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Original Research Article

Distribution, use, trade and conservation of *Paris polyphylla* Sm. in Nepal

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A B S T R A C T

Background: *Paris polyphylla* Sm. is an important perennial medicinal plant of the Himalayas that is increasingly being used in traditional medicines and pharmaceutical industries. To meet this accelerating demand, people are harvesting it at unsustainable rates and trading it across Nepal through both legal and illegal means. It is therefore imperative to understand the socio-ecological interactions regarding the current distribution, use, trade, and conservation of *P. polyphylla,* in order to guide its sustainable production in the future.

Methods: In this study, we employed both qualitative and quantitative methodology to collect data from primary and secondary sources. We first carried out extensive field surveys and informal interviews with key stakeholders across 51 of the 77 districts in Nepal. In all we laid 696 quadrats each measuring 1 m × 1 m to understand the prevalence and distribution of *P. polyphylla* and held discussions in each district to collect information on the use, trade and conservation of *P. polyphylla*. We also reviewed over 150 studies pertaining to population and use of *P. polyphylla*, along with 18 years (2000–2017) of trade records of the species. We lastly modeled the species' potential distribution using a maximum entropy (MaxEnt) with 310 ground control points and 20 predictive variables.

Results: In this study, we found *P. polyphylla* growing in all 51 districts, but were only able to find use records from 38 of these districts, and trade records from only 39 districts

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including 19 border districts. This pattern reveals that the production, collection, use and trade of *P. polyphylla* vary greatly across the country. Out model predicted a total of 51 mid-hill and mountainous districts as potential distribution areas of *P. polyphylla*, and this work shows that all of these districts except Surkhet and Mustang may be suitable for its growth in the future.

We have found that the high demand for *P. polyphylla* has driven people to conduct harvests prematurely resulting in habitat degradation. Illegal trade due to weak database management and porous border has also impacted the sustainability of these harvesting practices and made *P. polyphylla* vulnerable to extinction. To meet the need of market demand and to maintain sustainable production, *P. polyphylla* should be conserved and cultivated in forests and fringe areas respectively to the extent of its potential distribution and have more stringent sustainable harvesting guidelines applied to its trade.

1. Introduction

Paris polyphylla Sm. locally known as *Satuwa* in Nepali is an important member of the family Melanthiaceae, which is native to China, Taiwan, the Indian Subcontinent, and Indochina (KBG, 2020; Ji et al., 2006). The species is distributed in Bhutan, China, north-eastern India, Laos, Myanmar, Nepal, Thailand, Vietnam and one collection from Pakistan (Liang and Soukup, 2000; Meijboom, 2012; Shah et al., 2012; MBG, 2020). It is found throughout Nepal below the treeline at elevations between 1800–3500 m (Kanel et al., 2017). It is one of the most important medicinal plants of the Himalayas, used often in traditional medicines (Kunwar et al., 2013a). It is used as anthelmintic, antispasmodic, digestive and expectorant and to treat vermifuge problems, headache and intestinal worms (Bajracharya, 1979; IUCN, 2004; Bhattarai and Ghimire, 2006; KC et al., 2010; Kunwar et al., 2018; Uprety et al., 2010; Kunwar et al., 2013b).

The rhizome of this species is also medicinally important and indigenously used in Nepal against snake bites, insect bites, to alleviate narcotic effects, wounds, fever and food poisoning (KC et al., 2010; Dutta, 2007). The rhizome is fed to cattle to lessen diarrhea and dysentery (Baral and Kurmi, 2006). In India, it is applied against burn, cuts, diarrhea, dysentery, fever, stomachache and wounds (Pfoze et al., 2013; Tariq et al., 2016; Paul et al., 2015). The rhizomes of various species of genus *Paris* are used as a major source of raw material for '*Yunnan Baiyao*', a globally popular product used in Chinese medicine. Thus, *Paris* rhizomes are used against various diseases and injuries like fever, backpain, bleeding, fractured bones, fungal diseases, poisonous snakes, insect bites, skin allergy, tumors and a variety of cancers (Long et al., 2003; Shoemaker et al., 2005; Duke and Ayensu, 1985). For these ethnomedicinal purposes, *Paris* rhizomes are widely sold in traditional medicine markets in both China and Nepal (Acharya and Rokaya, 2005). The volume and value of trade of medicinal and aromatic plants (MAPs), including *P. polyphylla* has rapidly expanded over the last decade due to increased demand on the international market mainly from Indian and Chinese pharmaceutical and aromatic industries (Vasisht et al., 2016).

For both local uses and markets, *P. polyphylla* in Nepal is harvested mainly from wild populations and thus its stock is gradually diminishing (KC et al., 2010). Local communities have also harvested it unsustainably because they have a limited knowledge of the plant's ecology and growth (Uprety et al., 2010; Kunwar et al., 2013b; Gurung and Pyakurel, 2008; Pyakurel et al., 2017). Forest degradation, a clumped geographic distribution, and slow growth rates also constrain the population and distribution of *P. polyphylla* (KC et al., 2010; Cunningham et al., 2018a; Zhou et al., 2003). Unsustainable collection and harvesting practices combined with these other ecological factors have driven the species to be considered a vulnerable species (Meijboom, 2012; Bhattarai, 1992). The species is considered vulnerable not only in Nepal, but is also in India (Ved et al., 2005), Vietnam (Huong et al., 2012) and China as well (Ministry of Environmental Protection of China, 2013). However, it has not yet been assessed for consideration on the global IUCN red list (Cunningham et al., 2018a), the CITES list, or the Nepalese Plant Protection Priority List (Ministry of Forests and Soil Conservation, 2014).

