Traditional socio-cultural utilization and harvesting practices of an alpine medicinal herb, *Neopicrorhiza scrophulariiflora* in Khumbu Valley, Nepal

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Ethnobotany Research and Applications 26:64 (2023) - http://dx.doi.org/10.32859/era.26.64.1-15
Manuscript received: 29/05/2023 – Revised manuscript received: 08/11/2023 - Published: 17/11/2023

Research

Abstract

Background: This study aimed to document the traditional knowledge of people in the Khumbu Valley within Sagarmatha National Park and Buffer Zone in Nepal regarding the utilization and harvesting practices of the Himalayan medicinal plant *Neopicrorhiza scrophulariiflora*, which is under threat due to over-harvesting.

Methods: The study used focus group discussions and key informant interviews to gather ethnobotanical knowledge from residents of seven enclave settlements of the park buffer zone. These settlements were later grouped into three village clusters based on their elevation. A total of 145 individuals of four ethnic groups with age between 20 and 72 years were interviewed. We analyzed the variation in the knowledge and usage of the plant among respondents in different village clusters, by gender, age-class, and ethnicity.

Results: The majority of respondents were familiar with the plant and its medicinal value, mainly in the treatment of upper respiratory tract illnesses, gastrointestinal disorders, diabetes, and hypertension. There was no significant association between village clusters and the awareness of the plant's use for specific diseases. However, there was a significant relationship between the village cluster and the number of use reports for different diseases. This suggests variations in the applications of the plant for treating specific ailments across different geographic locations. Females showed higher awareness of the plant's medicinal uses, but gender did not significantly affect use reports for specific diseases or the overall number of use reports. Adults and seniors had the highest awareness of the plant's medicinal uses, with use reports increasing with age class. Ethnicity did not significantly influence awareness or use reports. Rhizomes of *N. scrophulariiflora* are primarily collected for local use, sometimes exchanged among villagers or used as gifts. Preferred harvesting seasons varied by age, with older individuals favoring mature stages. Younger harvesters showed less concern for sustainable harvesting practices.

Conclusions: *N. scrophulariiflora* is recognized for its potential in treating various health issues. The study reveals variations in the knowledge and utilization of *N. scrophulariiflora* based on geographic location, gender, and age-class, but not ethnicity. The study highlights a generational gap in the knowledge of plant usage, with younger generations losing traditional knowledge due to economic transformation, particularly as they transition to tourism-related livelihoods. To preserve this vital resource and its associated traditional knowledge, efforts should be made to educate and engage younger generations and promote sustainable harvesting practices in the region.
Keywords: Kutki, Khumbu Valley, Destructive harvesting, Ethnobotanical uses

Background

Himalayas stand as the world's youngest, highest and largest mountain ranges, supporting a rich diversity of plant life. The region boasts over 7000 to 10000 species of medicinal and aromatic plants (MAPs), which greatly support the livelihood needs of the people living in this area (reviewed in Heinrich *et al*. 2021, Pei 2001). The inhabitants of the Himalayas utilize their traditional ecological knowledge to harness the natural resources in their vicinity, giving them a profound understanding of their environment. The indigenous communities residing in the Himalayas possess extensive knowledge of plant use for primary health care (Manandhar 2002). MAPs hold significant value in various folk healing systems and scholarly systems of traditional medicine such as Ayurveda, Unani, Chinese and Tibetan medicine. These four major medical traditions in Asia heavily rely on Himalayan medicinal plants. Furthermore, MAPs used in traditional medicine serve as crucial sources of novel bio-molecules with applications in pharmaceuticals, nutraceuticals and cosmeceuticals (Heinrich & Gibbons 2001). Besides the importance of medicinal plants in health care, these plants carry high socio-cultural, symbolic, and economic significance, providing income and employment to millions of people living in the region (Ghimire *et al*. 2008a).

The Himalayas of Nepal are regarded as one of the storehouses of medicinal and aromatic plants (MAPs), and there exist diverse traditional and cultural practices related to the use of such plants in human and animal healthcare (Bhattarai 2018, Kunwar *et al*. 2021, Manandhar 2002). Previous studies have documented the use of about 2300 plant species for medicinal purposes among diverse ethnic communities in Nepal (reviewed in Rokaya *et al*. 2012). In addition to their direct medicinal applications, MAPs play a significant role in the household economy, particularly in rural Nepal. Every year, Nepal exports thousands of tons of MAPs, along with other non-timber forest products, to neighboring and overseas countries, amounting to millions of dollars (Ghimire *et al*. 2016). Many Himalayan MAP species are under threat due to over-harvesting, driven by the growing demand for raw materials by herbal and pharmaceutical industries worldwide and within the region (Pyakurel *et al*. 2018, 2019). These plants are primarily collected from the wild, as they are not commercially cultivated, making them increasingly scarce. Concerns also revolve around the rapid erosion of traditional knowledge and practices in Nepal due to biodiversity loss, resource scarcity, shift in socio-cultural practices, and economic transformations, among other factors (Atreya *et al*. 2018).

The Khumbu Valley in Mount Everest region is a globally renowned tourist destination in Nepal due to its unique topography, and rich biodiversity and culture. Over 100 species of non-timber forest products including MAPs have been documented from a narrower territory of this area (Bhattarai *et al*. 2009). Although various researchers have explored ethno-phytomedicine in different parts of Nepal (reviewed in Ghimire *et al*. 2008a, Kunwar *et al*. 2021, Rajbhandary and Winkler 2015), comprehensive studies on ethnomedicinal practice particularly in the high-altitude region, such as Khumbu and surroundings remain limited (e.g., Rawal *et al*. 2009). Thus, an initiative has been undertaken to document the traditional knowledge of various ethnic groups in the Khumbu Valley regarding the utilization and harvesting practices of one highly threatened Himalayan plant, *Neopicrorhiza scrophulariiflora* (Pennell) D.Y. Hong (family: Plantaginaceae), locally known as Kutki.

