Trade and Conservation of Nepalese Medicinal Plants, Fungi, and Lichen

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Trade in Nepalese medicinal plants, fungi, and lichens is huge, yet there is no overview of traded species, impeding the development of targeted and appropriate conservation interventions. This study intends to identify all traded species from Nepal, analyze their distribution patterns, and assess their vulnerability, none of which has been done before. Contemporary data on traded species were obtained from 113 sub-local traders, 105 local traders, and 75 central wholesalers for case year 2014–2015, and historical data from a review of trade-related publications. We recorded 300 species in trade, double that of previous estimates, distributed across 97 families and 197 genera. Most species are concentrated in subtropical and lower temperate regions indicating an economic potential for increased cultivation and domestication at middle altitudes. About 39% of commercial species are formally protected, including through bans on collection and trade of certain species. But this approach does not appear to protect species from commercial harvesting, driven by increasing demand and higher prices. The high-altitude species *Nardostachys jatamansi*, *Rheum australe*, and *Picrorhiza scrophulariiflora* are the most vulnerable traded species, warranting the development of alternative protection mechanisms, e.g., transferring management rights to local communities.

नेपाली जडीबुटीहरुको व्यापार तथा संरक्षण. नेपालबाट बर्षेनी अत्यधकि परमिाणमा जडीबुटीको नर्यिात हुने गर्दछ तथापि हालसम्म कुन्-कुन् प्रजातकिा जडीबुटीहरूको व्यापार भैरहेको छ भन्ने यकीन तथ्यांक उपलब्ध नहुँदा तनिको समुचति वकिास तथा संरक्षणमा व्यावधान आईरहेको छ । यस अध्ययनको उद्देश्य व्यापारमा रहेका सम्पूर्ण नेपाली जडीबुटीहरूको पहचिान, तनिको वतिरणको वश्लिेषण र जोखमिको आकलन गर्ने रहेको छ । अध्ययनका क्रममा ११३ गाउँ-स्तरीय व्यापारी, १०५ जल्लिास्तरीय व्यापारी र ७५ जना नर्यिातकर्तासँग आर्थकि वर्ष २०१४–२०१५ मा अन्तरवार्ताको माध्यमबाट व्यापारमा रहेका जडीबुटीहरूको तथ्याङ्क संकलन तथा व्यापारसँग सम्बन्धति सन्दर्भ सामग्रीहरूको समीक्षा गरएिको थयिो । तथ्याङ्कको वश्लिेषण गर्दा नेपालबाट कुल ३०० प्रजातकिा जडीबुटीको व्यापार हुने गरेको पाइयो, जुन ९७ परविार र १९७ जातभित्र अन्तरगतका वनस्पती, झ्याउ तथा ढुसी वर्गका थएि । उपोष्ण र समशतिोष्ण जलवायु भएका क्षेत्रहरूमा सबैभन्दा बढी व्यापारकि महत्वका जडीबुटीका प्रजातहिरू पाइयो, जसले नेपालका ती क्षेत्रहरूमा खेती र घरेलुकरणबाट हुन सक्ने आर्थकि सम्भावनालाई संकेत गर्दछ । संकलन र व्यापारका लागि प्रतबिन्धति सहति लगभग ३९% जडीबुटी प्रजातहिरू औपचारकि रूपमा संरक्षणको सूचीमा रहेको पाइयो, तर बढ्दो माग र मूल्यका कारण तनिको नरिन्तर व्यापार भैरहेको हुँदा यस दृष्टकिोणबाट मात्र पनि जडीबुटीको संरक्षण हुने देखदिैन ।

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व्यापारका लागगिरनि अतरि समयअगावैको संकलनले वशिषगरी उच्च हमिाली भेगमा पाइने जटामसी, पदमचाल र कुट्की सबैभन्दा बढी जोखमिमा रहेको पाइनुले पनि वैकल्पकि संरक्षण वधिकिो वकिास— जस्तै जडीबुटीको व्यवस्थापन अधकिार स्थानीय समुदायलाईनै हस्तान्तरण गर्नु पर्ने औचत्यिको पुष्टि गर्दछ।

Key Words: Altitudinal distribution, Commercialization, Illegal trade, Himalayas, South Asia, Vulnerability.

Introduction

Medicinal plants, fungi, and lichens have been used for millennia to improve health and cure diseases (e.g., Gurib-Fakim 2006; Peintner et al. 1998). Currently, official pharmacopeias mention medicinal uses of more than 28,000 plant species (Willis 2017) that benefit millions of people through primary health care (WHO 2002). Likewise, fungi are known to be important in various ways, also medicinal, in all countries (Boa 2011). In recent years, there has been a surge in the international trade of medicinal plants and their derivatives, with some 3000 species traded in response to demand for herbal products (Schippmann et al. 2006), with an annual global trade value at over USD 33 billion in 2014 (Vasisht et al. 2016).

Geographical disparities in supply and demand have led to common and long-distance trade for thousands of years; for example, Himalayan medicinal plants were traded to the Roman Empire (Jacob and Jacob 1993; Veen and Morales 2015). Nepal has exported medicinal plants for at least a thousand years (Dobremez 1976a), traditionally to India and China (Hamilton 1819; Kirkpatrick 1811). Nepal's current trade in medicinal plants, fungi, and lichens is mentioned in a number of studies (e.g., Edwards 1996; Olsen 1998, 2005; Subedi 2006) and in international statistics (Vasisht et al. 2016). As per the United Nations International Trade Statistics Database, Nepal exported more than 10,000 tons of primarily medicinal plants worth around USD 60,000,000 in 2014, destined for more than 50 countries (Ghimire et al. 2016). In addition, domestic processing (Sharma 2007) and consumption (Kafle et al. 2018) appears substantial and growing.

