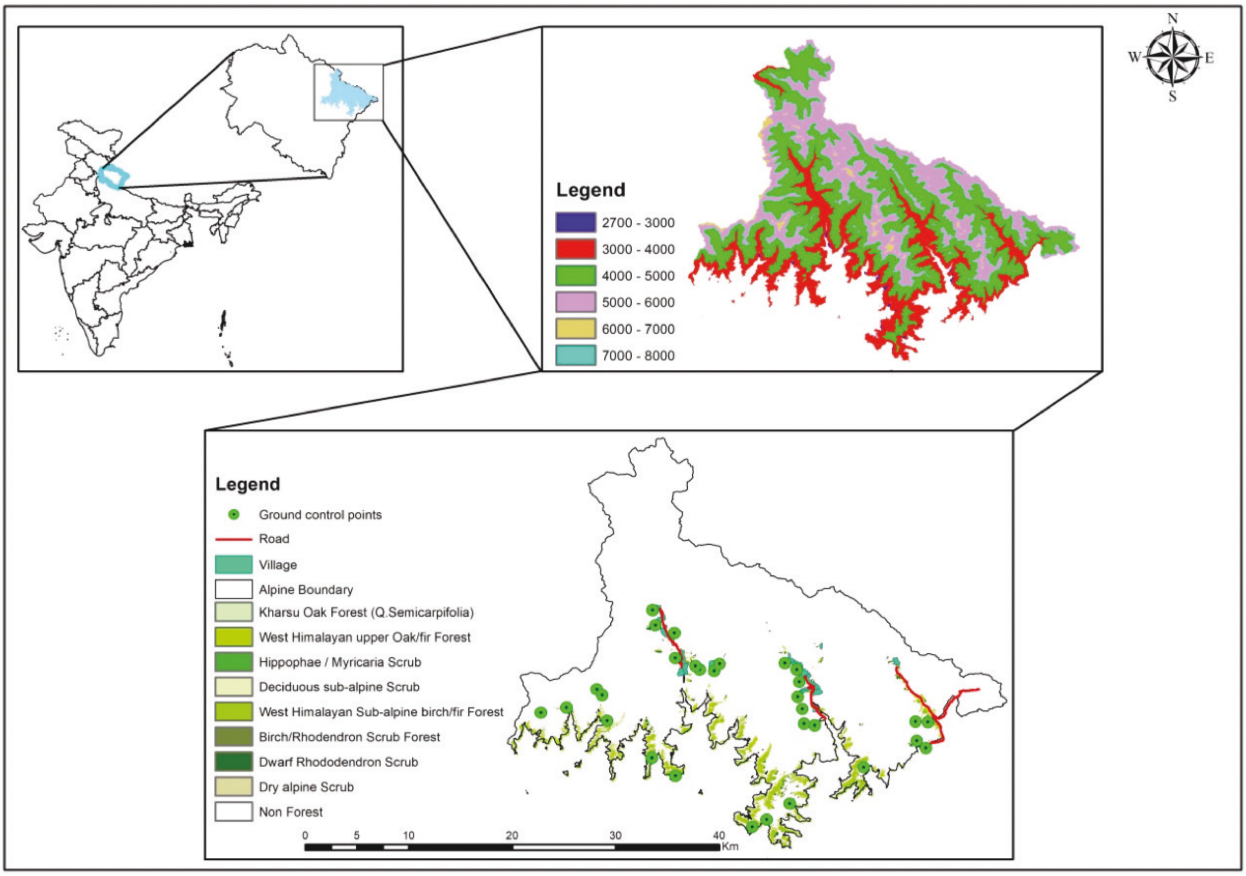

Figure 1. Study area geographical characteristic.