N. scrophulariiflora is particularly threatened due to unsustainable harvesting of its rhizomes for trade that negatively affects its vegetative and reproductive growth, resulting in population size reduction in different parts of the Himalayas (Bantawa *et al*. 2009, Poudeyal *et al.* 2019). Unethical export of the plant is a recurrent issue (Olsen 2005, Pyakurel *et al*. 2018), and local use also contributes to the strain on its population throughout the Himalayas. Nepal has been considered as the largest supplier of *N. scrophulariiflora* rhizomes in the international herbal market, with total annual exports ranging from 175 to 770 tons (Olsen 2005). However, the ethically harvested annual quantity for trade from Nepal is merely 31 tons (Poudeyal *et al*. 2021). Consequently, the majority of the export occurs through illegal channels. The rhizome of *N. scrophulariiflora* holds significant importance in both traditional folk healing system and scholarly system of traditional medicine. It is primarily used for treating conditions such as cough, cold, fever, headache, high blood pressure, and intestinal disorders in various parts of Nepal (Ghimire *et al*. 2008a). Studies have highlighted the plant's beneficial effects on various bodily systems, including the liver, immune system, cardiovascular system, nervous system, skin, muscles and bones, digestive system, respiratory system, and genitourinary system (Smit *et al*. 2000). The plant contains a wide range of biologically active

secondary metabolites, making it of great medicinal importance. The major compounds identified in the plant include caffeoyl glycoside, cucurbitacin glycoside, cyclopentanoid monoterpenes, hydroquinone glycoside, iridoid glucosides, non-glycosidic iridoid, phenol, phenyl glycoside, phenylpropanoid, phenylethyl glycoside, and secoiridoid glycoside (Sah &Varshney, 2013; Smit *et al*. 2000, Xu *et al.* 2020).

In this paper, we present the results of our ethnobotanical survey among the people of the Khumbu Vally regarding the use and harvesting of *N. scrophulariiflora*. We were particularly interested in addressing the following questions: (a) Does the local healthcare benefit from the use of *N. scrophulariiflora*? (b) Do existing usage patterns vary based on a person's age, gender, and ethnicity? (c) How is the younger generation's access to this knowledge deteriorating? (d) Are local people aware of sustainable harvesting practices in terms of collection timing?

Materials and Methods

Study area

We conducted a field study and interviews in Khumbu Valley, located in the lap of Mount Everest within the Sagarmatha National Park and Buffer Zone (SNPBZ) in the Solukhumbu District of northeastern Nepal (Fig. 1). SNPBZ spans from 27°45' to 28°07' N latitudes, and 86°28' to 87°07' E longitudes, covering a total area of 1423 km^2. This region showcases a diverse range of elevations, from 2715 m to the towering height of 8848.86 m asl, encompassing steep hills, glaciers, valleys, river terraces, and the debris left by glaciers (SNP 2016). Established in 1976, Sagarmatha National Park was designated as a UNESCO World Heritage Site in 1979, recognized for its remarkable natural and cultural attributes.

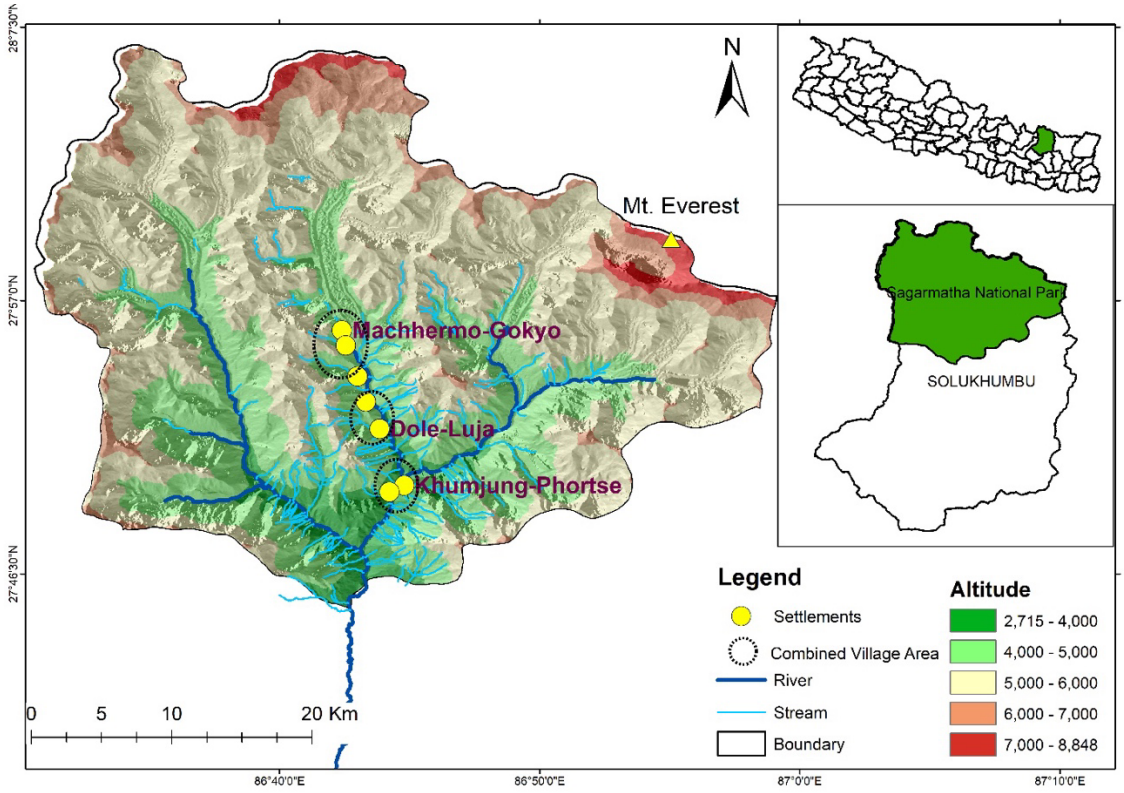

Figure 1. Map showing the study area.

A total of 67 small to medium-sized enclave settlements located within the core park area, and those located at the southern border of the park were declared as buffer zone in 2002. These settlements are home to approximately 7800 residents living in 1619 households (SNP 2016). The predominant ethnic group in the buffer zone is Sherpa, of Tibeto-Burman descent, constituting over 80% of the total population. Other ethnic communities in the region include Magar, Rai, Tamang, belonging to the Tibeto-Burman linguistic group, and some representatives of Indo-Aryans. The local communities in the buffer zone are organized into 28 user groups, under three Buffer Zone User Committees (BZUCs) and one Buffer Zone Management Committee (BZMC) for the participatory conservation and development activities (SNP 2016). The local livelihood is mainly supported by tourism-related activities. The Khumbu Valley's rugged terrain renders most of the land unsuitable for cultivation. Only a few crops, including potato, barley and buckwheat, are grown in limited pockets of arable land. Until the

advent of tourism in the 1960s, yak herding was the primary source of income, but nowadays, it serves as an alternative source of income for only a small proportion of households with limited involvement in tourism.