The Nepal Government realizes the economic potential for trade in *P. polyphylla* and the government's Herbs and NTFPs Coordination Committee has prioritized management of this species as well as 20 other medicinal plants to aid the country's economic development (DPR/MOFSC, 2006). However, the only way for *P. polyphylla* to have a sustaining economic benefit is if its harvesting and production can be done in a sustainable manner (Paul et al., 2015). Strategies and policies for conserving and protecting threatened species depend on identifying habitats where they can be grown (Kunwar et al., 2020; Casazza et al., 2016). Thus, the present study attempts to consolidate knowledge on the distribution, uses and trade of *P. polyphylla* in the Nepal Himalaya, in order to devise proper strategies for its management. Predicting and mapping the suitable habitat for a threatened species is critical for restoration of their declining populations (Kumar and Stohlgren, 2009). To our knowledge, this is the first study documenting and mapping the population, distribution, use and trade of *P. polyphylla* in Nepal.

2. Materials and methods

For this study, we utilized both qualitative and quantitative methodology to gather and analyze primary and secondary data. We adopted qualitative measures to obtain an in-depth understanding of the trade of the species, and used quantitative means to map the distribution, population and knowledge of human uses of *P. polyphylla*.

2.1. Study area description

Nepal, our selected study area, lies along the slopes of the Himalayan mountain between China and India between 80°04' − 88°12′ E and 26°22' − 30°27′ N (Fig. 1). Physiographically, it has the largest elevational gradient in the world (Li and Feng, 2015), extending from tropical alluvial plains as low as 59 m in the lowland Tarai region, through mid-hills of 1500 m−3000 m elevation, to the alpine-nival region including earth's highest summit Mt. Everest at 8848 m. Along with physiographical differentiation, it has high variation of climate, rainfall, altitude and soils (Miehe et al., 2015). This diverse terrain nurtures over 6000 species of flowering plants (Bhattarai and Chaudhary, 2011; Kunwar et al., 2010a), including about 2500 useful medicinal plant species (Ghimire and SapkotaBR Oli, 2008; Rokaya et al., 2010).

2.2. Target species

Paris is a small and very complex genus of about 27 species of understory perennial herbs distributed in temperate and tropical zones of Eurasia (Ji et al., 2007). Out of the approximate 27 species, more than two-third species are restricted to East Asia (22 species in China) (Duke and Ayensu, 1985). The center of diversity of this genus is the Yunnan-Guizhou Plateau, China with 12 endemic species (Li, 1998). Some important and useful species of *Paris* genus are *Paris polyphylla* Sm., *P. cronquistii* (Takht.) H.Li, *P. delavayi* Franch., *P. japonica* (Franch. & Sav.) Franch., *P. quadrifolia* L., *P. rugosa* H.Li & Kurita, and *P. verticillata* M.Bieb., etc. (Devkota, 2005). There are eleven varieties belong to *P. polyphylla* (Ji et al., 2006). Among these varieties, the ones found in Nepal are, *P. polyphylla*, *P. polyphylla* subsp. *polyphylla*, *P. polyphylla* subsp. *wallichii* H.Hara, *P. polyphylla* subsp. *marmorata* (Stearn) H.Hara, and *P. polyphylla* subsp. *appendiculata* H.Hara (Press et al., 2000). *P. polyphylla* has a wide range of pharmacological activities including immunoregulatory, anticancer, and cardiovascular effects (Zhang et al., 2014). Steroidal saponins in the genus *Paris* are active compounds that have hemostatic and anthelmintic effects and exhibit potential for ethnopharmacological uses (Devkota, 2005; Yun et al., 2007; Nohara et al., 1973). The major active constituents of *P. polyphylla*

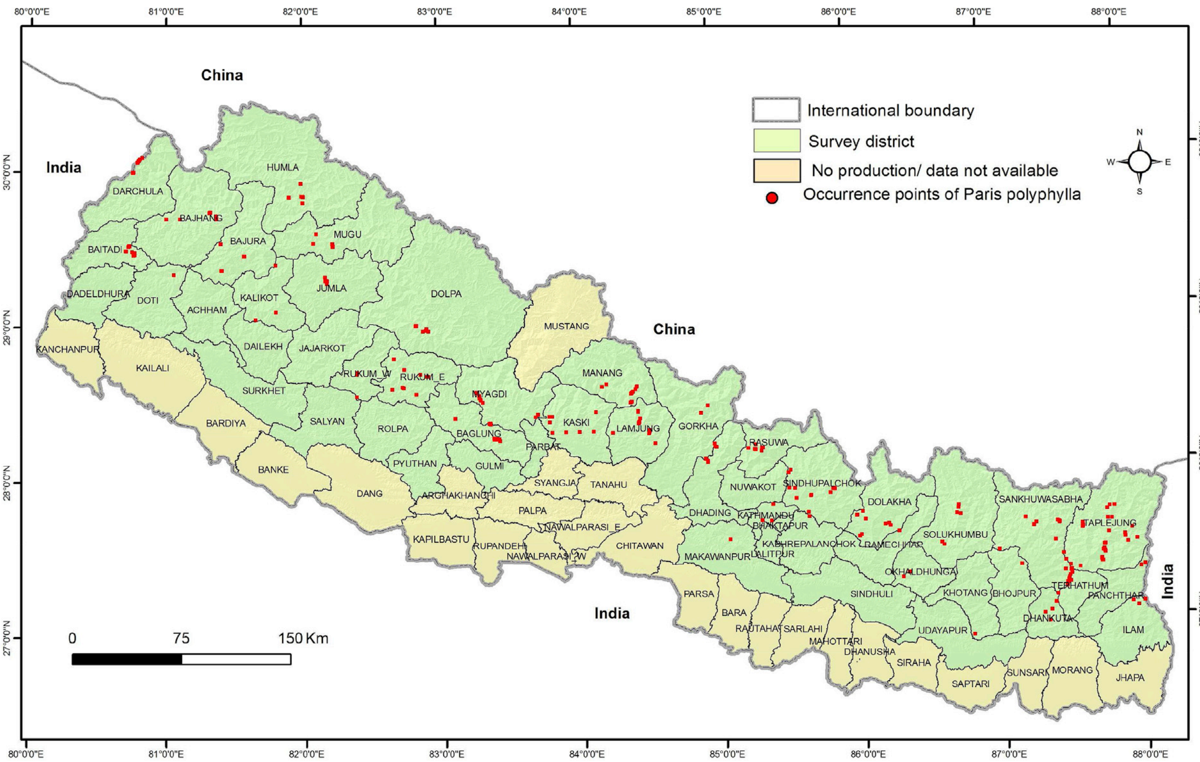

Fig. 1. Map showing occurrence points of *Paris polyphylla* and survey districts.