Despite the historical and contemporary importance, there is no comprehensive overview of what species are traded in and from Nepal, hampering identification of conservation priorities. Recent studies have estimated the number of traded species at 100 to 170 (Bhattarai and Ghimire 2007; Ghimire et al. 2015; Subedi 2006) but these are likely too low as: (i) the Government of Nepal (GoN) levies royalties for 217 taxa of medicinal plants, fungi, and lichens (Government of Nepal 2015, 2018), including groups of lichens and orchids that clearly contain different individual species (Devkota et al. 2017; Subedi et al. 2013); and (ii) several products with a single trade name are made up of many species, e.g., *Morchella* spp. and *Swertia* spp. (Adhikari 2000; Barakoti 2002). Demands change over time, leading some species to disappear from trade while others enter trade (Pyakurel et al. 2018). Combining the historical with the contemporary is the only way to create a comprehensive overview of species that have been or are in trade. Likewise, the increasing demand in recent years and the associated price increases for many products (Pyakurel et al. 2017, 2018) makes conservation assessment critical, as trade may lead to premature and over-harvesting, in particular of high altitude species whose growth is limited due to bio-physical constraints (Vetaas and Grytnes 2002) while they are simultaneously of high economic importance to harvesters (Olsen 1998; Olsen and Larsen 2003). In this paper, we conduct vulnerability assessment for Nepalese traded medicinal plants, fungi, and lichens. The specific objectives of the paper are thus to (i) identify all medicinal plant, fungi, and lichen species traded in and from Nepal; (ii) analyze their altitudinal distribution; and (iii) assess their vulnerability.

Study Area

Nepal (26° 20′–30° 35′ N latitude, 80° 05′–88° 10′ E longitude, 60–8848 m, 147,181 km^2) is in the central Himalayas at the crossroads of six floristic provinces: Irano-Turranean, Sudano-Zambian, Indian, Central Asian, Southeast Asian, and Sino-Japanese (Dobremez 1976b). The country has five ecological zones (tropical, subtropical, temperate, subalpine, and alpine) running parallel from east to west, and three physiographic zones: Tarai (southern lowland), Middle hills, and High mountains (Fig. 1). The floristic provinces and ecological zones have endowed Nepal with a rich biological diversity, from *Shorea robusta* Gaertn. forests in the tropical belt to the subalpine *Betula utilis* D. Don forests and the *Caragana* thickets in the Trans-Himalayan belt (Tree Improvement and Silviculture Component 2010). Diversity is also

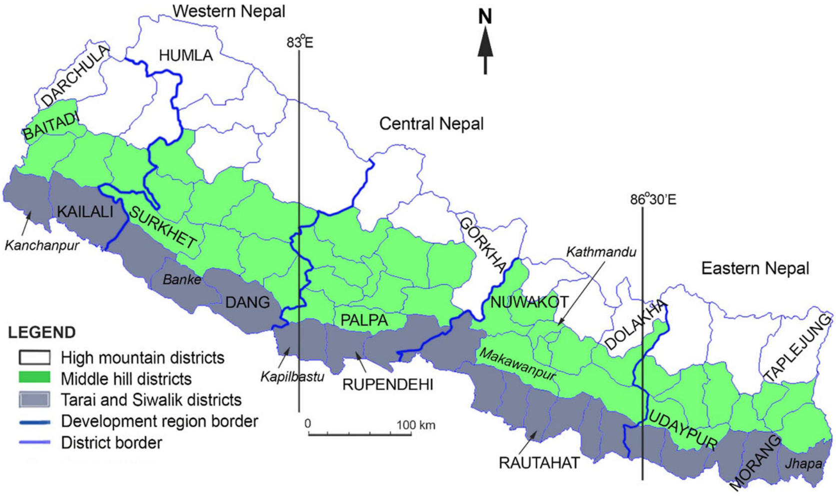

Fig. 1. The three main physiographic zones, five development regions, and three floristic regions of Nepal. Named districts (in CAPITALS) were included in the 2014–15 trade survey as were the central wholesalers (locations mentioned in italics). Map adapted from Stearn (1960) and Olsen and Larsen (2003).

influenced by the monsoon precipitation pattern: eastern Nepal is more humid and the west is more arid. Stearn (1960), using climatic, floristic, and ecological data, proposed the western, central, and eastern floristic regions in Nepal. Most botanical work (Polunin and Stainton 1984; Press et al. 2000; Tree Improvement and Silviculture Component 2010) has adopted Stearn's division and we apply it here to describe the distribution of commercial medicinal plant, fungi, and lichen species (Fig. 1).

Following Olsen and Larsen (2003), we selected one case district in each of the 15 cells created by the intersection of the three main physiographic zones and the five development regions: Kailali, Dang, Rupendehi, Rautahat, and Morang districts in the Tarai; Baitadi, Surkhet, Palpa, Nuwakot, and Udaypur districts in the Middle hills; and Darchula, Humla, Gorkha, Dolakha, and Taplejung districts in the High mountains. In addition, we interviewed the population of central wholesalers, located in Kanchanpur, Banke, Kapilbastu, Makawanpur, Kathmandu, and Jhapa districts (Fig. 1).

Material and Methods

Species Enumeration Inclusion Criteria

We focused on plants, fungi, and lichens traded to produce pharmaceuticals, dietary supplement products, natural health products, cosmetics, and other personal care products and culinary products (Smith-Hall et al. 2018). We used the following criteria:

(i) here must be a documented market exchange—a buyer and a seller negotiating a price after physical inspection. Thus, we included species traded in low volume in local markets (e.g., *Tetradium fraxinifolium* [Hook. fil.] T.G. Hartley and *Thymus linearis* Benth.), but excluded species having local uses but not reported as sold.

(ii) We included exotic species as long as they were sourced from Nepal and traded. Thus, we included commercially cultivated species (e.g., *Mentha arvensis* L. and *Matricaria chamomilla* L.) but excluded species that have only been cultivated on a trial basis (e.g., *Cinnamomum verum* J.S. Presl).

(iii) We excluded species that have medicinal value but are traded for non-medicinal uses (e.g., *Daphne* spp. traded to manufacture handmade paper, *Ageratina adenophora* [Spreng.] R. King & H. Rob. for bio-briquettes, and *Girardinia diversifolia* [Link] Friis for fibers).