The climate in SNPBZ is influenced by the monsoon, characterized by moist and cool summers and cold and dry winters. The summer monsoon season spans from June to September, bringing in 70–80% of the annual precipitation. Precipitation data from 2013 to 2017 (CBS 2019) from the nearest meteorological stations indicate that the region at its lower elevations (2378–2770 m asl) receive an average annual precipitation of about 1800 mm (range: 1300–2312 mm). Annual precipitation decreases to 1100 mm at 3450–3850 m asl and further drops to 465 mm at 5050 m asl (Thapa & Shakya 2008). In the north of the Himalayan range, toward the border of the Qomolangma National Nature Preserve in China, annual rainfall diminishes to less than 150–200 mm (SNP 2016). The mean annual temperature recorded at 2378 m asl (Salleri station: 27°30'N, 86°35'E) is 14°C, with a minimum of 4°C and a maximum of 22°C. The mean annual temperature decreases to 5.1°C at 3450–3850 m and plummets to -2.4°C at 5050 m asl (Thapa & Shakya 2008).

SNPBZ is characterized by high-altitude forests and rangeland ecosystems. Vegetation in the Khumbu Valley includes temperate mixed forests, subalpine forests comprising blue pine, fir, rhododendron, birch and junipers, and subalpine and alpine scrubs and meadows. These forests and meadows are extensively used for grazing livestock and for the extraction of firewood, fodder and non-timber forest products (NTFPs). A wide array of floras, including over 1000 species of flowering plants with 21 endemic taxa, have been documented in SNPBZ (Bhattarai & Upadhyay 2013, Bhuju *et al*. 2007, Ghimire & Jha 2013). SNPBZ is home to over 100 NTFPs, and certain plants like *Neopicrorhiza scrophulariiflora* (Kutki), *Nardostachys jatamansi* (Jatamansi), *Paris polyphylla* (Satuwa), *Dactylorhiza hatagirea* (Panchaunle), *Aconitum spicatum* (Bikh), and *Ephedra gerardiana* (Somlata) are considered threatened due to over-harvesting, and habitat encroachment and degradation (Bhattarai *et al*. 2009, Gaire 2014).

Study species

Neopicrorhiza scrophulariiflora (hereafter referred to as *Neopicrorhiza*; Fig. 2) is commonly known as 'kutki' in Nepali, 'katuka' in Sanskrit, 'hongling' or 'hunglen' in Sherpa, and 'honglen' in Tibetan (Ghimire *et al*. 2008a). The plant species is native to the Himalayas and China and is typically found at altitudes between 3500 to 4800 m asl in Nepal. *Neopicrorhiza* is a clonal perennial herb, up to 15 cm tall, producing 10–20 cm long rhizomes, bearing aboveground vegetative offshoot at frequent intervals. The leaves are up to 6 cm in length, spathulate to ovate in shape, with serrated margin. Summer rainy months are the best season for its growth. In late June to early August, it produces flowering spikes that are 1–2 cm long, terminating on a short glandular-hairy scape. The flowers are perfect, dark purple, hairy, featuring a 2-lipped corolla, with the upper lip much longer than the lower one. Flowers are pollinated by insects (Ghimire *et al*. 2005). Fruiting begins in late July and early August, giving rise to narrowly ovoid capsules that measure 8–10 mm in length, and contain numerous seeds. These seeds mature in September/October and are small and lightweight, primarily dispersed by the wind. Seed germination is limited and occurs from May to early June. Propagation is mostly by vegetative means through fragmentation of rhizomes (Ghimire *et al*. 2005).

Figure 2. *Neopicrorhiza scrophulariiflora*. (photo © S.K. Ghimire).

Ethnobotanical surveys, data collection and analysis

The fieldwork was conducted between October and November 2021, encompassing seven enclave settlements situated in the park buffer zone along an elevation gradient ranging from 3650 to 4750 m in the Khumbu Valley (Fig. 1, Table 1). Ethnobotanical information was gathered through focus group discussions (FGD) and key informant interviews (KII) with local residents, healers, and herders. A combination of semi-structured and unstructured questions was used during these FGDs and KIIs. Prior informed consent was obtained from all participants before conducting the FGDs and interviews. During interaction with the local community, it was made clear that the study was solely for academic purposes and that any knowledge shared by the locals would not be exploited for commercial gain. The local residents (respondents) subsequently provided verbal consent for the dissemination of their traditional knowledge.

Table 1. Composition of respondents in the study village clusters in Khumbu Valley.

Village clusters	Elevation	Number of respondents			Age (yr): mean and range	Ethnic groups (number respondents in parentheses)
		Male	Female	Total		
Khumjung–Phortse Thanga (settlemets: Khumjung and Phortse Thanga)	3650–3800 m	22	30	52	44 (24–72)	Sherpa (37), Rai (5), Tamang (5), others (5)
Dhole–Luja (settlemets: Doje and Luja)	4200–4300 m	18	25	43	47 (20–68)	Sherpa (30), Rai (4), Tamang (5), others (4)
Machhermo–Gokyo (settlemets: Machhermo, Phangga, and Gokyo)	4450–4750 m	25	25	50	42 (22–62)	Sherpa (26), Rai (4), Tamang (7), others (13)
	Overall	65	80	145	44.3 (20–72)	

FGDs were organized with 5–10 participants in each settlement, and participants for interviews were selected randomly among those who had consented to be interviewed. During the fieldwork, a total of 145 individuals (65 men and 80 women) aged between 20 and 72 years were interviewed (Table 1). The majority of respondents belonged to Sherpa ethnic group (64.1%), with the remaining participants being from the Rai (9%), Tamang (11.7%), and other (15.2%) ethnic groups. The study participants were queried about the specific parts of the plant they utilized, the disease or disorders it was used to treat, the method of preparation and application, the preferred harvesting season, and the technique employed for harvesting. We also measured the air-dry weight of rhizomes collected by some of respondents to calculate the annual quantity of usage. A voucher specimen of *Neopicrorhiza* (voucher number UGC-2019-05) collected and identified in the field, was deposited at Tribhuvan University Central Herbarium (TUCH).

