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Swertia chirayta, a Threatened High-Value Medicinal Herb: Microhabitats and Conservation Challenges in Sikkim Himalaya, India

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Assessing the impact of threats, identifying favorable growing conditions, and predicting future population scenarios are vital for the conservation and management of threatened species. This study investigated the availability, microhabitat characteristics, threat status, and community associations of Swertia chirayta*, a highly threatened Himalayan medicinal herb, in 22 populations in Sikkim, India, using the vertical belt transect method. Of the 14 microhabitats identified, open grassy slope emerged as the most favorable and wet grassy slope as the least favorable for* S. chirayta*. The species was dominant in 8 of the 10 major plant communities identified. Among 9 major types of disturbance identified, human movement and collection of non-timber forest products appeared as the biggest threats to* S. chirayta*. Disturbances significantly affected the availability of the species.* S. chirayta*, though under high anthropogenic threat, maintains high microhabitat pliability, which is vital for its conservation and management, provided immediate conservation measures are taken.*

Keywords: *Chirayta; disturbance; habitat pliability; management; population; regeneration; vulnerability; Sikkim.*

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Introduction

In recent years, extraction of natural resources, economic pressure, inappropriate forest management policies, inadequate knowledge, and insufficient legislative initiatives on sustainable use of bioresources (Wickens 1991; Uniyal et al 2011) have resulted in depletion of biodiversity (Badola and Aitken 2010). In addition, land-use changes and human-driven habitat fragmentation and destruction have become one of the biggest threats to existing ecosystems and a leading cause of species extinction (Duffy et al 2011; Yokogawa et al 2013). Estimating extinction risk and future population size based on current population structure (Guedje et al 2003), assessing the effect of habitat deterioration on population dynamics (Colling and Matthies 2006), and understanding the effects of natural and human-made changes to habitats (Hegland et al 2001) and their responses to disturbances (Ticktin 2004) are the most suitable practical approaches to determining the impact of exploitation.

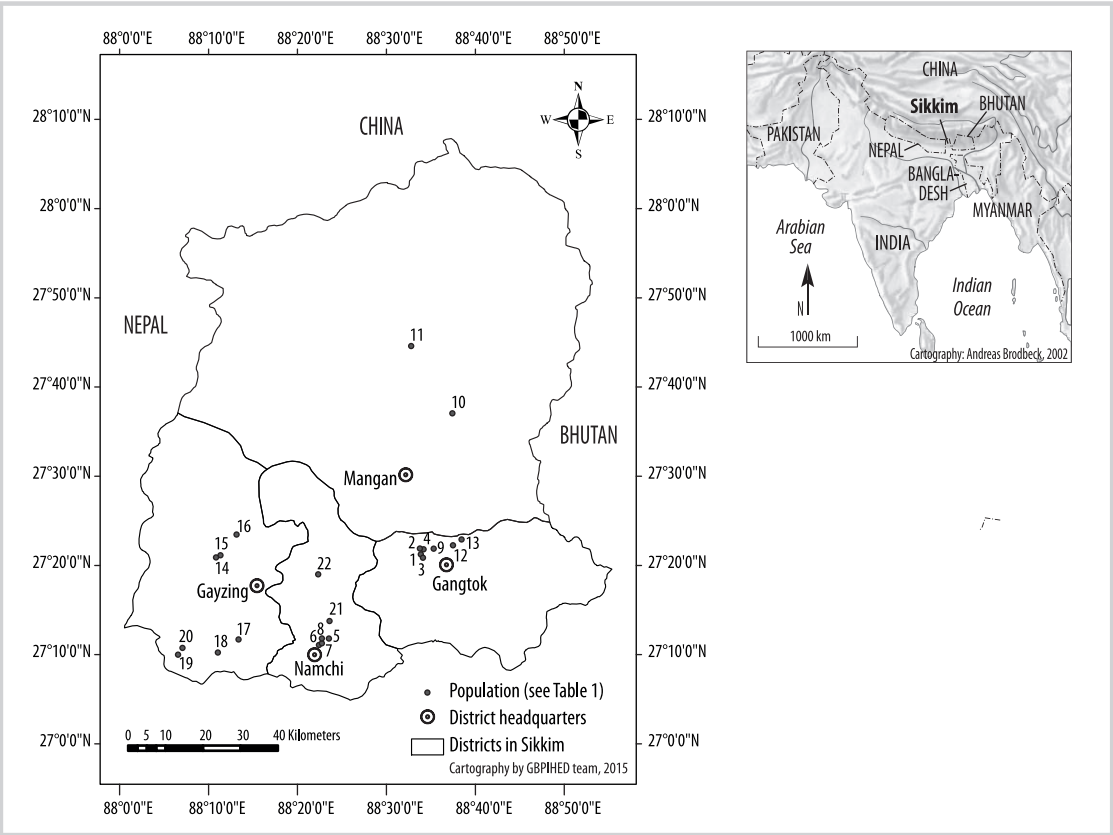
Studies have found that species performance varies among microhabitats (Shrestha and Jha 2010; Pradhan and Badola 2012). Species with habitat specialization and a narrow range of microhabitats have greater risk of extinction than species with a broad habitat range (Brys et al 2005; Samant et al 1996). Therefore, knowledge of threatened plants' microhabitat requirements would help in planning their conservation and management (Hegland et al 2001; Colling and Matthies 2006; Kalliovirta et al 2006; Pradhan and Badola 2012). This necessitates undertaking microlevel habitat assessment, which can help determine the performance of a species under different conditions and provide information on its ecological requirements (Hegland et al 2001; Pradhan and Badola 2012).