revealing pharmacological activities are ß sitosterol, daucosterol, diosgenin, kaemferol and quercetin, which show significant pharmacological activities (Devkota et al., 2007). Because of its high medicinal value, there has been unregulated harvestings of *P. polyphylla* from the wild to meet seemingly ever-increasing demand as a medication in itself and for drug formulation by pharmaceutical industries.

2.3. Field visit, inventory and meetings

We collected data on species occurrence and distribution using field surveys carried out annually between May 2016 and May 2019. These surveys were carried out in 51 of the country's 77 districts, representing mid-hill, lower mountain, subtropical and temperate bio-climates. A total of 696 quadrats, each measuring 1 m × 1 m, were laid in Oak, Laurel and Rhododendron forests following the stratified random sampling and the inventory guidelines developed by the government of Nepal (GoN, 2012). The *P. polyphylla* population was inventoried at each site along with the enumeration of major associated species. Informed consent was obtained from all stakeholders including the Department of National Park and Wildlife Conservation at central level, Divisional Forest Offices at district level and participating communities and individuals at field level prior to conducting fieldwork. Collection and use data of *P. polyphylla* was recorded via local communication procedures and *walking-in-the-woods*. Informal meetings and discussions were held with the key informants in each district to collect the information on the conservation, use and trade of *P. polyphylla*. A total of 66 medicinal plant traders, collectors and herders were consulted during these informal meetings and discussions.

2.4. Review, data analysis and GIS mapping

We utilized qualitative data and a detailed literature review to analyze the species' distribution and use. We reviewed over 150 articles pertaining to ecology and ethnobotany of *P. polyphylla* (Supplementary file 1). Of the literature consulted, 86 contained useful information on the use of *P. polyphylla* and assisted in locating districts where the ethnobotanical uses of *P. polyphylla* were reported. We qualitatively assessed the knowledge of *P. polyphylla* usage by applying a metric called the relative importance level (RIL) (Umair et al., 2019). RIL presents the level of prominence of a species at a study site (Friedman et al., 1986). We adopted and defined RIL as importance of each use type obtained by dividing the number of studies citing the usefulness of *P. polyphylla* (FCu) for that particular use type with total number of studies citing the usefulness of *P. polyphylla* (FCt) for all use types recorded in this study. The RIL varies from 0 to 1, with "1" being full importance of *P. polyphylla* for particular use type and "0" for no ailment cured by *P. polyphylla*.

$RIL = FCu/ FCt \ (0<RIL<1)$

The amount of trade was recorded by district when we reviewed the collection of trade data included in *Hamro Ban* issues (2000–2017). This 18 year of trade data helped identify the districts where the *P. polyphylla* has been extensively collected and traded. After identifying the districts of *P. polyphylla* production, the districts of ethnobotanical and trade uses were sorted out and overlaid on a map. We then analyzed the overlap and divergence of districts where production, use and trade of *P. polyphylla* were reported.

2.5. Modeling

For identifying the potential ecological distribution of *P. polyphylla* in Nepal, a total of 310 ground control points were used, which had been collected through the Flora of Nepal (www.floraofnepal.org), Global Biodiversity Information Facility (GBIF, https://www.gbif.org/), literature and field surveys (See species occurrence: Fig. 1). Nineteen environmental variables at 30 arc resolution (*ca.* 1 km^2) were downloaded from Worldclim (www.worldclim.org) (Hijmans et al., 2005), and slope (a physiographic variable) was extracted from a digital elevation model (SRTM, https://ita.cr.usgs.gov). Presence-only data was available for analysis, so we used MaxEnt modeling (MaxEnt 3.3.3 k software). A total of eight of these predictive variables: Mean Diurnal Range (Bio_2), Iso-thermality (Bio_3), Temperature Seasonality (Bio_4), Mean Temperature of Warmest Quarter (Bio_10), Annual Precipitation (Bio_12), Precipitation of Driest Month (Bio_14), Precipitation of Driest Quarter (Bio_17) and Slope were sorted out for modeling using Jackknife analysis and spearman ranked correlation (Phillips et al., 2009). We calculated Spearman correlation coefficient of the model in R program (R development core team, version 3.3.3.). We excluded highly correlated variables ($r > 0.7$) to avoid model over-fitting (Peterson et al., 2008). The MaxEnt output was converted into the suitable and unsuitable habitats following methodology devised by Xu et al. (2019). The species distribution map of *P. polyphylla* in Nepal was extracted by spatial analysis technology in ArcGIS. Four arbitrary categories of habitat suitability were defined as: no suitability (0–0.2), low suitability (0.2–0.4), medium suitability (0.4–0.6), and high suitability (0.6–1), based on predicted habitat suitability (Solomon et al., 2007). We lastly carried out a narrative analysis of the qualitative data to illustrate the dynamics of population, distribution, trade and conservation of *P. polyphylla*.