(iv) We excluded plants that are traded only for rituals or ornamental purposes (e.g., *Vanda tessellata* [Roxb.] Hook. ex G. Don).

(v) We excluded wild edible plants that are traded and consumed strictly as food (e.g., *Arundinaria* spp., *Bambusa* spp., *Diplazium* spp., and *Drepanostachyum* spp.).

Data Collection

Data were collected from May 2015 to February 2017 for the fiscal year 2014–2015. Information on *inter alia* trade names, quantity, unit price, and destinations were collected from the entire population of traders in the 15 case districts and the entire population of central wholesalers in Nepal using structured pretested questionnaires. See Smith-Hall et al. (2018) for details on data collection instruments. Adopting the actor terminology proposed by Olsen and Bhattarai (2005), we interviewed 113 sub-local traders (operated from villages, purchased from harvesters, never transported products out of district), 105 local traders (operated from major roadheads or district headquarters, purchased from sub-local traders or harvesters, transported products out of the district), and 75 central wholesalers (operated from Tarai cities or the capital city Kathmandu, purchased in bulk from local traders and exported).

In order to achieve as complete a list as possible of species traded in and from Nepal, given that trade is dynamic and that the commercial species portfolio changes over time (Pyakurel et al. 2018), we expanded the empirically-derived list of currently traded species by including (i) all products mentioned in the Government of Nepal's royalty list for medicinal and aromatic plants (Government of Nepal 2015, 2018) and the Department of Forest's annual yearbooks (*Hamro Ban*) that list and quantify all forest products officially traded in and from Nepal; (ii) the products mentioned in trade lists published by medicinal product trade associations, namely the Jadibuti Association of Nepal, and Nepal Herbs and Herbal Products Association; and (iii) products mentioned in the comprehensive review of gray literature in Smith-Hall et al. (forthcoming).

Identification

Photographs of live specimens and traded parts were taken (wherever possible) during the field surveys. Repeated central wholesaler visits in Kathmandu and Nepalgunj, the major trade hubs, were undertaken to produce a complete collection of traded parts. Trade names were verified with harvesters, traders, and wholesalers. Samples and field photographs were tallied with references (Ghimire et al. 2008a; Gurung and Pyakurel 2017; Polunin and Stainton 1984). Samples of unidentified specimens were labeled (with trade name, date, and place of collection) and identified by tallying with specimens at the National Herbarium and Plant Laboratories (KATH) and Tribhuvan University Central Herbarium (TUCH). Vouchers were deposited at TUCH. The government decision to ban the collection, use, sale, transportation, and export of lichens prevented the collection of lichen specimens; thus, we relied on published literature (Devkota et al. 2017) for identification of commercial lichens. We followed Roskov et al. (2018), accessed from 21 to 29 November 2018, for nomenclature.

Verification

The complete draft list of traded products, trade names, unit prices, and destinations (domestic or export) were discussed and validated during a workshop with central wholesalers ($n = 31$; average age 42.5 ± 10.6 years; average trade experience16.2 ± 8.3 years) in Kathmandu on 2 April 2018.

Characterization of Traded Species

The following were recorded for each traded species:

(i) ltitudinal range, global distribution, distribution in Nepal, and nativity based on eFloras (2018), Grierson and Long (1987), Press et al. (2000), Roskov et al. (2018), and Watson et al. (2013).
(ii) Nativity was further categorized as native (wild and cultivated, cultivated, or only wild harvested) or exotic (naturalized or cultivated).
(iii) Life form: trees, shrubs, herbs (including forbs, sedges, grasses, epiphytic and saprophytic herbs), climbers (herbaceous, woody, and perennial), lichens, fungi, and pteridophytes. Life form categorizations were based on empirical observations and verified in the literature (Ghimire et al. 2008a; Manandhar 2002; Polunin and Stainton 1984; Press et al. 2000; Rokaya et al. 2013; Stainton 1988).
(iv) Traded parts: underground (roots, rhizome, tubers, bulbs, pseudo-bulbs); stems; barks; leaves and twigs; flowers; fruits and seeds; whole plant; and others (wood, resins, gums).

(v) Conservation status: The conservation status was assigned to species listed under (a) conservation categories (from the International Union for Conservation of Nature (IUCN) red list of threatened species and the Conservation Assessment and Management Plan (CAMP 2001)—an intensive and interactive process to facilitate the systematic prioritization of research and management actions needed for in and ex situ species conservation); (b) national regulations (Government of Nepal protection list); and (c) the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Government of Nepal 2001, 2011; IUCN 2018; UNEP-WCMC 2018).

(vi) Contemporary or historically traded: Species were classified as contemporary if mentioned in a trade study since 2005 or if observed in the present trade survey.

Vulnerability Assessment

We used the rapid vulnerability assessment tool developed by Cunningham (1994, 1996), formalized by Wild and Mutebi (1996) and Wong (2000), and adopted by other researchers (Ghimire and Aumeeruddy-Thomas 2005; Pyakurel et al. 2017; Shrestha and Shrestha 2012) to assess the vulnerability of traded species. A total of 10 predictors of vulnerability were used, and each predictor was scored from 1 (low vulnerability) to 4 (high vulnerability) using the scoring scheme in Table 1.

Data Analysis

The total elevation gradient of traded species (that ranged from 60 to 6000 m) was divided into 60 bands, each of 100 m. Each species was assigned to one or more of these bands based on its upper and lower elevation limits (for details on interpolation, see Rahbek 1997; Vetaas and Grytnes 2002). Species richness was calculated as the total number of species present in each 100 m elevation band. Band-wise species richness of native species was plotted against elevation, and the relationships between species richness and elevation was tested through polynomial regression. The regression analysis was also made separately for different life forms and different trade characteristics (high-value and high-volume). The export volume reported by all central wholesalers was aggregated to estimate the volume of trade; price/kg was calculated as the national average central wholesaler purchasing price of each species. Calculations were done using Microsoft Excel and Stata 12.1 software (StataCorp 2011).