Before data analysis, the seven enclave settlements were categorized into three village clusters based on their elevation (low, mid and high; Table 1, Fig. 1). The reported uses of the plant by respondents were grouped into four disease/disorder categories, namely upper respiratory tract illness, gastrointestinal disorder, diabetes, and hypertension. Respondents were divided into four age classes (20–30, >30–40, >40–50 and >50 years). The field data were analyzed to calculate the frequency and percentage of respondents (under different age classes, gender, ethnic groups and village clusters) using the species for the four categories of disease/disorder. Total use-reports and disease/disorder-specific use-reports were also calculated, along with the mean use-report per respondent. The association between the medicinal knowledge of respondents and their demographic (gender, age and ethnicity) or geographic (village cluster) profiles was examined using Pearson's chi-square test of independence, which assesses the interdependence of two nominal variables (McDonald 2014). In cases where the expected values were less than 5, Fisher's exact test of independence was employed, which is more accurate than the chi-square test when sample sizes are small (McDonald 2014). In addition, we used one-sample chi-square test to determine whether there was a statistical difference between the observed and expected sets of use-report frequencies related to each disease/disorder category among village clusters, age classes or ethnic groups. A binomial test was conducted to assess whether the observations between any two categories significantly deviated from a theoretically expected distribution. We used generalized linear model (GLM) to test the variation in number of use-report per respondent according to village cluster, gender, age class and ethnic group (using Poisson distribution of count data, and log link function). All of the analyses were carried out using R version 4.1.2 (R Core Team, 2021).

Results

Use pattern

All respondents knew the plant by its vernacular names – 'honglen', 'hunglen', 'hunglin' or 'kutki'. A majority of them were also knowledgeable about the plant's growing locations. Nevertheless, there were variations in use pattern based on village clusters, gender and age-groups (Table 2 and 3). Out of the 145 respondents, nearly 83% were aware of the plant's potential medicinal applications for one or more health issues. There were a total of 228 use-reports cited by 120 respondents for a combination of four disease/disorder categories. The highest number of use-reports, 93 (40.8% of total reports), pertained to upper respiratory tract illness (URTI). Gastro-intestinal disorder (GID) accounted for 27.6% of the reports, while hypertension and diabetes each constituted 15.8% of the total use-reports (Fig. 3, Table 3). All respondents who were aware of the plant's medicinal properties mentioned using its rhizome in their remedies.

Table 2. Awareness about the use of *Neopicrorhiza scrophulariiflora* according to (a) village cluster, (b) gender, (c) age class, and (d) ethnic group in Khumbu Valley, Nepal.

Respondent categories	Total respondents	Awareness about the use of the plant: number and % of respondents for each respondent category		Chi-square/FET tests
		Aware about the use for any of the disease/disorder	Unaware about any of the use	
a. Village cluster-wise awareness				
Khumjung – Phortse Thanga	52	43 (82.69%)	9 (17.31%)	$\chi^2 = 0.59$*
Dole – Luja	43	37 (86.05%)	6 (13.95%)	df = 2
Machhermo – Gokyo	50	40 (80.00%)	10 (20.00%)	$p = 0.744$
b. Gender-wise awareness				
Male	65	48 (73.85%)	17 (26.15%)	$\chi^2 = 6.56$*
Female	80	72 (90.00%)	8 (10.00%)	df = 1
				$p = 0.01$
c. Age class-wise awareness				
20-30 yr	25	8 (32.00%)	17 (68.00%)	FET, value =
>30-40 yr	32	24 (75.00%)	8 (25.00%)	59.37**
>40-50 yr	41	41 (100.00%)	0	$p<0.0001$
>50 yr	47	47 (100.00%)	0	
d. Ethnic group-wise awareness				
Rai	13	10 (76.92%)	3 (23.08%)	FET, value =
Sherpa	93	80 (86.02%)	13 (13.98%)	4.50**
Tamang	17	15 (88.24%)	2 (11.76%)	$p = 0.200$
Others	22	15 (68.18%)	7 (31.82%)	
Total	**145**	**120 (82.76%)**	**25 (17.24%)**	

*In the first two cases, the χ^2- and associated *p*-values are based on Pearson's chi-square test of independence which test the mutual dependency of awareness with village cluster and gender.

**In the last two cases, Fisher exact test (FET) was performed to test the mutual dependency of two attributes (awareness and age class or ethnicity). Here, chi-square test of independence was not done because some of the expected values in unaware group of respondents were small (<5).

Table 3. Total, mean and disease-wise use-reports for *Neopicrorhiza scrophulariiflora* according to (a) village cluster, (b) gender, (c) age class, and (d) ethnic group in Khumbu Valley, Nepal.

Respondent categories	Total use-reports	Mean use-reports per respondent (range in parentheses)	Use-reports under each of the four disease/disorder categories			
			Diabetes	Gastro-intestinal disorder (GID)	Hyper-tension	Upper respiratory tract illness (URTI)
a. Village cluster-wise use-reports						
Khumjung – Phortse Thanga	69	1.7 (1-4)	14[a]	12[a]	7[a]	36[a]
Dole – Luja	92	3.3 (1-4)	18[a]	27[a]	20[b]	27[a]
Machhermo – Gokyo	67	1.7 (1-3)	4[b]	24[a]	9[a]	30[a]
		χ^2 = 28.97* p<0.0001	χ^2 = 19.25**; df = 6 p = 0.004			
b. Gender-wise use-reports						
Male	83	2.1 (1-4)	18	20	12	33
Female	145	2.2 (1-4)	18	43	24	60
		χ^2 = 0.144* p = 0.704	χ^2 = 3.65**; df = 3 p = 0.302			
c. Age class-wise use-reports						
20-30 yr	14	1.1 (1-2)	3	4	1	6
>30-40 yr	44	1.8 (1-3)	6	11	4	23
>40-50 yr	70	2.1 (1-4)	10	23	13	24
>50 yr	100	2.6 (1-4)	17	25	18	40
		χ^2 = 8.94* p = 0.030	FET, value = 6.259*** p = 0.719			
d. Ethnic-wise use reports						
Rai	20	2.3 (1-4)	2	4	4	10
Sherpa	154	2.2 (1-4)	27	42	24	61
Tamang	30	2.3 (1-4)	4	9	6	11
Others	24	1.7 (1-3)	3	8	2	11
		χ^2 = 1.61* p = 0.658	FET, value = 3.76*** p = 0.937			
Total	228	2.2 (1-4)	36 (15.8%)	63 (27.6%)	36 (15.8%)	93 (40.8%)

*Variations in the number of use-reports per respondent (in column 3) according to village cluster, gender, age class and ethnic group were computed based on generalized linear model.