forms an interior most region. It is bounded by Chamoli district on the west, Tibet on the north, Nepal on the east, and Almora on the south. The total area covered between 3,000 to 5,300 m altitude is 4,617km^2. For the present study about 30 alpine meadows were surveyed. Major vegetation, road, village, altitude, and sample points are illustrated in Figure 1. These sites are under heavy snow cover for 4 to 6 months during winter, and maximum daytime air temperature reaches 25°C during the summer, followed by nearly freezing temperatures at night. Six major vegetation formations occur in the alpine region of Uttarakhand: tall forbs, short forbs or mixed herbaceous formations, matted shrubs/shrubberies, Danthonia grasslands, Kobresia sedge meadow, and cushioned vegetation (Rawat 2005). The maximum area is represented by Danthonia grassland (252.3km^2), followed by herbaceous meadows (159.3km^2) (Padalia et al. 2018). The region has nearly 40 small and large glaciers and many high-altitude lakes. Pindari, Gori, Kali, Dhauli, and Ramganga are rivers of glacial origin of this region, which harbours flora that are quite different from the flora of other areas.

Methods

Fieldwork in the alpine region is conducted from June to September, when most of the area is snow-free and plant blooming allows for easy identification. Intensive field surveys were conducted in 30 alpine meadows during 2016–19. Representative populations were found in 15 meadows, and where sizes were estimated using the rapid mapping exercise (RME) technique. Transects 500m long having 10 plots (5m circle) at every 50m interval were laid to assess major habitat types. Within each 5m circular plot, four quadrats of 1×1 m in north, east, west, and south (NEWS) directions were laid to assess the population of *P. kurroa* (Figure 2). About 30 to 40 plots were laid in each site where *P. kurroa* has been recorded.

Occurrence data and environmental variables

About (29) well distributed primary and secondary occurrence records of *Picrorhiza kurroa* were collected through field surveys and literature surveys (viz., herbarium survey of Forest Research Institute (DD) Dehradun, Botanical Survey of India (BSD), Kumaun

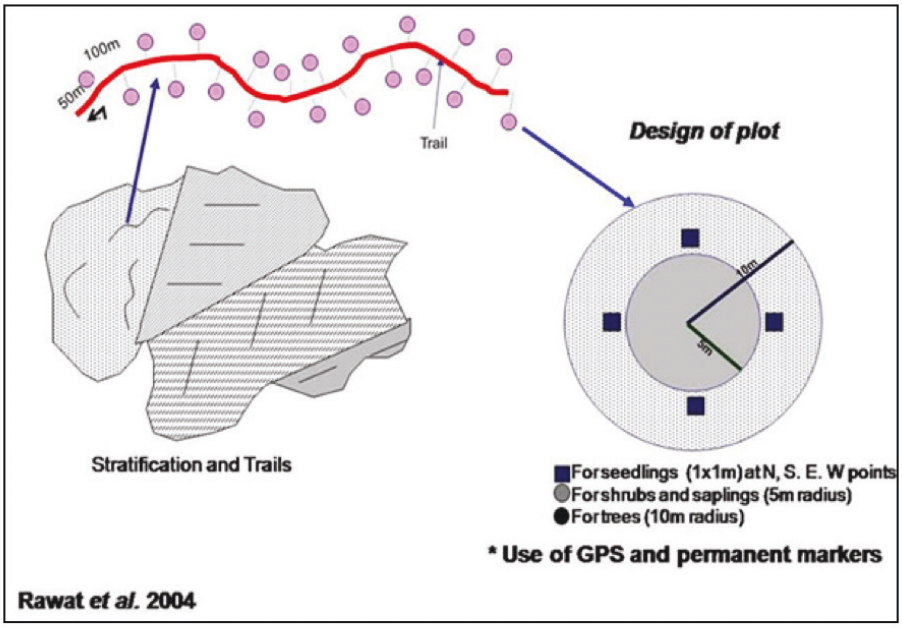

Figure 2. Rapid mapping exercise technique for estimation of MAPs (Rawat et al. 2004).

University Nainital (KU), Wildlife Institute of India (WII), and Regional Ayurvedic Research Institute (RARI) Thapla, Ranikhet), and from published literature.

The environmental variables used in this study were 25 predictors, 19 of them (bio layers) downloaded from the WorldClim v1.4 dataset at resolution of 2.5 arc-minutes (http://www. worldclim.org/bioclim). To find out the habitat suitability of the species, we used variables that included digital elevation model (DEM), slope, aspect, Euclidean distance from drainage, forest type and degradation (camping site), along with bioclimatic variables. Layers were rescaled at 1km spatial resolution (30 arc-second).