To address these critical issues, our study focused on the highly threatened *Swertia chirayta* (Roxb.) Karst. (Gentianaceae) (hereafter chirayta), a perennial herb indigenous to the temperate Himalaya that grows in Afghanistan, Bhutan, India, Nepal, and Pakistan from 1200–3000 masl. Chirayta has high pharmacological importance (Joshi and Dhawan 2005; Pradhan 2011). The entire plant is used in traditional medicine and in many herbal drugs such as Diabecon, D-400, Himoliv, and Melicon V (Pradhan 2011). Because of high commercial demand (Badola and Pal 2002; Pradhan 2011), chirayta has been vigorously harvested in different parts of the Himalaya (Anonymous 2008; Phoboo and Jha 2010), leading to tremendous pressure on its natural populations. Indiscriminate extraction has made the species vulnerable in Nepal (Phoboo et al 2010), and it has been prioritized for immediate conservation in India (Badola and Pal 2002). Despite its high conservation value, little quantitative

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FIGURE 1 Map of the study area and chirayta populations. (Map by Johny Lepcha)



information exists on its availability, microhabitat diversity, the impact of exploitation, and the degree to which it is threatened. Better data on chirayta populations (Guedje et al 2003) in the Himalayan region are needed to assess the conservation status of this important species.

This study aimed to (1) evaluate the current status of and threats to chirayta populations, (2) identify its microhabitat characteristics and community structures, (3) assess the likely future impacts of disturbances and of the presence of associate species, and (4) develop recommendations for its conservation and management.

Study area and research methods

Our study took place from May 2005 to November 2006 in the Sikkim Himalaya, India (Figure 1), which lies between 27°00′46″ and 28°07′48″ north latitude and 88°00′58″ and 88°55′25″ east longitude and from 220 to 8598 masl, covering an area of 7096 km^2 (0.2% of the land area of India).

Before doing the field studies, we conducted an extensive literature review and consulted with state forest department field staff, villagers, and experienced harvesters and herders to identify possible distribution areas of chirayta in Sikkim. Subsequently, we conducted intensive field surveys and explored 22 populations with elevations from 1500–3000 masl in different parts of Sikkim (Figure 1). Populations were distinguished based on their separation by a physical barrier such as a river, mountain, or aspect or by a distance of at least 500 m (Osunkoya 1999).