3. Results

3.1. Vernacular names

Paris polyphylla Sm., Synonym - *Daiswa polyphylla* (Sm.) Raf., is a member of Family Melanthiaceae. It is called as *Tangma* in Kham; *Satuwa* in Nepali; *Haimavati* in Sanskrit; *Dhumbi Mendo* in Sherpa; and *Mauro, Bajuro, Natardap,* and *Kalchang* in Tamang language. It is an important perennial medicinal plant growing in the temperate forests of mid-hills and lower mountains of Nepal.

3.2. Production, distribution, use and trade

We found the average density of *P. polyphylla* 0.078/m^2 resulted in a production range between 0.04 tons and 38.62 tons per annum. *P. polyphylla* was found to be growing in 51 mid-hill and mountainous districts across a wide range of elevation between 1500 m and 3500 m in Nepal. In this range, it grows specifically in *Rhododendron*, Oak and Laurel forests, bamboo patches and stream-banks in the old growth and undisturbed habitats with dense canopy over. It associated with other plant species such as *Arisaema costatum* Mart., *Cyrtomium anomophyllum* (Zenker) Fraser-Jenk, *Daphne bholua* Buch.-Ham. ex D.Don and *Viburnum erubescens* Wall.

3.3. Modeling and key variables

The area under curve (AUC) 0.899 in this study shows that our model performs well (Walden-Schreiner et al., 2017). Among the selected eight variables for modeling, the Mean Temperature of Warmest Quarter (Bio_10) contributed 51%, Temperature Seasonality (Bio_4) 40%, and Precipitation in driest month (Bio_14) 3% for model construction. The MaxEnt modeling revealed that the current and potential distributions of the species are mostly overlapped. The potential distribution of *P. polyphylla* was found mainly in subtropical and temperate mid-hills and mountainous area. The habitat of mid-hill and mountainous districts that include subtropical and temperate areas was found to be supportive for production and distribution of *P. polyphylla*. However, there were two differences in areas that the model thought would support cultivation and those districts that did have records of *P. polyphylla* being grown. Notably the Surkhet district, which has production record for *P. polyphylla*, was found by the model to not be suitable for production while the Mustang was found by the model to be suitable as potential habitat for the species despite there being no production record for the species from that district (Fig. 2).

P. polyphylla rhizome has long been used in Nepal for primary health care as an active ingredient of anthelmintic and as an antidote. Across Nepal there were 190 use reports for the species under 41 emic categories that were grouped into 26 use-types for convenient analysis following the methodology of Kunwar et al. (2018). Frequent ailments treated by *P. polyphylla* were stomachache, cuts/wounds and fever. *P. polyphylla* has high level of prominence (Relative Importance Level: RIL) for anthelmintic (0.21), followed by antiseptic (0.18), antidoting (0.14) and antipyretic (0.14) (Table 1).

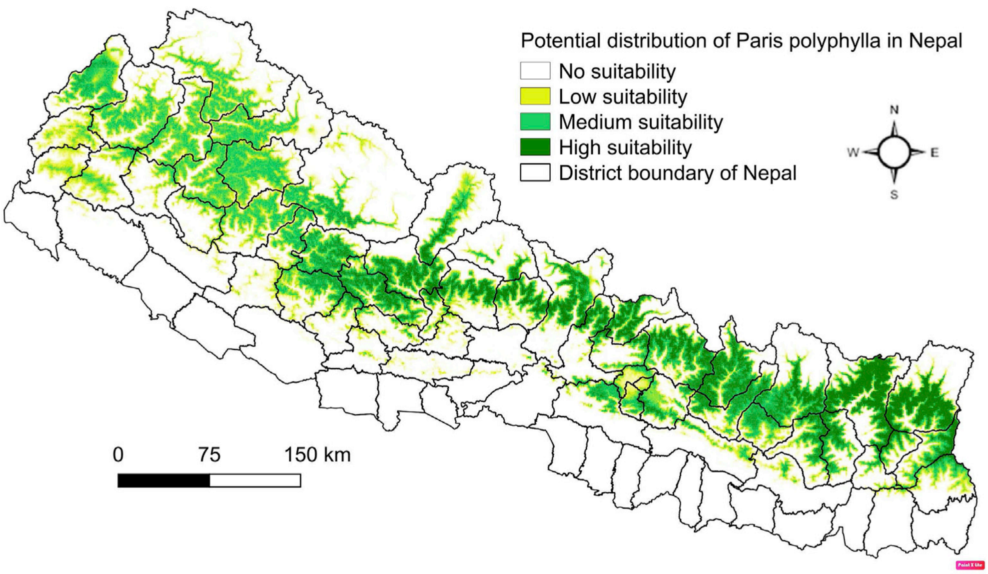

Fig. 2. Potential distribution of *Paris polyphylla* in Nepal.

Table 1
Use reports and use types of *P. polyphylla* recorded in Nepal.

Use type	Total use reports (FCu)	RIL
Stomachache, gastritis, anthelmintic, constipation	39	0.21
Cuts, wounds, antiseptic	34	0.18
Fever	26	0.14
Use against snake bites, insect stings, poisons	26	0.14
Tonic, aphrodisiac	12	0.06
Diarrhea, cholera	8	0.04
Boils, burns	5	0.03
Headache	5	0.03
Vomiting	5	0.03
Abdominal pain	4	0.02
Cough, cold	4	0.02
Galactogogue	3	0.02
Joint pain, bodyache	4	0.02
Piles	2	0.01
Tumor, breast cancer	2	0.01
Eaten, spice	2	0.01
Appetizer	1	0.01
Blood pressure	1	0.01
Epilepsy	1	0.01
Expectorant	1	0.01
Gallstone	1	0.01
Hemorrhage	1	0.01
Jaundice	1	0.01
Menorrhea	1	0.01
Paralysis	1	0.01
Respiratory	1	0.01
FCt	**190**	