Species distribution modelling

We used a maximum entropy model (MaxEnt version 3.3.3; Phillips et al. 2006) and pixel dimension of 250×250 m grid cell, as it performs better with small sample sizes relative to other methods (Elith et al. 2006; Pearson et al. 2007). MaxEnt (Phillips et al. 2006) uses presence only data to predict the distribution of a species based on the theory of maximum entropy. The program attempts to estimate a probability distribution of species occurrence that is closest to uniform while still subject to environmental constraints (Elith et al. 2011). The maximum number of background points was 10,000. Linear or quadratic or product, categorical threshold and hinge features were used with the values 0.050, 0.250, 1.000, and 0.500, respectively. To reduce model overfitting and over-prediction, regularization multiplier value was set to 0.1 (Phillips et al. 2004) with 5,000 iterations and the rest of the values were kept as default (Yang et al. 2013). We selected 75% data for model training and 25% for model testing, keeping other values as default. Jackknife analyses were performed to determine variables that reduce the model reliability when omitted. Area under the receiving operator curve (AUC) were used to evaluate model performance, where AUC value ranges between 0 and 1, of which 1 indicates the ideal model (i.e., AUC value near to 1 indicate good predictive power of model). The model with the highest AUC value was considered the best performer (Swets 1988). To validate the model robustness, we executed 20 replicated model runs for the species with a threshold rule of 10 percentile training presence. In the replicated runs, we employed a cross-validation technique where samples were divided into replicate folds and each fold was used for test data. Other parameters were set to default as the program is already calibrated on a wide range of species datasets (Phillips & Dudík 2008).

RESULT AND DISCUSSION

Distribution of *P. kurroa*

Among 30 surveyed meadows of the Kumaun region, about 25 showed presence of *Picrorhiza kurroa* and 15 meadows had representative population sizes. Of the 15 populations assessed, seven were present in grassy slopes, five in *Rhododendron* forest margins, two in

Table 1. Site characteristics of the selected populations of *P. kurroa*.

Sites	Lattitude	Longitude	Altitude (m)	Slope (°)	Aspect	Habitat
Kuti	30.298636	80.751549	3000–3600	25–30	SE	Grassy slopes
Ralam	30.302094	80.263975	3200–3700	30–34	NW	*Rhododendron* forest margin
Milam	30.428777	80.167999	3000–3300	30–35	SW	Grassy slopes
Martoli	30.355871	80.213086	3400–3600	30–35	SE	Grassy slopes
Burfa	30.374958	80.189717	3100–3400	25–35	SE	Grassy slopes
Gunji	30.185613	80.863236	3200–3800	20–30	NW	Betula-Taxus forest
Panchachuli	30.218561	80.504378	3100–3300	30–38	SE	Grassy slopes
Napalchu Nala	30.175536	80.839672	3000–3200	30–40	NW	Grassy slopes
Laspa	30.291611	80.202882	3100–3200	25–40	SW	*Rhododendron* forest margin
Bilju	30.403455	80.173656	3150–3360	25–30	SW	*Juniperus* mixed forest
Dwali	30.180867	80.007178	3000–3150	25–35	SW	*Juniperus* mixed forest
Phurkia	30.214633	80.001388	3100–3200	25–30	NW	*Rhododendron* forest margin
Pindari	30.248124	80.000129	3200–3400	30–40	SE	Grassy slopes
Sunderdunga	30.191111	79.911033	3200–3800	25–30	NW	*Rhododendron* forest margin
Devikund	30.193395	79.890615	3900–4400	30–40	NW	*Rhododendron* forest margin

Juniperus mixed forest, and one in *Betula-Taxus* forest. Maximum populations were found in the northwestern aspect (6), followed by south-east (5) and south-west (4) between 3,000–3,900 m (Table 1).