**The mutual dependency of use-reports (for four disease/disorder categories in columns 4–7) with village cluster and gender (in column 1) was based on Pearson's chi-square test of independence.

***The mutual dependency of use-reports (for four disease/disorder categories in columns 4–7) with age class and ethnicity (in column 1) was based on Fisher exact test (FET) of independence; here, chi-square test of independence was not done because some of the expected values were smaller (<5).

In the village cluster-wise use-reports with significant Pearson's chi-square value, one-sample chi-square test of goodness-of-fit was also performed to show if there was statistical difference between observed and expected sets of frequencies of use-reports related to particular disease category among village clusters. In columns 4–7, use-reports for each disease/disorder type with same superscript letters are statistically insignificant between any two categories of village cluster based on binomial test.

The awareness of the plant's use for at least one disease/disorder category did not demonstrate a significant association with village clusters (Pearson's χ^2 = 0.59, df = 2, P = 0.744; Table 2). However, Pearson's chi-square test of independence revealed a significant association between use reports for different disease/disorder categories and the respondents' geographic location (village cluster) (χ^2 = 19.247, df = 6, p = 0.004; Table 3). Through one-sample chi-square test of goodness-of-fit, followed by binomial (exact) tests, we found statistical differences between the observed and expected sets of frequencies among village clusters for diabetes and hypertension (Table 3), with respondents from Dole – Luja inclined more towards treating hypertension than those from other two village clusters (Fig. 3, Table 3). Similarly, respondents from Dole

– Luja and Khumjung – Phortse cited diabetes significantly more often than those from Machhermo–Gokyo. For GID and URTI, citation frequency did not differ among village clusters. The number of use-reports per respondent was significantly higher for Dole – Luja (3.3), while Khumjung – Phortse and Machhermo – Gokyo had nearly equal mean use report of 1.7 (GLM, $\chi^2 = 28.97$, $p < 0.0001$).

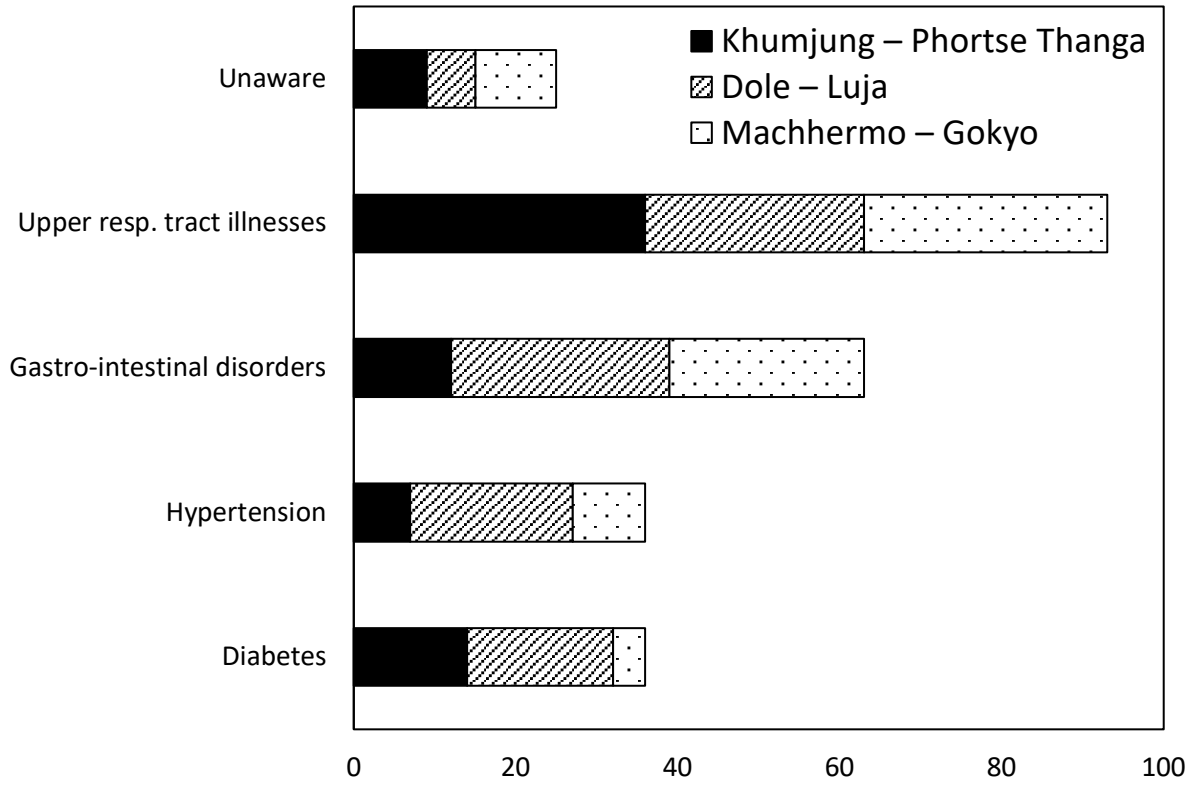

Figure 3. Number of respondents from three village clusters in Khumbu Valley citing the use of *Neopicrorhiza scrophulariiflora* for different health complaints.

Female respondents exhibited greater awareness compared to male respondents (Table 2). Of the total 80 female interviewees, 72 (90%) were aware of the plant's use, while among males, only 48 out of 65 (73.8%) were aware (Pearson's $\chi^2 = 6.56$; df = 3; $p = 0.01$). However, there was no significant association between the respondents' gender and use-reports for different disease/disorder categories (Pearson's $\chi^2 = 3.645$, df = 3, $p = 0.302$; Table 3). Similarly, the number of use-reports per respondent did not significantly differ by gender (GLM, $\chi^2 = 1.44$, $p = 0.704$).

An age group comparison revealed that 100% of the adults and seniors (age group >40–50, and >50 year) were familiar with *Neopicrorhiza*'s usage for different disorders. In contrast, only 32% and 75% of informants in the age groups 20–30 and >30–40 years, respectively, were aware of its use (Fisher exact test, $p<0.0001$; Table 2). The use-report values for the combined dataset ascended (from 14 to 100) with increasing age class (Table 3). But the number of use reports per respondent was almost two times higher in the age groups >30–40 and >40–50 years than in 20–30-year age group, and more than two time higher in the age group >50 year than in the 20–30- year group (Table 3). However, use-reports for different disease/disorder categories did not exhibit a significant association with age (Fisher exact test of independence, $p = 0.719$; Table 3).