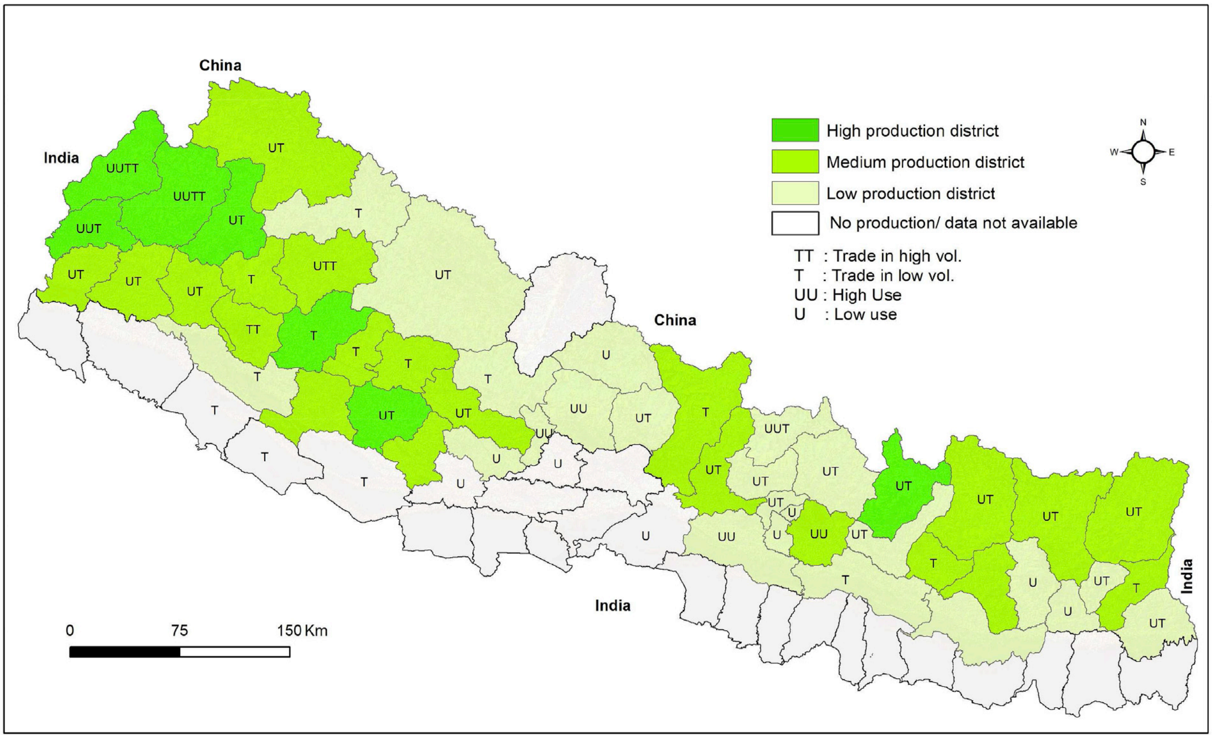

Fig. 3. Distribution, trade and use records of *Paris polyphylla* in Nepal.

We found *P. polyphylla* growing in all 51 districts, but its use reports were recorded only from 38 districts and trade was documented only from 39 districts (Fig. 3). Out of these 39, 19 were border districts. There were other three districts Syangja, Arghakhanchi and Chitwan with no production records, yet the use reports were recorded from these places. Similarly, there

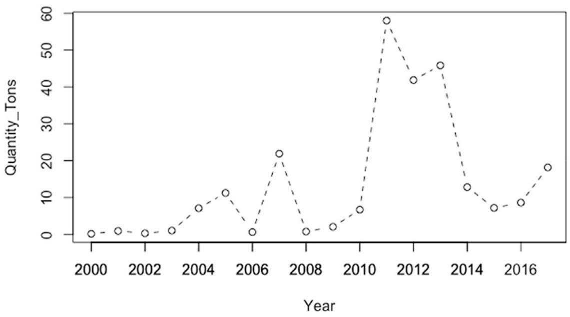

Fig. 4. Total quantity of *Paris polyphylla* dry rhizomes traded from Nepal.

were trade records from the border districts such as Dang, Banke and Bardia but the plant was not found to have the potential of production nor was it witnessed in field visits to these areas. There were five districts: Khotang, Pyuthan, Salyan, Sindhuli, and Udayapur, which have production records but neither the use reports nor the trade records.

There were no records of commercial trading of *P. polyphylla* before the year 2000. Before 1990, medicinal plants were mainly used locally, bartered for grains, traded at trans-boundaries and low land areas, and all these non-commercial transactions were not readily documented. The limited exports of *P. polyphylla* before 2000 were mostly to India. From the trade reports reviewed in this study, it was found that large-scale commercial trade of *P. polyphylla* started after 2001. The trade of *P. polyphylla* rhizome from Nepal grew significantly after 2010 and the highest amounts, 58, 41 and 45 tons, were traded between 2011 and 2013 consecutively (Fig. 4). Of the total quantity traded, about two thirds goes to China and the rest to India and local markets. The export to China often occurs through the Kathmandu airport or through border districts.

3.4. Conservation

We found that during the harvesting process, the whole plant is often uprooted to collect the rhizome, which leads to the destruction of the stock. This unsustainable harvesting practice, combined with illegal/cross-border trades of rhizome, and habitat destructions were common in the northern border districts. Old-growth habitat decline and fragmentation were major threats to the population of *P. polyphylla*. Market driven collection was also shown to result in rushed and premature collection and habitat degradation. Cultivation of the species coupled with *in-situ* conservation could be a solution to address the escalated herbal demand (Cunningham et al., 2018a). Local communities opined that the need of risen market demand for its medicinal, biological and pharmaceutical purposes can be met once the *P. polyphylla* be sustainably harvested and cultivated with the active involvement of local communities and application of sustainable harvesting guidelines.