Results

Species in Trade

A total of 300 commercial species were registered (Online Resource 1—Electronic Supplementary Material, ESM), including 254 angiosperms, 11 gymnosperms, 5 pteridophytes, 20 lichens, 9 fungi, and shilajeet (a plant-derived asphalt that oozes out from rock crevices). They were distributed into a total of 97 families and 197 genera. Orchidaceae had the highest number of traded species ($n = 24$), followed by Asteraceae ($n = 15$) and Lamiaceae ($n = 11$). Thirty-seven families were represented by a single traded species. *Dendrobium* was the genus with highest number of traded species ($n = 12$), followed by *Swertia* ($n = 9$), *Aconitum* ($n = 7$), and *Allium* ($n = 6$).

Contemporary trade (species recorded in trade since 2005) included 283 species, ranging from products traded for centuries such as tejpat (*Cinnamomum tamala* [Buch.-Ham.] Th. G.G. Nees) and kutki (*Picrorhiza scrophulariiflora* Pennell) to products that have only entered trade in the past decade, such as livlite chyau (*Ganoderma lucidum* [Curtis] P. Karst.), jewel orchid (*Goodyera biflora* [Lindl.] Hook.f.), and ganaino (*Hymenidium dentatum* [Wall. ex DC.] M.G. Pimenov & E.V. Kljuykov). Six lichens (*Hypotrachyna* sp., *Leptogium* sp., *Parmelia* sp., *Peltigera* sp., *Ramalina* sp., and *Stereocaulon* sp.) remain unidentified at species level.

Of the 300 species, 267 were native (234 wild harvested, 31 wild and cultivated, 2 cultivated) and 33 were exotic (25 cultivated, 8 naturalized). Wild native species are harvested from government-managed forests (national forests and conservation area forests), community-managed forests (a semi-autonomous local committee is formally managing a certain area of forest or meadow under the government's community forestry program), and occasionally from private forests. Cultivation is uncommon, with larger scale cultivation limited to *Asparagus racemosus* Willd., *Cinnamomum tamala* and *Swertia*

TABLE 1.. PREDICTORS AND SCORING SCHEME FOR RAPID VULNERABILITY ASSESSMENT OF TRADED MEDICINAL PLANT, FUNGI, AND LICHEN SPECIES.

Predictors	Score (minimum to maximum vulnerability)				Remarks
	1	2	3	4	
Life form	Annual herb, herbaceous climber, fungi	Perennial herb, perennial climber, lichen	Shrub, woody climber, pteridophyte	Tree	Slow-growing trees are more vulnerable than fast-growing annual herbs (Wild and Mutebi 1996)
Traded part	Leaf and twig	Fruit and seed, flower, resin	Bark, stem, wood	Root, whole plant	Harvesting of root and whole plants is more destructive than harvesting leaves, fruits, and seeds (Cunningham 1993; Gaoue and Ticktin 2007)
Global distribution	Pluri-regional, cosmopolitan	More than two phytogeographic regions	Pan-Himalaya (Himalaya and surroundings)	Nepal and Himalayan endemic	Widely distributed species are less vulnerable (Rabinowitz 1981)
Altitudinal span (m)	More than 3200	2200 to < 3200	1200 to < 2200	200 to < 1200	Species with narrow altitudinal span are more vulnerable (Wild and Mutebi 1996)
Bioclimatic region	Tropical	Subtropical	Temperate	Subalpine and alpine	Harsh environmental conditions in higher altitudes increase vulnerability (Bennet 1992)
Trade volume (kg/yr)	Low < 1000	Medium 1000 to < 10,000	High 10,000 to < 100,000	Very high ≥ 100,000	High harvest levels increases vulnerability
Price (USD/kg)	Very low < 0.1	Low 0.1 to < 1	Medium 1 to < 10	High ≥ 10	Higher price may lead to premature and/or overharvesting
Conservation status	Not assigned	In one category	In two categories	In more than two categories	Species assigned to more conservation categories are more vulnerable
Local population size	Mostly large	Mostly large, somewhere small	Mostly small, somewhere large	Everywhere small	Species growing in smaller areas are more vulnerable (Soule 1980)
Habitat specificity	Habitat generalist 2 (more than two habitats including farmlands and wastelands)	Habitat generalist 1 (more than 2 habitats excluding farmlands and wastelands)	Habitat specialist 2 (more than one specialized habitat)	Habitat specialist 1 (single, very specific habitat e.g., rocky slopes; moist forests, epiphytes, lithophytes)	Species growing in specific habitats are more vulnerable (Rabinowitz 1981)

chirayita (Roxb.) H. Karst; there was also domestication (such as through preferential treatment of regeneration) of a limited number of species (e.g., *Sapindus mukorossi* Gaertn. and *Zanthoxylum armatum* DC.). Sixteen and nine exotic species are cultivated in the tropical and subtropical regions, respectively, in response to (i) high international demand (e.g., *Matricaria chamomilla* and *Mentha arvensis* for essential oil production), (ii) domestic demand (e.g., *Anacyclus pyrethrum* [L.] Lag.), and (iii) initiatives to provide alternative sources of income (e.g., *Chlorophytum borivilianum* Santapau & R.R. Fern and *Crocus sativus* L.).

The production network was similar throughout the country and involves harvesters, traders (sub-local and local), wholesalers (central and regional), and processors. Harvesters wild collect or gather cultivated/domesticated products, air-dry them, and sell (in cash or credit) in the district of origin to sub-local traders in villages, hamlets, or small market centers along the road and trail network. Sub-local traders bulk and sell the products to local traders operating from the district headquarters or major market centers along highways. Local traders obtain the legally required permit to transport out of the district of origin, pay the government royalty, and transport the products to the warehouses of central wholesalers, mostly located in Tarai cities and Kathmandu. Finally, the central wholesalers export the air-dried products, mainly to India and China, or sell to the growing domestic processing industry in Nepal. A few species, e.g., siltimur (*Litsea cueba* [Lour.] Pers., *Lindera neesiana* [Wall. ex Nees] Kurz), timur (*Zanthoxylum armatum*), and yarsagumbu (*Ophiocordyceps sinensis* [Berk.] G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora) are exported to the USA, Germany, Singapore, South Korea, and Vietnam.