Furthermore, we did not find significant association between ethnicity and respondents' awareness about the use of *Neopicrorhiza* (Fisher exact test, $p = 0.200$; Table 2) or between ethnicity and use reports for different disease/disorder categories (Fisher exact test of independence, $p = 0.937$; Table 3). Number of use-reports per respondent also did not significantly vary by ethnicity (GLM, $\chi^2 = 1.61$, $p = 0.658$; Table 3).

Formulation of use

Decoction was the major and common mode of formulation used for the medicinal purpose. In 67.54% of total cases (i.e., 228 use-reports), respondents, combining all village clusters, cited this mode of use (Fig. 4). In 21.93% of cases, respondents mentioned chewing the rhizome directly for medicinal purpose; and in rest of the cases (10.53%), they used to prepare a

paste of rhizomes before use. The choice of formulation method exhibited significant associations with village cluster (Fisher exact test of independence, p<0.0001) and the age of the respondents (p = 0.014). Both decoction preparation and rhizome chewing were prevalent across all three village clusters, but rhizome paste use was primarily confined to respondents in the Machhermo – Gokyo cluster (Fig. 4). Furthermore, the frequency of decoction usage increased with the respondents' age. The mode of preparation by local individuals was also influenced by their convenience and available time. Typically, a decoction was prepared by boiling a 2–3 cm-long rhizome piece in one liter of water, with two teaspoonfuls of this solution provided for oral consumption twice a day. Dosage adjustments were made based on the patient's condition, and the decoction was used until the bitterness was extracted.

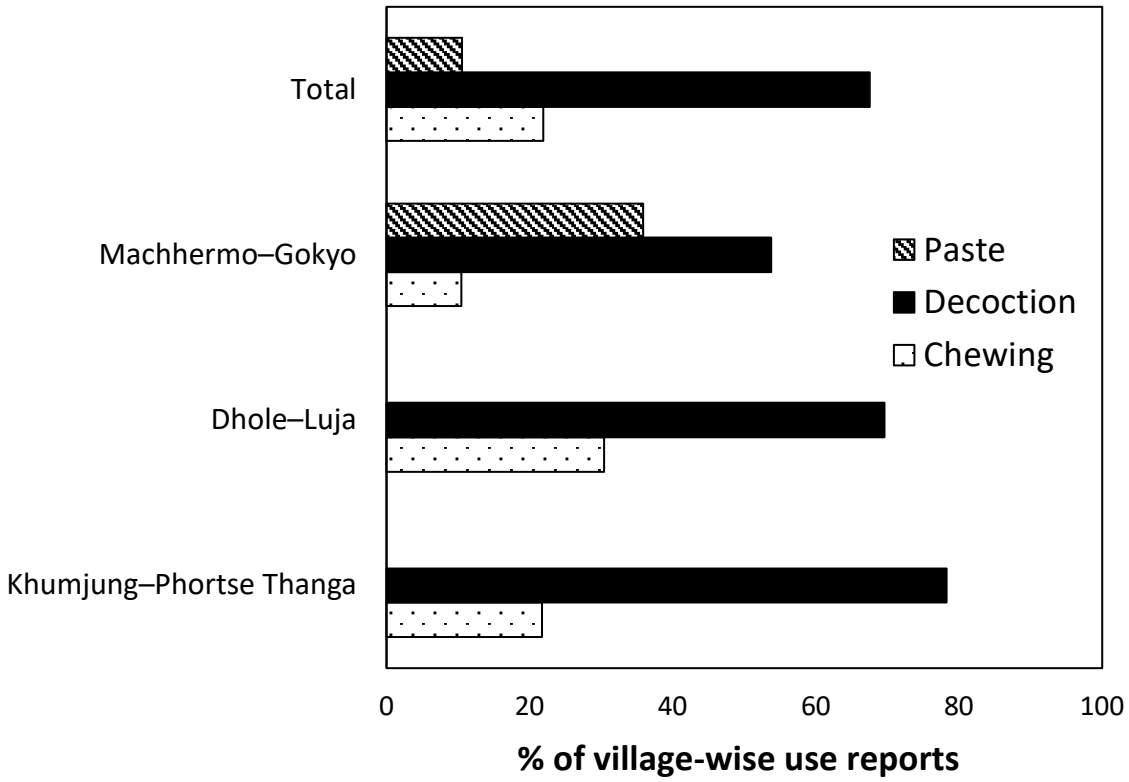

Figure 4. Mode of preparation of medicines based on *Neopicrorhiza scrophulariiflora* in Khumbu Valley.

Harvesting

In the Khumbu Valley, rhizomes of *Neopicrorhiza* are collected mostly for local use. While our study did not identify commercial trade in the region, local inhabitants indicated occasional exchanges of rhizomes for other herbs or medicinal ingredients among villagers or outsiders. Some villagers also offered rhizomes as gifts to visiting relatives. The mean air-dry weight of harvested rhizomes per respondent (n = 5) was calculated as 250 g (range: 50–700 g). Local people said that the collected amount is sufficient for their annual requirement. Due to a limited sample size, we did not conduct further statistical analyses regarding variations in harvest quantities according to demographic factors. Following collection, rhizomes underwent proper cleaning to remove soil and other plant debris, were dried in the shade, and stored in cloth sacks or plastic containers under air-dried condition for future use.

The preferred harvesting season differed among respondents, dependent on their age (Fisher's exact test of independence, p<0.0001). A majority of middle-aged respondents (age class >40–50 year: 75.6%), and seniors (>50 year: 51%) preferred harvesting *Neopicrorhiza* in its mature stage (Fig. 5). Moreover, 38.3% of senior respondents (>50-year-old) were well-informed about the appropriate harvest season at the plant's post-mature stage, primarily during September-October, and displayed concern for sustainability. Conversely, younger individuals (age class 20–30 and >30–40 year) preferred harvesting at any time when the plant is available or during the plant's early growth season (June-July) when it was immature or in its early flowering stage (Fig. 5), suggesting a lack of awareness about sustainability and future availability of the species. Fisher's exact test of independence indicated no significant associations between preferred harvesting season/stage and respondents' geographic location (i.e., village clusters, p = 0.071), gender (p = 0.076), or ethnicity (p = 0.497).