Population structure and habitat preference of *P. kurroa*

In general, *Picrorhiza kurroa* mostly prefers matted/mixed shrub, herbaceous meadows and *Danthonia* grassy slope habitats. Population status across different meadows ranged 0.6–3.8 individuals/m^2 (Table 2). Of the 15 representative meadows, 13 had more than 1.0 individuals/m^2. The low density and frequency across the meadows showed low availability of this species. During the present investigation, *P. kurroa* was distributed in Laspa, Gunji, Bilju, Martoli, Ganghar, Milam, Kutti, Ralam, Johar, Panchachuli, & Napalchunala in Pithoragarh District and Devikund, Sunderdunga, Dwali, Phurkia, & Pindari in Bageshwar District. Phytosociological analysis revealed that *P. kurroa* grows gregariously in moist, rocky slopes as well as in organic rich soil. Past studies reported that moist rocky slopes and under scrub habitats of >3,600m altitudes showed highest density (Uniyal et al. 2002; Semwal et al. 2007). The maximum density was 3.8 individuals/m^2 in Panchachuli and 3.2 individuals/m^2 in Laspa, while minimum density was observed in Phurkia and Johar (0.64 individuals/m^2) areas. Low frequency and density shows that this species is rare and adapted to specific microhabitats.

Some habitat-based studies assert that *P. kurroa* has restricted and localized distribution in its native range. In alpine region of Gori Valley, its mean density was reported 3.89 individuals/m^2 having highest in moist rocky slopes (12.92 individuals/m^2) and least in grassy slopes (0.085 individuals/m^2). It is completely absent in the undulating and marsh meadows (Uniyal et al 2002). Degree of constancy (measure of omnipresence of a species in a given community) for *P. kurroa* was measured as 'often' in three sites 'mostly' in two sides and 'seldom' in 10 pockets having poor occurrence.

Habitat suitability

Habitat variables including slope, aspect, temperature, precipitation, drainage, altitude, and forest type were used along with bioclimatic variables to predict suitable sites for *P. kurroa*. Of the total geographical area of the Kumaun Himalaya, MaxEnt predicted 202km^2 as highly suitable and about 489km^2 as less suitable, and the rest not suitable (Figure 3). The threshold value training (0.91) and test (0.86) was close to 1, thereby showing the high accuracy of the model

Table 2. Phytosociological attributes of *P. kurroa* in different location.

	Location	Density (individuals/ m²)	Frequency (%)	Abundance	A/F ratio	Degree of constancy
1.	Kutti	1.3	60	7.1	0.11	seldom
2.	Ralam	1.5	50	3.0	0.06	seldom
3.	Milam	0.6	40	1.5	0.03	seldom
4.	Martoli	2.4	50	4.8	0.09	often
5.	Burfa	1.8	30	6	0.2	often
6.	Gunji	1.8	60	3.0	0.05	seldom
7.	Panchachuli	3.8	50	7.6	0.15	mostly
8.	Napalchu Nala	1.2	50	2.4	0.04	mostly
9.	Laspa	3.2	40	9.7	0.24	often
10.	Bilju	2.4	60	4.0	0.06	seldom
11.	Dwali	1.4	60	2.3	0.03	seldom
12.	Phurkia	0.6	30	2.0	0.06	seldom
13.	Pindari	1.9	40	2.5	0.06	seldom
14.	Sunderdunga	1.8	50	3.6	0.07	seldom
15	Devikund	1.6	50	3.2	0.06	seldom