For each population, we used the vertical belt transect method (Michael 1990) for sampling, in which a 20 × 150-m plot was marked and divided into 3 subplots (20 × 50 m). In each subplot, the density of chirayta was determined using 10 random quadrats (1 × 1 m), which created 30 quadrats for each population. Within each quadrat, we noted the microhabitat occupied by chirayta and enumerated the individuals of associated species.

Density, abundance, frequency percentage, relative density, relative frequency, importance value (Mishra 1968; Michael 1990), and diversity index (Shannon and Weiner 1963) were calculated for the species. Pearson's correlation was used to assess the relation of different parameters among themselves as well as with the elevation and geographic coordinates. We used 1-way analysis of variance ($\alpha = 0.05$) to compare the differences in means of density between different populations and microhabitats, and the significant differences were tested using the Bonferroni test ($P < 0.05$).

Based on an abundance-to-frequency ratio (Whiteford 1949), we analyzed distribution patterns. The value <0.025 indicated regular distribution, 0.025 to 0.05 indicated random distribution, and >0.05 indicated

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contagious distribution (Curtis and Cottam 1956). We observed various natural and anthropogenic disturbances: collection of fodder, fuelwood, non-timber forest products, and chirayta itself; agriculture; grazing; road clearing; human trampling (due to footpaths passing through the population sites); and landslides. Multiple disturbances were observed in some of the sites. We combined all disturbances for a site into a disturbance index (DI) by taking into account the presence or absence of disturbances. We assigned a value of 1 to each disturbance present, and calculated the DI for each site as well as cumulatively for each disturbance, as follows:

$$\text{DI (for each popultion)} = \frac{\text{Sum of disturbances in each population}}{\text{Total number of populations}} \quad (1)$$

$$\text{DI (for each disturbance)} = \frac{\text{Sum of each disturbance in entire populations}}{\text{Total number of populations}} \quad (2)$$

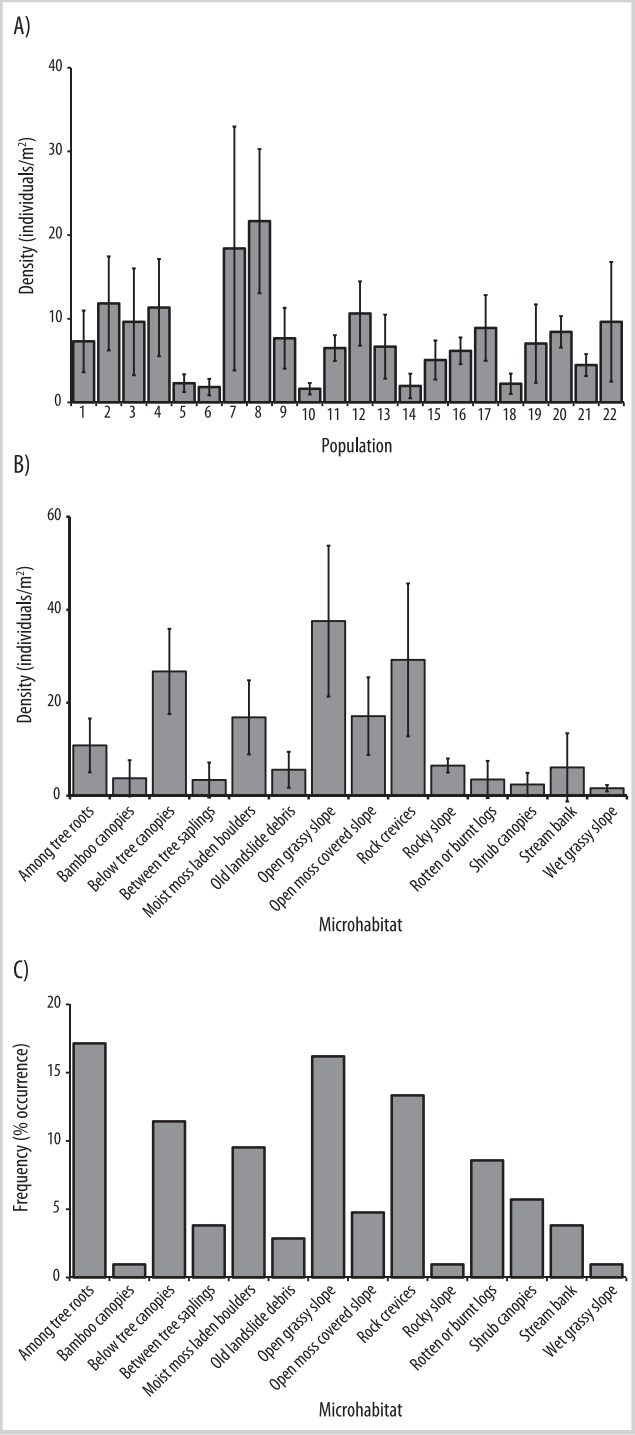
We clustered the DI values using K-mean clustering into 3 clusters (low = 0–0.30, moderate = 0.30–0.60, and high =>0.60), which were used to interpret the availability of the chirayta. Further, the effect of disturbance level on chirayta density was interpreted using box plots.