The 300 species (including shilajeet) were traded as 220 products. The number of products is lower than the number of species because (i) one product may be made up of more than one species from the same genus, e.g., five species of *Morchella* were traded as guchi chyau, and (ii) one product may encompass several species from different genera, e.g., *Aconitum heterophyllum* Wall. and *Delphinium himalayae* Munz were traded as attis. In total, lichens consisted of 20 species, sungava of 15 species, and guchi chyau and nakkali chiraito of five species each; 13 products consisted of three and two species each; and 190 products consisted of a single species (Online Resource 1, ESM).

Trade encompassed a total of 319 plant parts (from the 300 species), as more than one plant part was traded from 18 species, e.g., bark and leaf of *Cinnamomum tamala* and petiole and rhizome of *Rheum australe* D. Don. Underground parts of 84 species (26%) were traded, followed by fruits and seeds ($n = 70$; 22%), whole plants ($n = 56$; 18%) and leaves and twigs ($n = 47$; 15%). Other traded parts were bark ($n = 20$; 6%), stems ($n = 15$; 5%), flowers ($n = 14$; 4%), and others (plant-derived asphalt, resin, and gums, $n = 13$; 4%) (Fig. 2a).

The majority of traded species ($n = 134$; 45%) were herbs, followed by trees ($n = 68$; 23%), shrubs ($n = 37$; 12%), climbers ($n = 26$; 9%), lichens ($n = 20$; 7%), fungi ($n = 9$; 3%), and others (pteridophytes and shilajeet, $n = 6$; 2%) (Fig. 2b). Underground parts or whole plants were harvested from 91 out of 134 herbaceous species.

Altitudinal Distribution of Traded Species

We plotted the altitudinal distribution of native commercial species ($n = 247$; Fig. 3A), excluding the 33 exotic species that can be cultivated at a wide range of altitudes, and the 20 lichen species for which information is lacking. There was a unimodal distribution ($r^2 = 0.874$, $p < 0.0001$) along the elevation gradient, with richness increasing up to 1000 m, remaining fairly constant up to 2500 m, and then decreasing with altitude. The highest recorded elevation was 6000 m (for *Delphinium brunonianum* Royle). The 1000–2500 m range held an average of 128 species (min = 120; max = 139) per 100 m elevation band, maximum diversity from 2000 to 2200 m (average = 136, min = 135, max = 139), with, however, a slight decrease from 1600 to 1900 m. We further distinguished the altitudinal distribution of herbs (Fig. 3B), shrubs (Fig. 3C), and trees (Fig. 3D). The number of species of herbs ($n = 119$) increased up to 1600 m, then remained fairly constant up to 3600 m with an average band richness of 60 species, after which it decreased ($r^2 = 0.934$; $p < 0.0001$). The peak was observed between 1900 and 2400 m (average = 64) for commercial herbs. The number of species of commercial shrubs ($n = 37$) increased up to 1100 m, was fairly constant up to 2000 m, and then decreased ($r^2 = 0.789$; $p < 0.0001$). The average number of species was about 22 in each band in the 1100–2000 m range, with the maximum elevation of 5500 m recorded for *Rhododendron anthopogon* D. Don. Commercial tree species ($n = 57$) were most common from 700 to 1500 m (average = 34, min = 3 0, max = 38), with a peak between 900 and 1200 m ($r^2 = 0.803$;

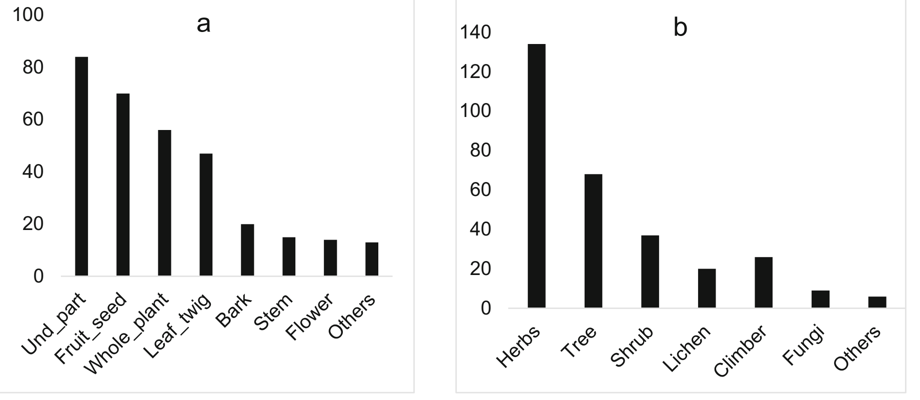

Fig. 2. Traded part **a** and life form **b** of commercial Nepalese medicinal plants, fungi, and lichens.

$p < 0.0001$) and a maximum elevation of 4600 m (*Juniperus recurva* Buch.-Ham. ex D. Don).

The number of native high-volume species (n = 47, > 10 tons) increased up to 900 m, remained almost constant up to 2300 m (average = 25, min = 24, max = 27) and then decreased ($r^2 = 0.882$, $p < 0.0001$), Fig. 4. *Cinnamomum tamala*, *Zanthoxylum armatum*, *Machilus odoratissima* Nees, and *Swertia chirayita* were major high-volume medicinal plants. The maximum number of native high-value species (n = 31; > USD 10/kg) was observed between 2000 and 3000 m (average = 17, min = 14 max = 19). Major high-valued species found around the peak are *Morchella* spp., *Delphinium denudatum* Wall., *Paris polyphylla*, and *Ganoderma lucidum*. From 3000 m, the richness slightly decreased (average = 12) but remained almost constant up to 4100 m, showing a concentration of high-value species also at higher elevations ($r^2 = 0.871$, $p < 0.0001$) including *Ophiocordyceps sinensis*, *Picrorhiza scrophulariiflora*, *Nardostachys jatamansi*, and *Fritillaria cirrhosa* D. Don.