4. Discussion

4.1. Distribution

According to the result of the MaxEnt model, the distribution of *P. polyphylla* is mainly in subtropical and temperate mid-hills and mountainous areas of the country. Mean warmest temperature (Bio_10) greatly influenced the distribution of *P. polyphylla* followed by Bio_4 (difference between the annual maximum and minimum temperatures) because the warm temperature followed by monsoonal precipitation helps break the dormancy of seeds. When the precipitation occurs during the warmest season (Bio_14), it readily facilitates germination of *P. polyphylla* (Zhou et al., 2003). The probability of occurrence of *P. polyphylla's* presence was also found to be correlated with slope. Precipitation during the warmest season and slope were the significant variables predicting habitat suitability of *P. polyphylla* in India (Lepcha et al., 2019). A few studies have been carried out on the population structure of *P. polyphylla* in Nepal. We report the average density of *P. polyphylla* to be 0.078/m^2 which is less than the findings of other studies carried out in Rasuwa (Gurung, 2007) (0.12/m^2), Dhankuta (Paudel et al., 2019) (0.2/m^2) and Kaski (Bhattarai and Ghimire, 2006) (2.2/m^2) districts. A higher range of *P. polyphylla* density (0.42–3.8/m^2) was reported from India (Paul et al., 2015; Lepcha et al., 2019). *P. polyphylla* is frequently reported from the moist habitat of Rhododendron, Oak, and Laurel forests in mid-hills and lower mountains (KC et al., 2010) and associated with *Arisaema costatum, Cyrtomium anomophyllum, Daphne bholua, Sarcococca* species and *Viburnum erubescens* (Deb et al., 2015). It is estimated that over 400 tons of *P. polyphylla* rhizome is produced annually in Nepal of which only about 100 tons is the amount to be sustainably harvested (Kanel et al., 2017).

4.2. Use

In Nepal, *Paris polyphylla* rhizome has long been used in at least 26 different ways. In China (Shoemaker et al., 2005), it has been used to treat liver cancer whereas in Indian folklore it has been applied for curing burns, cuts, diarrhea, dysentery, fever, stomachache and wounds (Pfoze et al., 2013). The diverse use-types were related to the species richness and availability. Since Nepal has high species richness of medicinal plants (Kunwar et al., 2010b), it is apparent that local communities use different species and diversify their repertoire, resulting in diverse use-types and knowledge of plants (Shrestha and Dhillion, 2003). Local medical systems are associated with rich medicinal plant diversity and traditional knowledge (Acharya et al., 2015). Phillips and Gentry (1993) (Phillips and Gentry, 1993) stated that the local availability of a plant is linked to its relative importance to a given community. Higher use reports for a plant relates to its higher abundance and frequent encountering (Giday et al., 2003; Bhattarai, 1989; Weckerle et al., 2006). Thus, abundant and apparent medicinal plants are an essential part of the traditional ecological knowledge of a culture (Saslis-Lagoudakis et al., 2014). The rich traditional ethnomedicinal knowledge in utilizing medicinal plants could open avenues for future drug discovery and development.

4.3. Trade

The trade of medicinal plants in Nepal started in 1990s and has since grown rapidly (Olsen and Helles, 1997). The first trade record of *P. polyphylla* was documented in 1995 (Edwards, 1996a), and at that point of time the trade was confined to the border districts (Manzardo, 1977) exporting to India (Edwards, 1996b). Before 2000, the trade of *P. polyphylla* was limited to small quantities and was sporadic (Olsen, 2005). There were only collection and trade records of 250 kg *Paris* rhizome from Jumla and the minor amounts from Baitadi district in 1997 (ANSAB, 1999; Amatya and Sayami, 1998). The large-scale commercialization of the Nepal-China MAPs trade only started to increase after 2010 (Cunningham et al., 2018a; He et al., 2018). Now, the *P. polyphylla* rhizomes are widely sold in traditional medicine markets in China and Nepal (Acharya and Rokaya, 2005). *P. polyphylla* is one of the seven medicinal plants of Nepal traded to China in bulk volume. Eighteen years (2000–2017) of trade record of *Hamro Ban* issues showed that the reported average quantity of collection and trade of *P. polyphylla* rhizome, totaling about 15 tons/yr., is less than the amount able to be sustainably harvested, estimated by Kanel et al. (2017). This could be the reason that these records of medicinal plants in *Hamro Ban* issues are constrained (Banjade et al., 2008; Ghimire et al., 2016) and conservative (Olsen, 2005; Maraseni et al., 2006) because of the limited database management used (Kunwar et al., 2011). Sometimes the trade data recorded in the government accounts is about half the transactions made in the market (Pyakurel et al., 2018). Of the quantity traded, about 75% is exported to China and the rest to Nepalese and Indian markets (Chapagain et al., 2014; Pyakurel and Oli, 2013). Despite the large quantity of *Paris* rhizome is exported to China and the fact that China is Nepal's fourth largest export market (He et al., 2018), there is still limited data and documentation of the medicinal plant trade in Nepal.

With the expansion of Chinese and global herbal market, the importance of Nepalese *P. polyphylla* has grown rapidly in the recent years. It is estimated that about 300 tons of *P. polyphylla* rhizomes are sold annually in China (Cunningham et al., 2018a; Li et al., 2015). The volume and value of MAP trade has expanded over the last decade (Kunwar et al., 2015) due to increasing demand for natural products from the international market and in particular from the Indian and Chinese pharmaceutical and aromatic industries (Vasisht et al., 2016). The accelerated demand is attributed to the large and unrestricted harvestings from the natural population resulting in its decline. This decline is not only limited to *P. polyphylla* but also extended to its associated species such as *Arisaema costatum, Daphne bholua* and *Trillidium govanianum* Wall. ex D. Don. In rural villages of Nepal, *T. govanianum* is used as a substitute of *P. polyphylla* however, the *T. govanianum* is inferior in quality and its adulteration debases the trade value of *P. polyphylla* (Gyawali and Paudel, 2011). Local depletion of *P. polyphylla* populations cause a "ripple effect" onto several other species that are harvested and traded as substitutes for *P. polyphylla* (Cunningham et al., 2018b). Some MAPs including *P. polyphylla* are also exported illegally and undocumented due to the lack of strict control at Nepal's highly porous borders (with India towards south and China towards north) (Olsen and Helles, 1997). Illegal collection and trade of *P. polyphylla* to China (Pyakurel et al., 2017; Kunwar et al., 2016; Kunwar, 2018) is common in the northern and western border districts of Nepal. These illegal and premature collections are attributed to its declining population at local and district scales (KC et al., 2010; Gurung and Pyakurel, 2008; Luitel et al., 2014; Pyakurel et al., 2014).