Results

We recorded 5136 individuals of chirayta in the 22 populations, growing in diverse microhabitats (*Supplemental material*, Table S1: http://dx.doi.org/10.1659/MRD-JOURNAL-D-14-00034.S1). Chirayta density varied among the populations (Figure 2A); populations 10 and 8 recorded the lowest (mean = 1.63, SE = 0.69 individuals/m^2) and the highest (mean = 21.67, SE = 8.62 individuals/m^2) average density, respectively. Elevation ($r = 0.016$), latitude ($r = -0.201$), longitude ($r = 0.178$), soil pH ($r = 0.084$), species richness ($r = -0.04$), and species diversity ($r = -0.324$) had a nonsignificant effect on chirayta density; humus depth significantly affected the availability of the species ($r = 0.372$; $P < 0.10$) (Figure 3). The number of associate species (which ranged from 2 to 11) and the slope (which ranged from 25° to 65°) also revealed insignificant correlation with chirayta density. Chirayta showed 100% frequency of occurrence in 59% of the total populations, which increased significantly with ascending elevation ($r = 0.423$; $P < 0.05$) (Figure 3), but the degree slope and frequency showed insignificant correlation.

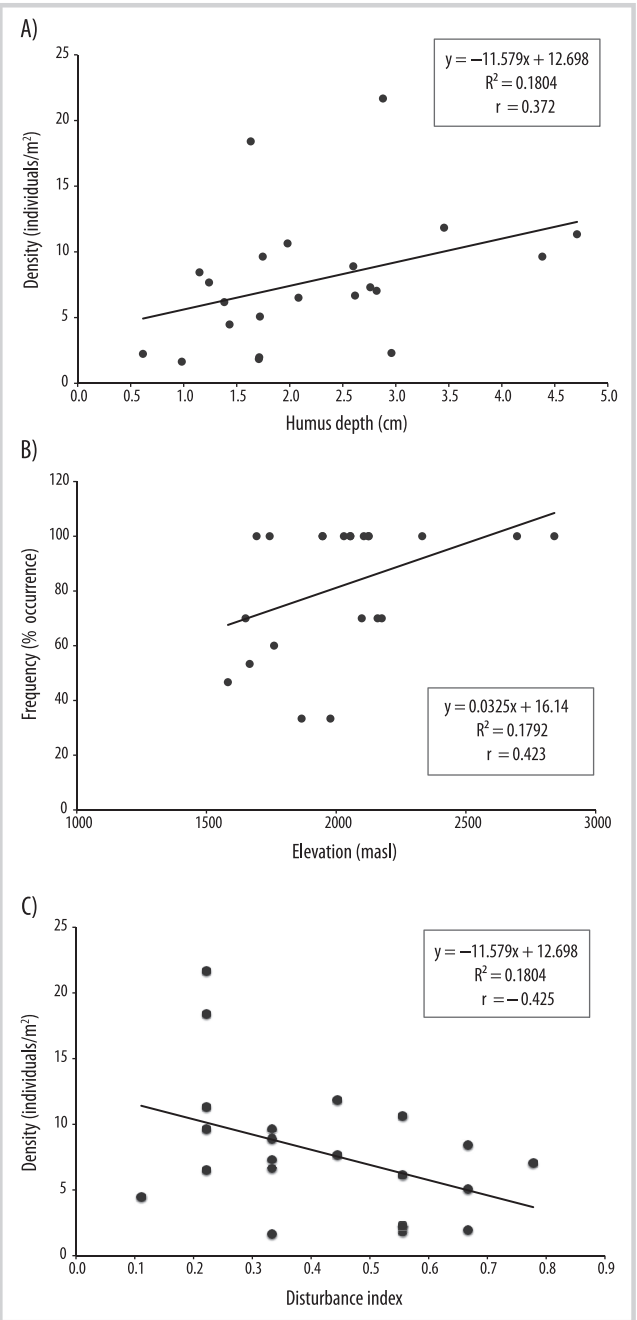
The relative density of chirayta ranged between 8.27% (site 6, dry grassy slope) and 78.38% (site 12, shrublands) and significantly correlated with elevation ($r = 0.511$; $P < 0.02$). With regard to relative frequency, site 1 (24.79%) recorded the lowest value and site 19 (65.22%) recorded the highest value. The abundance-to-frequency ratio marked contagious distribution of chirayta in the majority of the populations; none of the populations