Conservation and Vulnerability of Traded Species

Of the 300 commercial species, 117 (39%) are listed in one or more conservation categories. Two species (*Nardostachys jatamansi* and *Taxus wallichiana* Zucc.) fall into four conservation categories; three species (*Dactylorhiza hatagirea* [D. Don] Soó, *Pterocarpus marsupium* Roxb., and *Rauvolfia serpentina* [L.] Benth. ex Kurz) into three; 15 species into two; 99 species into one; while 184 species do not fall into any conservation category (Online Resource 1, ESM). Using the vulnerability assessment tool in Table 1, we analyzed the vulnerability of the 246 native commercial species (excluding 20 lichen species and shilajeet), Table 2 (details in Online Resource 2, ESM). *Nardostachys jatamansi* came out as the most vulnerable commercial species (score 33), followed by *Rheum australe* and *Picrorhiza scrophulariiflora*. Fifteen out of the 17 most vulnerable species are high altitude herbs (growing > 3000 m) and underground parts are harvested from 16 out of these 17 species. These results indicate that high altitude species whose underground parts are harvested are generally more vulnerable than species from lower elevations. *Pterocarpus marsupium* is the only vulnerable traded tree found at low altitude.

Discussion

Species in Trade

Out of 2331 Nepalese medicinal plant species (Rokaya et al. 2012), we recorded 300 species (13%, including fungi and lichen) in trade, almost twice the number of previous estimates for the country (Bhattarai and Ghimire 2007; Ghimire 2008; Subedi 2006). Some of the increase came from enumerating product groups at the species level, e.g., the 12 species of *Dendrobium* traded as sungava. We also enumerated all traded orchids (n = 24) and lichens (n = 20). There are several reasons for this high number of traded species in Nepal: (i) the country and its neighbors have a long history of using medicinal plants, fungi, and lichen in Ayurvedic and Traditional Chinese Medicine (Jaiswal et al. 2016); (ii) India and China have imported such products from Nepal for centuries

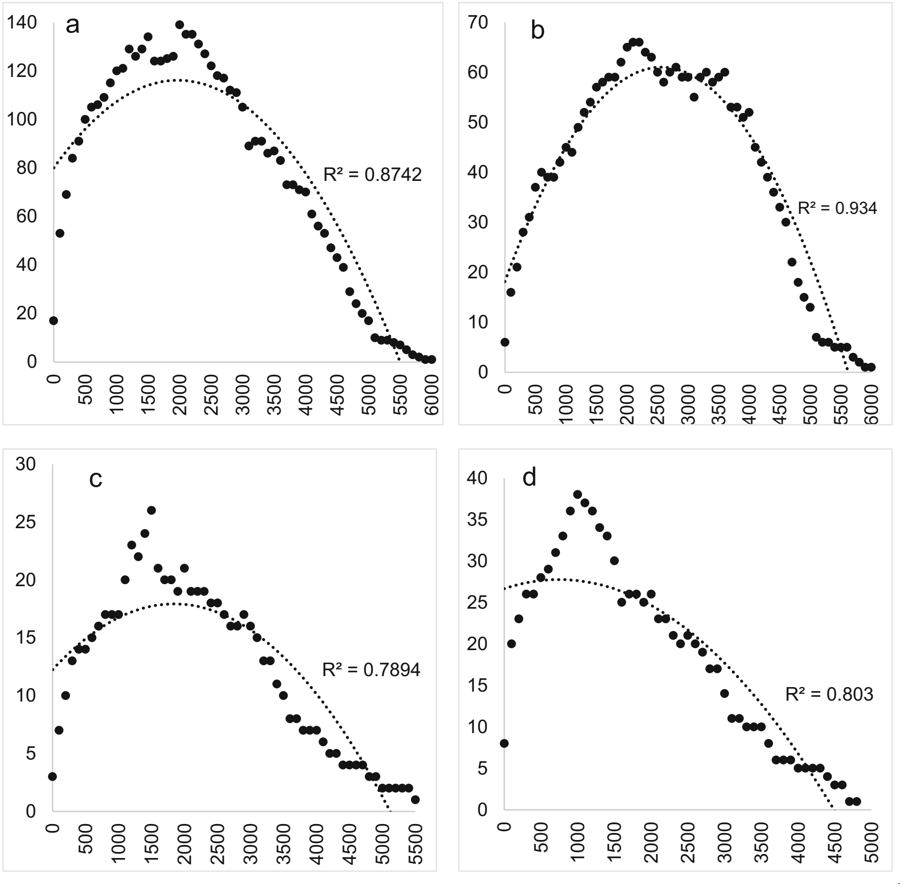

Fig. 3. Altitudinal distribution of native commercial Nepalese medicinal plants, fungi, and lichens **a**, herbs **b**, shrubs **c**, and trees **d**. Altitude (in m) on x-axis and number of species on y-axis.

(Hamilton 1819; Kirkpatrick 1811) and continue to do so (Edwards 1996; He et al. 2018; Olsen 2005; Vasisht et al. 2016); (iii) it appears that the 4.3 and 11.4 fold rise in per capita income for India and China from 1996 to 2016 (IndexMundi 2018) has increased demand for consumer products

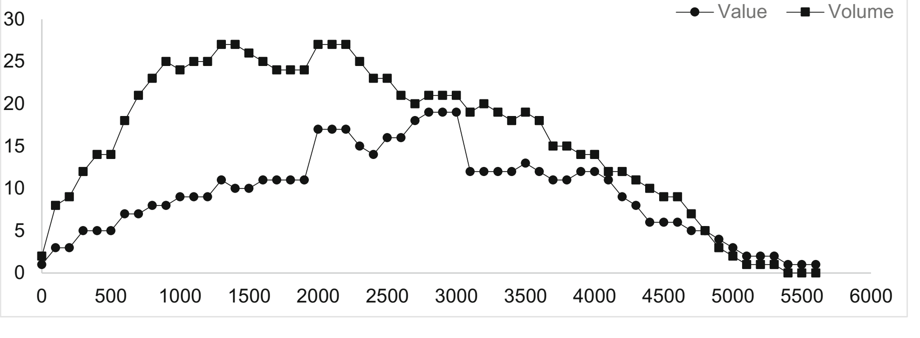

Fig. 4. Altitudinal distribution of high-value and high-volume native Nepalese medicinal plant, fungus, and lichen species. Altitude (in m) on x-axis and number of species on y-axis.