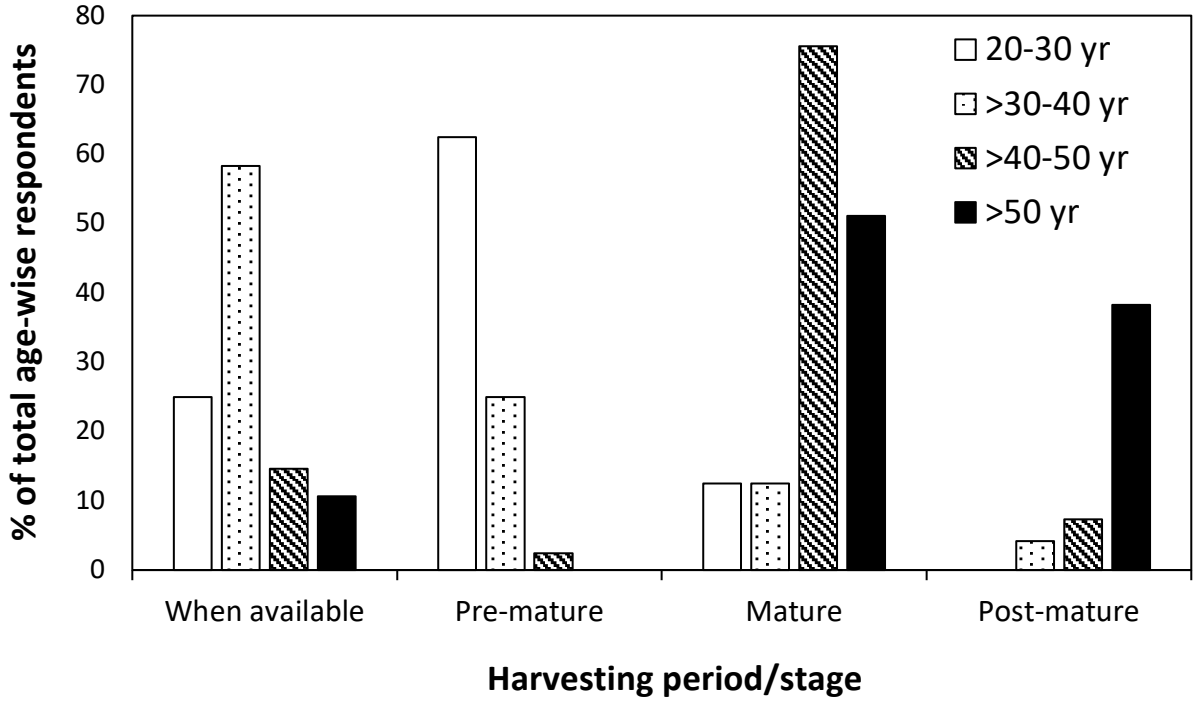

Figure 5. Harvesting of *Neopicrorhiza scrophulariiflora* in different periods/maturity stages in Khumbu Valley, Nepal. Data shown are percentage of respondents in different age classes who are involved in plant harvesting.

Discussion

In this study, we have documented traditional knowledge of the people living in the Khumbu Valley regarding the utilization and harvesting of *Neopicrorhiza scrophulariiflora*. The local population, particularly those of Sherpa culture, has a centuries-old tradition of utilizing, and managing natural resources based on customary system (Spoon 2011). Other ethnic groups such as the Magar, Rai, Tamang, and some Indo-Aryans also live in the Khumbu region and possess substantial ethnobotanical knowledge. This local knowledge is valuable not only for sustaining traditional medical practices but also for addressing future healthcare needs and conservation, with potential applications in modern pharmacology. In countries like Nepal, where contemporary pharmaceuticals are expensive and limited in remote mountain areas, the centuries-old practice of traditional medicine remains a practical and essential alternative (Chaudhary *et al*. 2023, Kunwar *et al.* 2015, Rokaya *et al*. 2020).

Our results indicate that *Neopicrorhiza* is closely linked to the livelihood and socio-cultural traditions of the local inhabitants as it has been given high preference for traditional medicinal use, and it continues to be an important commodity for exchange among inhabitants and as a gift item for their relatives living outside the valley. The fact that all respondents were aware of the plant by its local name, and a significant majority of them (83%) possessed knowledge of its traditional medicinal use highlights its socio-cultural significance. Additionally, the species is well featured in local languages, folklores, and traditional medicinal texts consulted locally by learned healers. Such culturally important species are referred to as 'cultural keystone species' (Cristancho & Vining 2004, Garibaldi & Turner 2004), a concept with implication for biodiversity conservation (Garibaldi & Turner 2004).

Neopicrorhiza is commonly prescribed in the study area for treating upper respiratory tract illnesses (e.g., sore throat, cough and cold) and gastrointestinal disorders (e.g., gastritis, stomachache, diarrhea), which are prevalent in rural areas. It is also used by knowledgeable individuals in the study area to treat more complex health problems like diabetes and hypertension, often associated with lifestyle and dietary change (Dhimal *et al*. 2019, Shrestha *et al*. 2020). These results corroborate with findings from previous studies conducted in various parts of Nepal (Bhattarai 2006, Ghimire & Nepal 2007, Ghimire *et al*. 2022, Kafle *et al*. 2018, Manandhar 2002). However, it's worth noting that there are additional medicinal uses of the plant reported in other regions of Nepal but not recorded from the study area, such as treating fever, eye diseases, paralysis, and bites from scorpions and snakes (Bhattarai *et al*. 2006, Ghimire *et al.* 2005, Manandhar 2002), as well as for managing conditions associated with bile imbalances in the traditional amchi medicine system (Ghimire *et al*. 2022).

The study reveals a lack of significant associations between awareness and geographic location or ethnicity, indicating that people from different village clusters or ethnic groups possess similar levels of knowledge about the plant's use for at least one disease/disorder category. However, in terms of total and mean use-reports, people living in Dole – Luja cluster stand out with the highest citations. This could be related to their intermediate geographical location, which likely facilitated knowledge exchange with people from both higher (Machhermo – Gokyo) and lower (Khumjung – Phortse) elevations.

Women were the primary beneficiaries of this knowledge system, with 90% of female respondents being aware of the plant's use compared to about 77% of male respondents. This suggests that the indigenous knowledge system in the region is predominantly held by women. In Khumbu Valley, the female population outnumbers the male population among individuals over the age of 40, which can be attributed to the migration of many males to urban areas within Nepal and abroad in search of employment and educational opportunities (NPHC 2021).