Despite the production and potential distribution were somewhat coincided; the production, use and trade of the species were found to be random. Khotang, Pyuthan, Salyan, Sindhuli, and Udayapur districts have production records but no records of plant use and trade. This could be because either the *P. polyphylla* has barely been used in the districts resulted in limited ethnobotanical reports or because the collected *P. polyphylla* was traded from adjoining districts. Although we reported collection, use and trade of *P. polyphylla* from 57 districts, Pyakurel and Baniya estimated that the cultivation of *P. polyphylla* is possible in all districts that have temperate and moist climates (Pyakurel and Baniya, 2011). A few farmers of 16 districts of Nepal have already started cultivation of *P. polyphylla* in Nepal (Kanel et al., 2017; KC et al., 2010; Gurung, 2007; Chapagain et al., 2014; Joshi, 2014a) in their land to meet the commercial demand and some of them are in a early stage of success (Long et al., 2003). However, the commercial cultivation and trade is yet to be extended and it needs more investment to expand to other districts of Nepal (KC et al., 2010; Paul et al., 2015; Pyakurel et al., 2017; Gurung, 2007). Some steps for a more sustainable conservation of the *P. polyphylla* should include proper management of habitats between 1500 and 3500 m, and large-scale cultivation of *P. polyphylla* as a farmed plant in mid-hills and lower mountainous districts of Nepal.

5. Conclusions

Paris polyphylla has enormous value for maintaining health and generating household income for rural communities. It is distributed widely and grown in moist areas of the mid-hills and lower mountainous districts of Nepal, consistent with the predicted potential distribution areas. However, limited global distribution, slow growth rate, high demand, destructive harvesting practices and habitat degradation constrain the plant's distribution, use, trade and conservation. Proper understanding of the species' population structure, use knowledge and distribution are useful in developing appropriate and necessary conservation strategies for the species.

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Author contributions

RMK designed the study. RMK, SC, BR, KB, RB, ST, ASA, HRP, PS carried out fieldworks. HPD, HPS, BR, SB, YA, CL and RPA reviewed literature, analyzed the data and performed simulations. All analyzed the results and contributed to the paper writing, editing and revisions.

Declaration of competing interest

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2020.e01081.

Appendix

Supplementary Table 1
Ethnobotanical studies related to *Paris polyphylla* carried out in Nepal

Year	District	Form or mix with	Use
1979	Nepal (Singh et al., 1979)		Anthelmintic
1979	Nepal (Bajracharya, 1979)		Anthelmintic, expectorant, digestive, tonic, alterative
1984	Kaski, Parbat, Syangja (Coburn, 1984)		Headache, stomachache, antidoting
1986	Jumla (Manandhar, 1986)		Anthelmintic
1990	Rasuwa, Sindhupalchok (Joshi and Edington, 1990)		Anthelmintic, fever, antipoisoning
1991	Makawanpur (Bhattarai, 1991)		Antidote, internal wounds, galactogogue
1992	Jumla (Bhattarai, 1992)		Anthelmintic, febrircide, wounds
1993	Dolakha (Bhattarai, 1993)		Boils and carbuncle
1994	Kathmandu, Kavre, Lalitpur, Bhaktapur, Dhading, Nuwakot, Sindhupalchok, Rasuwa (Malla, 1994)		Anthelmintic
1994	Kathmandu, Makawanpur, Lalitpur, Bhaktapur, Kavre, Sindhupalchok, Rasuwa, Nuwakot, Dolakha, Dhading, Ramechap (Bhattarai, 1994)	Paste with honey, milk	Galactogogue, tonic
1996	Taplejung (Shrestha and Ghimire, 1996)		Stomachache
2001	Taplejung (Sherpa, 2001)		Stomachache, wounds
2002	Kaski (Gurung, 2002)		Constipation, snake bite, cuts/wounds, cholera, gastritis
2003	Arghakhanchi (Panthi and Chaudhary, 2003)	Paste, powder	Diarrhea, anthelmintic and snake bites
2003	Baitadi (Devkota and Karmacharya, 2003)	Paste, dry	Boils, abdominal pain, snake bite
2003	Dolakha (Shrestha and Dhillion, 2003)	Water	Fever
2003	Achham, Bajhang, Bajura, Doti (Kunwar and Duwadee, 2003a)		Anthelmintic
2003	Achham, Bajhang, Bajura, Doti (Kunwar and Duwadee, 2003b)		Anthelmintic

(continued on next page)

Supplementary Table 1 (*continued*)