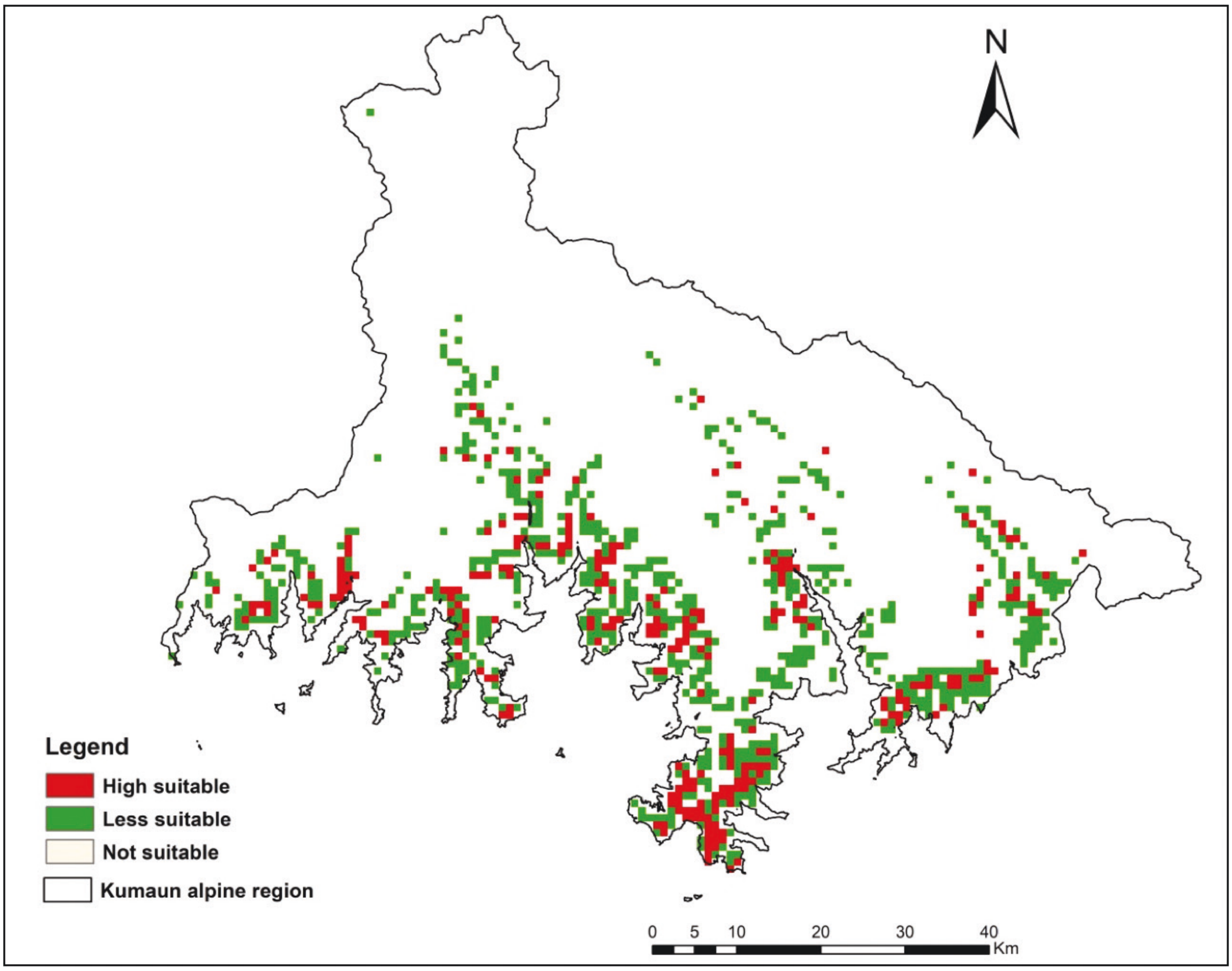

Figure 3. Habitat suitability of *Picrorhiza kurroa*

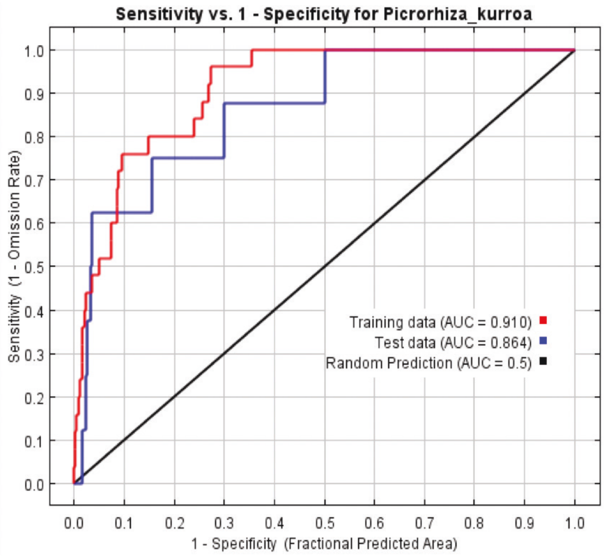

Figure 4. Receiver operating characteristic curve with area under curve (AUC).