We found variations in awareness of plant use and the number of use-reports cited for different disorders among respondents according to age. Despite high socio-cultural importance of the species, the younger generation (below 40 years of age), whose livelihoods are primarily dependent on tourism, appears reluctant to continue traditional medicinal practices. This has been reflected from our results that out of 57 respondents of this age group about 44% were unaware about the use of the species, whereas cent percent of respondents (n = 88) of age more than 40 years had knowledge about the traditional medicinal use. Even among those who were aware, the use citations decreased significantly among the younger age groups (Table 3). Several studies report rapid loss of traditional knowledge and practices in indigenous societies due to change in socio-cultural practices and economic transformation in pursuit of modern ways of life (Atreya *et al*. 2018; Geng *et al*. 2016). In addition, the loss of traditional knowledge has also been attributed to loss of biodiversity and less availability of resources (Atreya *et al*. 2018). The SNPBZ is an important tourist destination in Nepal receiving 30–60 thousand annual visitors (IUCN 2020). Tourism sector in Khumbu Valley has provided different types of services, including seasonal restaurant, hotel, porterage, tourist guide, camping, mountaineering, summit expedition, and so on. The tourism industry has provided significant economic opportunities to the younger population of the Khumbu region, which has transitioned from collecting and trading medicinal and aromatic plants to working in the tourism sector. However, this shift in livelihoods has contributed to a decline in traditional knowledge preservation.

In such situations where younger generation is reluctant to peruse traditional practices, preservation of traditional knowledge and effective methods for knowledge transfer within the society, along with resource protection, become essential. Medicinal and aromatic plants growing at higher elevations are sensitive to harvest (Chapagain *et al*. 2019, 2020; Ghimire *et al*. 2008b; Poudeyal *et al*. 2019), and overharvesting poses a significant threat to the population of many such species in Nepal (Chapagain *et al.* 2021, Ghimire & Nepal 2007, Ghimire *et al*. 2005, Pyakurel *et al*. 2018). In Khumbu Valley, harvesting of very small amount of *Neopicrorhiza* strictly for local use probably may not pose great threat. Based on our interviews, no trade of dry rhizomes was recorded, the harvesting of rhizomes was mainly for local use as medicine. Harvesting *Neopicrorhiza* for trade was found to be significantly reduced after the establishment of the national park, but concerns remain regarding overharvesting by visitors and outsiders, particularly during specific events or festivals. Particularly in Gokyo, the harvest of the plant was highest during the Hindu festival 'Janai Purnima', a full moon day that falls according to Bikram Sambat calendar in the month of Shrawan/Bhadra (July/August) at which time devotees gather to perform their ancient rites. Thousands of people (both local and outsiders) used to visit the religious Gokyo Lake during this festival and during which time they also harvest rhizomes of *Neopicrorhiza*. Studies have shown that in a harsh environment such clonal herbs invest less in sexual structures compared to vegetative ones to compensate for the limited time of the favorable growing season and the nutrient availability (Eriksson 1989, Ghimire *et al*. 2005). A previous study (Bhattarai *et al*. 2009) stated that the increasing tourism industry along with the increasing use of the animal as a means of transportation of goods pose great threat to such herbs.

Harvesting time is also crucial, as harvesting immature plants can be detrimental to the population. Many elderly respondents in Khumbu have suggested that for alpine herbs like *Neopicrorhiza* the harvesting should be done at the end of growing season (about September-October) to obtain fully mature rhizome having high medicinal potency. At this period the plant also completes fruiting and seed dispersal. However, for majority of the young harvesters the preferred harvesting time remains to be the period when the plant is in early growing stage (chiefly in June-August). The preference of harvesting during premature stage is that during which time the soil remains moist due to the monsoon rain thus making it easy to uproot rhizomes. When the soil is moist, rhizomes are harvested by pulling up of the whole plant. In dry conditions, simple hoe (kuto) or spade should be used for digging up of the rhizomes.

Conclusion

Local people in the Khumbu region have greatly benefitted from the use of *Neopicrorhiza*, a traditional medicinal plant. The level of familiarity with its applications varies among the local population, with the elderly being particularly experienced in using the plant for treating ailments such as sore throat, cough and cold, gastrointestinal disorders, hypertension, and diabetes. Elderly people are also well-familiar with the proper harvesting season. However, this knowledge is not effectively passed down to the younger generation. The rise of tourism-related businesses is contributing to the erosion of local ethnic knowledge regarding the use and sustainable management of plant resources, especially among the youth. Proper conservation strategies need to consider both traditional knowledge and sustainable harvesting practices to protect these valuable resources in the context of changing socio-economic and cultural landscapes in the region. It is essential to raise awareness among local people about the value, applications, and sustainable collection of valuable medicinal plants like *Neopicrorhiza* to preserve this traditional knowledge and resource for future generations.

Declaration

Ethics approval and consent to participate: This study was approved by the Department of National Parks and Wildlife Conservation, Government of Nepal because the study was conducted in Sagarmatha National Park of Nepal.
Consent for publication: Not applicable.
Availability of data and materials: All the data are available in this manuscript.
Competing interests: Not applicable.
Funding: The research has been funded by the University Grants Commission of Nepal (Grant Id: CRG-76/77- S&T-3). The funding body has no role in the study design, data collection, analysis and writing of a manuscript.
Authors' contributions: Narayan Prasad Ghimire collected the data and wrote the original manuscript; Arati Gurung, Kushal K.C. and Hari Datta Bhattarai participated in the field survey and collected the data; Mukti Ram Paudel collected the data, and performed the preliminary analysis and interpretation; Mukti Ram Poudeyal first analyzed and interpreted the preliminary data, reviewed and edited the manuscript; Suresh Kumar Ghimire designed the field method, re-analyzed and interpreted the data, and thoroughly reviewed and edited the original manuscript. All the authors approved the manuscript.

Acknowledgements

We gratefully acknowledge the University Grants Commission, Nepal for financial support. We thank Mr. Basu Dev Poudel for the preparation of map of the study area. We are also thankful to Department of National Park and Wildlife Conservation (DNPWC), and Sagarmatha National Park and Buffer Zone (SNPBZ) authorities for granting the research permission. We thank local people for sharing their valuable knowledge about the studied species.

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