Year	District	Form or mix with	Use
2004	Darchula (Pant and Panta, 2004)		Anthelmintic, boils
2005	Chitwan (Bishokarma et al., 2001)		Medicinal
2005	Dolpa (Kunwar and Adhikari, 2005)	Paste, decoction	Anthelmintic, antiseptic, wounds, fever, sprain
2005	Kathmandu, Kavre (Acharya and Rokaya, 2005)		Wounds, antidoting
2005	Nepal (Watanabe et al., 2005)		Anthelmintic, tonic
2006	Arghakhanchi (Panthi and Chaudhary, 2006)	Paste, powder	Insect bite and snake bites
2006	Baitadi (Bista and Webb, 2006)		Stomachache, bodyache, wounds
2006	Dolpa, Humla, Jumla (Kunwar et al., 2006)		Anthelmintic, antiseptic, wounds, antidoting
2006	Manang (Bhattarai et al., 2006)	Hot water	Getting rid of worms
2007	Nepal (WWF/Nepal, 2007)		Wounds, tonic, diarrhea, dysentery
2008	Baglung (Sapkota, 2008)	Decoction	Poisons and cuts
2008	Dolpa (Devkota, 2008)		Minimize poisons
2008	Kaski (Gurung et al., 2008)		Cuts/wounds, snakebite, abdominal pain
2008	Manang (Gewali, 2008)	Hot water	Getting rid of worms
2008	Nepal (Ghimire and SapkotaBR Oli, 2008)	With *Dactylorhiza hatagirea*	Cuts/wounds
2008	Rasuwa (Prasai and Shrestha, 2008)		Cuts/wounds
2008	Solukhumbu (Giri and Rana, 2008)		Minimize poisons
2009	Baitadi (Kunwar and Bussmann, 2009)		Snake bite
2009	Baitadi (Kunwar, 2009)		Snake bite
2009	Baitadi, Darchula (Kunwar et al., 2009)		Epilepsy, digestive, antivomiting, fever, snake bite
2010	Humla (Rokaya et al., 2010)	Paste	Cuts/wounds
2010	Kaski (KC et al., 2010)		Jaundice, fever, headache, wounds, antidoting
2010	Rasuwa (Uprety et al., 2010)		Fever, vomiting, anthelmintic
2011	Kaski, Parbat, Syangja (Bhattarai and Chaudhary, 2011)	Powder	Joint pain
2011	Nepal (Gaire and Subedi, 2011)		Fever, vomiting, worms
2012	Gulmi (Acharya, 2012)		Cuts/wounds, blisters, burns, headache, antidote
2012	Kaski (Chhetri et al., 2012)	Paste	Wounds, antidote, fever, headache, stomachache
2012	Parbat (Thapa, 2012)	Cow milk	Intoxification, antidoting
2013	Baitadi Dadeldhura, Darchula (Kunwar et al., 2013b)		Antiseptic
2013	Dolakha Ramechap (Sigdel et al., 2013)		Anthelmintic
2013	Gorkha (Shrestha, 2013)		Wounds
2013	Ilam (Parajuli, 2013)		Wounds, tonic, diarrhea, dysentery
2013	Makawanpur (Hasan et al., 2013)	Paste	Fever, vomiting, worms
2014	Bhojpur (Chapagain et al., 2014)		Anthelmintic
2014	Makawanpur (Luitel et al., 2014)	Powder	Fever, vomiting
2014	Makawanpur (Joshi, 2014b)	Paste powder dry	Wound, antiseptic, tonic, anthelmintic
2014	Rasuwa (Shrestha et al., 2014)	Decoction	Fever, anthelmintic
2015	Baitadi, Darchula, Dadeldhura, Bajhang (Kunwar et al., 2015)		Epilepsy, shock, fever, vomiting, snakebite
2015	Kaski (Adhikari and Pokhrel, 2015)		Fever, cough and cold
2015	Parbat (Malla, 2015)	Boil	Eaten
2015	Parbat (Malla et al., 2015)	Juice, paste	Gastritis, pain, tonic, cuts/wounds, remove worms
2016	Baitadi, Darchula, Humla, Bajhang (Uprety and Poudel, 2016)		Tonic, febrifuge, gastritis, cough, wounds
2016	Ilam (Bhattarai and Khadka, 2016)	Dried	Aphrodisiac, stomachache
2016	Rasuwa (Yadav and Rajbhandary, 2016)		Fever, vomiting, worms
2016	Sankhuwasawa, Terhathum, Taplejung (Shrestha et al., 2016)	Hot water	Gastritis, piles, blood pressure, cough, fever
2016	Taplejung (Uprety et al., 2016)		Antidoting
2017	Bajhang, Darchula (Chaudhary et al., 2017)	Dry paste	Dizziness, boil, tumor, gallstones, cuts, paralysis, gastritis
2017	Humla (Atreya et al., 2017)		Abdominal pain, constipation
2017	Kaski, Parbat, Syangja (Subedi, 2017)		Fever, diarrhea, cuts/wounds, appetizer, indigestion, cold, piles, antidoting, inflammation
2017	Lamjung (Bhattarai, 2017)		Diarrhea, cuts/wounds, pain killer
2017	Lamjung (Dovydaitis, 2017)	Decoction	Anthelmintic
2017	Makawanpur (Bhattarai and Tamang, 2017)		Anthelmintic, tonic, cuts/wounds, diarrhea
2018	Baitadi (Atreya et al., 2018)	Hot water	Stomachache, headache
2018	Chitwan (Joshi et al., 2018)		Burn, cuts, injury, antidoting
2018	Darchula (Aryal et al., 2018)		Antidote
2018	Darchula (Ghimire et al., 2018)	Paste	Cuts/wounds, breast cancer

Supplementary Table 1 (*continued*)

Year	District	Form or mix with	Use
2018	Ilam (Bhattarai, 2018)	Paste, decoction, crude	Gastritis, ulcer, wounds, diarrhea, diarrhea, menorrhea, body pain
2019	Dhankuta (Paudel et al., 2019)		Antidoting
2019	Kathmandu, Makawanpur, Rasuwa, Nuwakot, Dhading, Kaski, Lamjung, Lalitpur, Bhaktapur, Sindhupalchok, Kavre (Shrestha and Khadgi, 2019)	Juice	Anthelmintic, useful to livestock
2020	Rolpa (Budha-Magar et al., 2020)		Cuts/wounds, Antidote

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