FIGURE 2 *Swertia chirayta* (A) density per population; (B) density per microhabitat; (C) frequency of occurrence of microhabitats in the Sikkim Himalaya. Error bars in sections A and B indicate the standard error.



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FIGURE 3 Effect of different environmental variables and disturbances on *Swertia chirayta* density and frequency of occurrence in the Sikkim Himalaya.



showed regular distribution of chirayta, revealing its distribution to be patchy (Table 1).

Table S2 (*Supplemental material*, Table S2: http://dx.doi.org/10.1659/MRD-JOURNAL-D-14-00034.S1) shows the phytosociological attributes of chirayta. The dominant associate species varied among the populations; however, *Ageratina adenophora* (synonym *Eupatorium adenophorum*), *Gleichenia gigantea, Anaphalis margaritaceae,* and *Artemisia vulgaris* were the main dominant associates. *A. adenophora*, a common invasive species (Kunwar 2003), showed greater ecological amplitude (700 m) compared to other species. Based on importance value, we identified 10 ground community structures in 17 populations; for the remaining 5 populations, chirayta was present without associate species (*Supplemental material*, Table S2: http://dx.doi.org/10.1659/MRD-JOURNALD-14-00034.S1). Chirayta was dominant in 8 of the 10 identified ground community structures. Altogether we identified 14 microhabitats for chirayta (Box 1).

BOX 1: Chirayta microhabitats in Sikkim Himalaya

(1) Among tree roots, (2) bamboo canopies, (3) below tree canopies, (4) between tree saplings, (5) moist moss-laden boulders, (6) old landslide debris, (7) open grassy slopes, (8) open moss-covered slopes, (9) rock crevices, (10) rocky slopes, (11) rotten or burnt logs, (12) shrub canopies, (13) stream banks, (14) wet grassy slopes.