TABLE 2. THE 17 MOST VULNERABLE (SCORE ≥ 30) COMMERCIAL MEDICINAL PLANT AND FUNGI SPECIES TRADED IN AND/OR FROM NEPAL (ADDITIONAL DETAILS IN ONLINE RESOURCE 2, ELECTRONIC SUPPLEMENTARY MATERIAL).

Common Name	Scientific Name	Life form	Traded part	Global distribution	Altitudinal span	Bioclimatic region	Trade volume	Price	Conservation status	Local population size	Habitat specificity	Score
Jatamansi	*Nardostachys jatamansi*	2	4	3	3	4	4	3	4	3	3	33
Padamchal, Karaj chulthe	*Rheum australe*	2	4	3	3	4	4	3	2	3	4	32
Kutki	*Picrorhiza scrophulariiflora*	2	4	3	3	4	4	4	3	2	3	32
Nirmasi	*Aconitum heterophylloides* (Brühl) Stapf	2	4	4	3	4	2	4	1	4	3	31
Panchaaule, Hatajadi	*Dactylorhiza hatagirea*	2	4	2	3	4	1	4	4	4	3	31
Kakoli	*Fritillaria cirrhosa*	2	4	3	3	4	3	4	2	4	2	31
Padamchal, Karaj chulthe	*Rheum nobile* Hook. fil. & Thoms.	2	4	3	4	4	1	3	2	4	4	31
Sarmaguru	*Swertia multicaulis* D. Don	2	4	3	4	4	1	3	2	4	4	31
Bish	*Aconitum ferox* Wall. ex Seringe	2	4	4	3	3	3	3	2	3	3	30
Attis	*Aconitum heterophyllum*	2	4	3	3	4	2	3	3	4	2	30
Nirmasi	*Aconitum orochryseum* Stapf	2	4	4	2	4	2	4	1	4	3	30
Pakhanved	*Bergenia purpurascens* (Hook. fil. & Thoms.) Engl.	2	4	3	3	4	4	2	1	3	4	30
Attis	*Delphinium himalayae*	2	4	4	2	4	3	3	2	3	3	30
Dhupjadi	*Dolomiaea macrocephala* Royle	2	4	3	4	4	1	3	2	4	3	30
Padamchal, Karaj chulthe	*Rheum moorcroftianum* Royle	2	4	3	4	4	1	3	2	3	4	30
Satuwa (kalo)	*Trillium govanianum*	2	4	3	3	4	3	4	1	3	3	30
Bijaysal	*Pterocarpus marsupium*	4	3	2	4	1	2	3	4	4	3	30

containing medicinal plants, fungi, and lichen—there are several studies indicating a positive correlation between use of traditional medicine and higher income (Chao and Wade 2008; Shih et al. 2012), even (iv) leading to demand for new species such as the only recently traded *Ganoderma lucidum*, *Goodyera biflora*, *Dendrobium denudans* D. Don, *Dendrobium eriiflorum* Griff. and *Dendrobium nobile* Lindl. from Nepal (He et al. 2018; Pyakurel et al. 2018). Expanding trade may also be a response to increased global search for alkaloids that cure complex diseases, e.g., the relative recent trade of *Taxus* spp. from Nepal is a response to the demand for taxol in cancer treatment (Thomas and Farjon 2011).

Altitudinal Distribution

We recorded the maximum species richness for commercial native species at elevations from 1000 to 2500 m. Rokaya et al. (2012) argue that this is due to higher population density leading to higher ethnobotanical usage, less frequent modern healthcare facilities, and a higher diversity of secondary metabolites at such altitudes. Two other studies (Acharya et al. 2009; Bhattarai and Vetaas 2003) agree with the hypothesis of O'Brien (1998), who suggests that higher rainfall and optimum energy conditions lead to high tree diversity around subtropical regions, and perhaps such a pattern also exists for medicinal plant species. Optimal growth conditions may also lead to rapid population growth, thereby making the species less susceptible to overharvesting in this region. In addition, the road network expansion in the Middle hills in the past two decades has improved market access for low value products (Pyakurel et al. 2018). And finally, the higher forest cover (38%) in the Middle hills (Department of Forest Research and Survey 2015) could increase species richness.

Lower diversity at higher altitudes is surely caused by eco-physiological constraints, such as low temperature, low energy, and shorter growing season (Colwell and Lees 2000; Vetaas and Grytnes 2002). These constraints, along with high prices, contribute to making high altitude species more vulnerable to commercial harvesting. On the other hand, the lower diversity at lower altitudes, below 1000 m, may be due to the low forest cover of 7% in the Tarai lowlands (Department of Forest Research and Survey 2015).

The high-altitude regions of Nepal have always been the central focus for policy makers and researchers working with medicinal plants because of the presence of easily visible, economically important, and high unit-value products like those from *Ophiocordyceps sinensis*, *Picrorhiza scrophulariiflora*, *Nardostachys jatamansi*, and *Fritillaria cirrhosa*. Our study finds, however, that the elevation range of 2000–2300 m features the highest number of high-value and high-volume species, thus indicating a potential for economic development, not least through promotion of cultivation and domestication (which has already happened, from the bottom up, for species like *Swertia chirayita* and *Zanthoxylum armatum*) and benefitting from an already established extensive network of roads in the Middle hills.