(Figure 4).

The observed and predicted *P. kurroa* sites were mostly in forest fringes (42%) followed by grassy (30%) and rocky slopes (23%), with slopes between 15^0 and 30^0 in south-west and north-west aspects being highly preferred. Among the various environmental variables used for the prediction of distribution, mean diurnal range (Bio2 59.3%) and precipitation of driest quarter (bio17 10.9%) showed the maximum contribution, followed by aspect, forest and annual precipitation (bio12), which contributed 10.7%, 8.3%, and 4.4%, respectively. The Jackknife test showed that Bio2 (mean temperature of driest quarter) and bio17 (precipitation of driest quarter (bio 17) were the two most important predictors of *P. kurroa* when used independently (Figure 5).

Variables response to habitat suitability

Response curves show the quantitative relationship between environmental variables and the logistic probability of presence (also known as habitat suitability), and they deepen the understanding of the ecological niche of the species. The responses of 10 variables to the habitat suitability of *P. kurroa* are illustrated in Figure 6. According to the response curves, the suitable elevation range is 2,700–4,000m, which records that *P. kurroa* mainly grows at altitudes within this range on grassy slopes and *Rhodododendron campanulatum* scrub margins. Altitude usually is a key eco-factor for local plant distribution. The slopes of all sample points were lower than 38^0, with *P. kurroa* preferring 30–38^0 slope. The probability of presence was close to zero when altitude, slope, mean diurnal range (bio 2), precipitation of wettest quarter (bio 16), precipitation of driest quarter (bio 17) and mean temperature of driest quarter (bio 9) were less than 2,400m, 15^0, 17^{0}c, 320mm, 53mm, and -15^{0}c, respectively. According to the suitability grade, the suitable distribution area (probability 0.8) for *P. kurroa* requires mean diurnal range, precipitation of wettest quarter, precipitation of driest quarter, mean temperature of driest quarter to be 6–7 ^{0}C, 850–900 mm, 132–138 mm, and 30–38 ^{0}C, respectively. It was also found that forest fringe, moist rocks and *Danthonia* grassy slopes were the prefered habitats for *P. kurroa*.

DISCUSSION

In the Indian Himalayan region, a large number of studies have been carried out on ecology, systematics, and inventorisation of phytodiversity (Dhar et al. 1997; Samant et al. 2002; Joshi & Samant 2004); however, a few studies are available on population ecology and

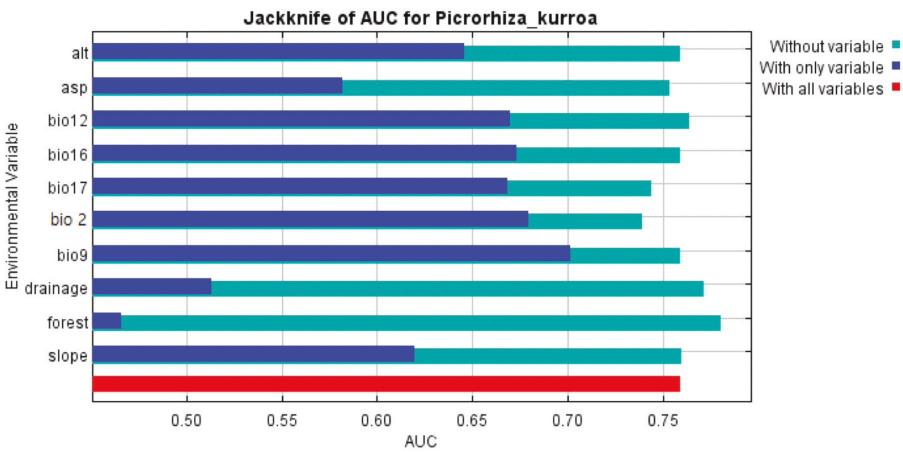

Figure 5. Result of jackknife test for evaluating the relative contribution of the predictor environmental variables to the habitat model of *P. kurroa*.