The number of microhabitats per population ranged from 1 to 8 (*Supplemental material*, Table S2: http://dx.doi.org/10.1659/MRD-JOURNAL-D-14-00034.S1). We recorded the highest chirayta density in open grassy slopes (mean = 37.57, SE = 16.24 individuals/m^2; $P < 0.001$), rock crevices (mean = 29.23, SE = 16.45 individuals/m^2; $P < 0.05$) and below tree canopies (mean = 26.73, SE = 9.17 individuals/m^2; $P < 0.05$) (Figure 2B). In the 14 microhabitats identified, chirayta was found to be growing most frequently among tree roots (17.14%) followed by open grassy slopes (16.19%), whereas bamboo canopies, rocky slopes, and wet grassy slopes were the least preferred microhabitats (Figure 2C).

Of the 9 major types of disturbances identified for chirayta populations (Figure 4A), human movement and collection of non-timber forest products appeared as the greatest threats, whereas landslides, grazing, and agriculture were not common. The number of disturbances per population ranged between 1 and 7; we did not observe all 9 types of disturbances together in any of the populations. Of the 22 populations, population 19 recorded the highest number of disturbances, followed by populations 14, 15, and 20 (Figure 4B). K-mean clustering grouped these populations into a high disturbance cluster (above 0.67 mean DI value); the remaining populations were grouped in 2 clusters with low (0.11 to 0.22 mean DI value) and moderate (0.33 to 0.56 mean DI value) disturbance; the majority of the populations (12) showed moderate mean DI value (Figure 4B).

Disturbance significantly affected chirayta density ($r = 0.425$; $P < 0.05$) (Figure 3) but revealed nonsignificant effect on its frequency of occurrence ($r = -0.049$, ns). The availability of chirayta in different populations is highly influenced by aspect; the maximum average chirayta density

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TABLE 1 Distribution of *Swertia chirayta* at different population sites in the Sikkim Himalaya.

Population #	Number of associates	Relative density (%)	Frequency (%)	Relative frequency (%)	Abundance to frequency ratio
1	8	23.30	100.00	24.79	0.073
2	11	42.21	100.00	32.26	0.118
3	5	56.67	70.00	31.82	0.197
4	5	66.93	100.00	60.00	0.113
5	2	12.85	70.00	58.33	0.047
6	4	8.27	46.67	35.90	0.084
7	2	61.81	53.33	61.54	0.647
8	3	51.88	100.00	71.43	0.217
9	5	50.44	100.00	51.72	0.077
10	3	13.92	60.00	25.71	0.045
11	3	61.71	100.00	46.88	0.065
12	5	78.38	100.00	43.48	0.106
13	5	44.64	100.00	47.62	0.067
14	6	43.38	33.33	38.46	0.177
15	7	36.36	100.00	33.33	0.051
16	7	33.58	100.00	35.29	0.062
17	7	37.19	100.00	43.48	0.089
18	4	29.91	33.33	33.33	0.201
19	3	69.87	100.00	65.22	0.070
20	1	55.97	100.00	50.00	0.084
21	7	13.23	70.00	27.63	0.091
22	7	77.07	70.00	53.85	0.188

was recorded along a west-facing slope (20.03 individuals/m^2), and cumulatively, the highest frequency of occurrence (100%) was recorded along a north-facing slope (Figure 5), indicative of better growing conditions. Figure 6, a box plot showing density by disturbance level, indicates the greatest density of chirayta in minimally disturbed areas.

Discussion

In our study, chirayta showed either contagious or random distribution, comparable to the findings of Bhatt et al (2006). This is the most common type of distribution in natural conditions because of significant variations in environmental conditions (Odum 1971). Our most interesting observation was that elevation, latitude, longitude, soil pH, species richness, species diversity, and degree of slope had little or no effect on chirayta.