Conservation

Underground parts, the whole plant, or bark are harvested from 50% of all the investigated commercial species in Nepal. Such harvesting is considered destructive (Cunningham 1993) compared with harvesting fruits, seeds, flowers, and leaves (Gaoue and Ticktin 2007). More than 44% of the traded Nepalese species are herbs (including sedges, grasses). Underground parts and whole parts of medicinal herbs are often harvested by uprooting the whole plant before seed dispersal, thereby inhibiting natural propagation (Ghimire et al. 2008b). There is a string of existing conservation categories and initiatives, and our vulnerability assessment provides a set of clear findings with implications for development of conservation interventions: (i) 15 of the 17 most vulnerable commercial medicinal plant species of Nepal are found in the alpine and subalpine regions (*Aconitun ferox* and *Pterocarus marsupium* being the exceptions) and underground parts are harvested from 16 of the 17 species; and (ii) all of these 17 species are wild-harvested. Less than 20% of all commercial Nepalese species (native and exotic) are in cultivation; low levels of cultivation are common around the globe where most species continued to be sourced from the wild (Bhattarai 1997; Lange and Schippmann 1997; Uniyal et al. 2000). There seems, however, to be scope for domestication and cultivation as indicated by the existing bottom-up examples (e.g., Hertog and Wiersum 2000). A rigorous review of experiences and associated policies and investments is lacking.

Another potentially promising way of improving the management and conservation of high-altitude

Fig. 5. A heap of prematurely harvested *N. jatamansi* **a** and the subsequent sheep transport to the harvesters' village, north-west Nepal, August 2015 **b**.

species, to the benefit of both local communities and plant protection, is through the establishment of community-forestry type tenure arrangements where local communities obtain formal management rights of high-altitude habitats, including alpine meadows. The need and potential for such interventions can be illustrated through direct observations made during fieldwork in one of the districts of northwest Nepal: The biological harvest time for jatamansi (*Nardostachys jatamansi*) is in October after seed dispersal. But in the first week of August 2015, we observed tons of freshly harvested jatamansi drying in the sun and transported to nearby villages using sheep (Fig. 5). When we probed about sustainability, one harvester said, "Harvesting of wild medicinal plants is one of our major income sources and everyone come here to harvest. If I come late, then I may collect less. Further, the soil becomes very hard due to thick frost in October and it will be virtually impossible to harvest. Thus, no one come here during October at this altitude (4,200m) because of extreme cold, so we have to harvest prematurely." This empirical observation is in line with the outcomes of the vulnerability assessment identifying *Nardostachys jatamansi* as the most vulnerable commercial Nepalese medicinal plant species, not least due to premature harvesting and overharvesting of underground parts which lead to decline in population as sexual reproduction is hampered. It also points to the need for community management if such local institutions can regulate the timing of access to resources.

While almost 39% of the investigated commercial Nepalese species are included in one or more national or international conservation lists, such as the government ban on trade of *Dactylorhiza hatagirea*, bark of *Juglans regia* L., and lichens, the effectiveness of such listings appear doubtful (Fig. 6). Banned products are traded informally, often camouflaged with other products. One sub-local trader said, "I am purchasing lichens from harvesters and I know there are other traders who are purchasing lichens, but they don't disclose because it is banned." It must be recognized that conservation measures such as trade bans can serve many purposes, including opportunities for regulatory authorities to generate informal incomes. The practice of rent-seeking at all nodes in the production network has been documented in the past (Olsen and Helles 2009) and present (Pyakurel et al. 2018). Statements by actors support that such

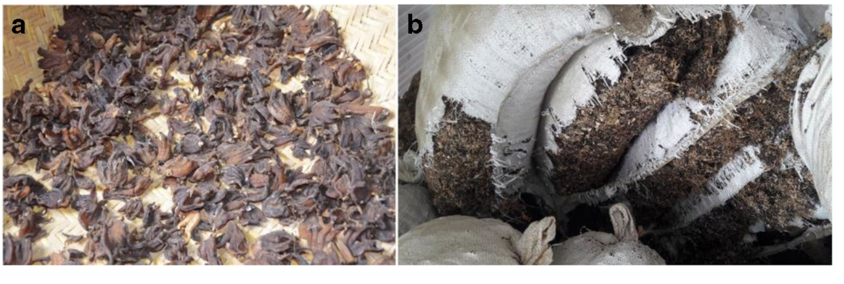

Fig. 6. Dried *D. hatagirea* tubers ready for sale at Bajhang **a** and seized lichen at the District Forest Office, Makawanpur **b**.

practices are still common. For instance, a central wholesaler said, "The banned products are seized when there are misunderstandings. If properly negotiated, then there is almost no problem." This also indicates that strict regulation is ineffective for products that have market demand, explaining why there are high levels of trade (Olsen 2005; Pyakurel et al. 2018) but few cases of seizure of banned species. New ways must be found to achieve positive conservation outcomes, including obtaining a better understanding of the political ecology of the commercial medicinal plant sector (why does rent-seeking persist) and trying new interventions, such as rolling out community forestry at high altitude, establishing sustainable harvest rates for the most vulnerable species, and enhancing understanding of domestication and cultivation processes.

Conclusion

We documented that trade of commercial medicinal plant, fungi, and lichen species in and from Nepal involved twice as many species as previously reported. The number of commercial species in Nepal is highest at middle altitudes, but the most vulnerable species are found at high altitude. Hence, it is recommended that domestication and cultivation initiatives be targeted towards middle-altitude species, while conservation at higher altitude is pursued through greater local community involvement in common pool resources management, e.g., through formal handing-over of high altitude resource areas to local communities building on the best experiences from the community forestry program. We also found that many formally protected species are traded, indicating that traditional conservation interventions, such as government bans on trade, are insufficient to achieve widespread positive conservation outcomes.

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Compliance with Ethical Standards

Ethical Approval. With every individual participant, we clarified the purpose of the research, including how their contributions would be used and shared. No individual participants can be identified. All interviewees gave their prior informed consent to participation and were informed that they could withdraw at any point. Preliminary results were shared with the trading community through the Project Advisory Committee meetings of the Transiting to Green Growth project. Research adhered to the European Code of Conduct for Research Integrity, the University of Copenhagen Rules on Good Scientific Practice, and the ethical standards of the International Society for Ethnobiology. All necessary research permits were obtained. By focusing on trade, this study gave voice to actors in an invisible sector. Samples/vouchers were collected with the informed consent of traders. The image of harvesters has been blurred in Fig. 5 to make them unidentifiable.

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