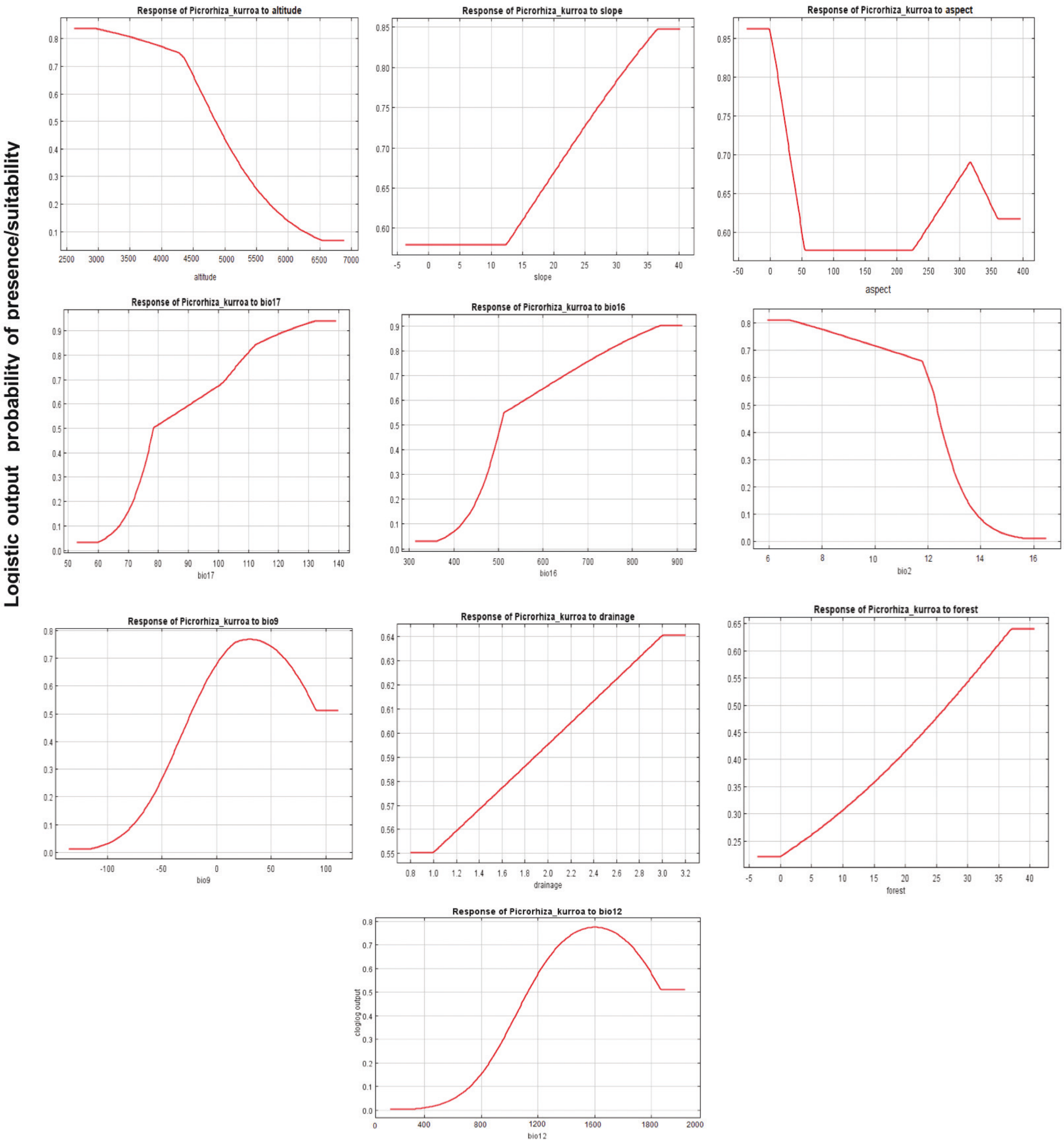

Figure 6. Response curves for environmental predictors in the species distribution model for *P. kurroa*.

ecological niche modelling (ENM) (Ray et al. 2011; Adhikari et al. 2012; Barik & Adhikari 2012; Yang et al. 2013; Samant & Lal 2015) in the region. Of the total vegetated area (3,828km^2) between 3,000–5,300 m, 202km^2 are highly suitable for *P. kurroa.* Habitats most suitable to this species are in the northwestern part of the Kumaun region, endowed with high rainfall during the rainy season. Habitat modelling illustrated that Napalchunala, Panchachuli base, Chhipla Kedar, Rongkong, Ralam, Milam, Dwali, and Pindari have prime habitats for *P. kurroa*. These areas would act as an in situ conservation area for the species and could be used for natural assisted regeneration sites. Field based surveys reveal that *P. kurroa* have more suitable habitats near the treeline of Himalayan Birch *Betula utilis* forests, *Rhododendron campanulatum*, and *Danthonia* grassy slopes. The species was mostly present in shrub canopy (40%) followed by *Danthonia* grassy slopes (35%) and rocky slopes (25%). The species was more frequent in areas having >20° slopes and south-west and north-west. Superimposing the predicted map on high-resolution satellite images (LISS-IV and Cartosat-2 merge product) revealed that mosaic of habitats are more suitable for this species.

The abundance of the *P. kurroa* across the meadows is low. Only four meadows, viz., Panchachuli, Laspa, Bilju, and Martoli had a density over 2.0 individuals/m^2. Overall, the highest density was recorded on moist *Danthonia* grassy slopes. Low population density may be due to overexploitation for medicinal purposes, poor regeneration, low seed germination, habitat loss, and anthropogenic pressure. The maximum numbers of populations (7) were represented by grassy slopes habitat indicating that such habitats form the best platform for the overall development of the species. The high density of species in grassy slopes and *Rhododendron* forest margin habitats indicated that such habitat is suitable for the germination of seeds and development of seedlings.

It is also observed that population of *P. kurroa* was low in sites close to shepherds' camps and high in areas where collection was negligible. Threat assessment indicates this species is being diminished day by day. Owing to various anthropogenic activities and their intensity, the species is locally common hence designated as locally common heavy pressure (LCHP). Among the habitat suitability classes, three classes, i.e., high, moderate and less suitability classes can be considered for the reintroduction (conservation) of the species. The model output result predicted that ecological niche coincides with the literature and field geographical distribution. Better population status of the species in areas of higher model thresholds such as Panchachuli, Laspa, Bilju, and Martoli revealed that these areas have suitable conditions for the persistence of species. For the in situ and ex situ conservation, mass multiplication of species through seeds and awareness and active participation of local people, community-based organizations, non-government organizations, and forest department are essentially required.

CONCLUSION

The study provides comprehensive information on population and habitat distribution of *P. kurroa.* Meagre information exists on the ecology, distribution, and population status of *P. kurroa* in the wild, and its populations and habitats are diminishing at alarming rate. *P. kurroa* has been listed among top 20 species prioritized for conservation and development keeping in view the status in the wild, sensitivity to anthropogenic impacts and its increasing demand in the market. Of the total vegetated area above 3,000m in the Kumaun, only 5.27% is highly suitable for the species; however, another 12.8% (489km^2) is less suitable, which includes meadows with excessive anthropogenic pressure and degradation. The observations on population, habitat distribution and threat status of *P. kurroa* illustrate that although suitable habitats were present in different locations, this species is restricted to very few sites with comparatively low population. Highly suitable sites less are accessible due to excessive livestock grazing and trampling and uprooting plants for medicinal purpose or marketing by local inhabitants. If immediate steps for management and regulation in collection are not taken, this species will be extinct from many localities in the near future.

Although *P. kurroa* is categorised as critically endangered, there is no management plan for conservation due to lack of related information and exploitation of species continues from the wild through unscientific manner. In nature, the species preferred moist, rocky slopes, and organic rich soil for rich populations. Therefore, for the domestication of the species, moist sites preferably north-west facing slopes would be more appropriate. Besides this, long term monitoring of *P. kurroa* is needed having specific conservation plots in the wild across meadows. Similarly, areas already reported to be rich in population of *P. kurroa* should be marked as control sites for future monitoring and repeated sampling. The strengthening of medicinal plant conservations areas established in the region would not only conserve and multiply medicinal and aromatic plants, but also will protect soil erosion and original habitats of the plants.

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