Similar to other studies (Maliakal-Witz et al 2003; Kalliovirta et al 2006), this study revealed that the quality of microhabitat significantly affects the availability and performance of the species. For example, chirayta performed well in open habitats such as open grassy slope, old landslide debris, and open moss-covered slope, possibly because of the low interspecific competition for sunlight, moisture, and nutrients (Kalliovirta et al 2006). We observed fewer chirayta individuals in wetland habitats. This might be due to the high moisture levels increasing the chances of fungal attack (Fidelis et al 2008), or to uprooting of seedlings and washing away of seeds, or to soil erosion prohibiting the humus accumulation required for seedling emergence and growth. Microhabitat diversity significantly affects species abundance (Yu et al 2008); this means that populations with a single microhabitat are more vulnerable to extinction. However, we discovered that chirayta has high microhabitat

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FIGURE 4 Level of threat to *Swertia chirayta* in the Sikkim Himalaya (A) by type of disturbance; (B) by population.

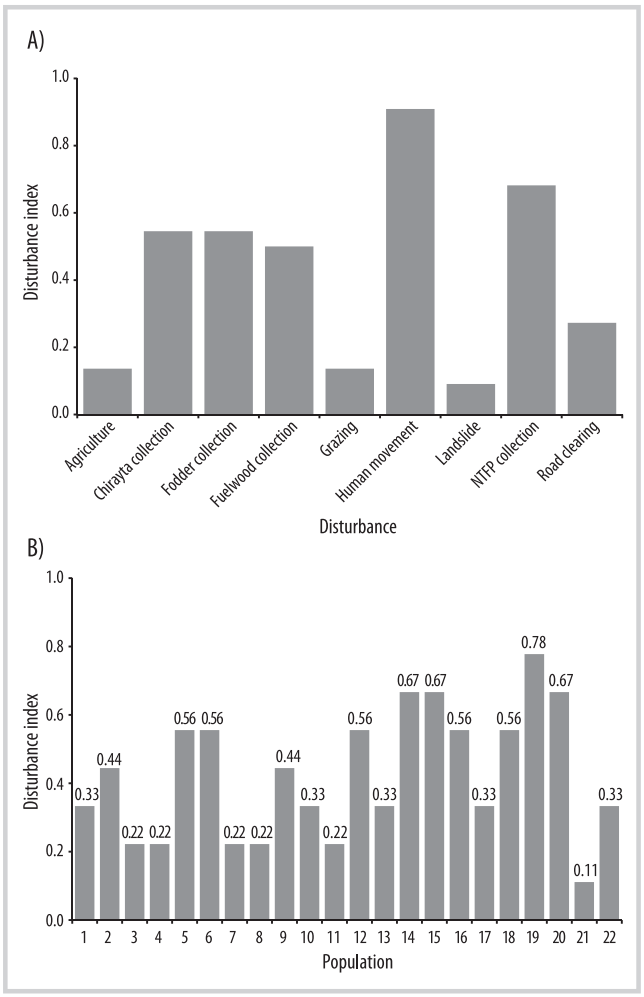
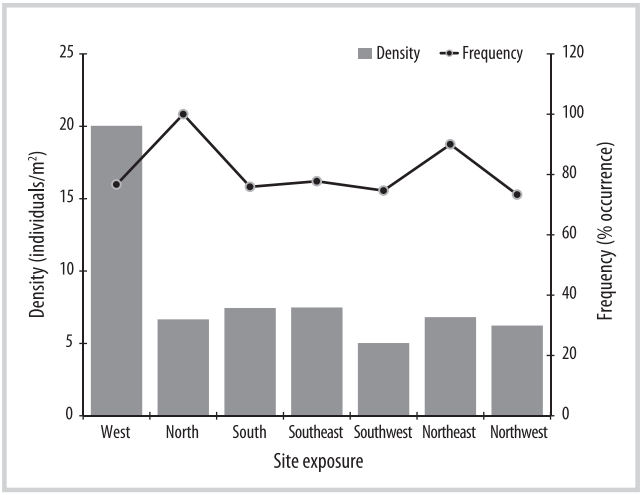


FIGURE 5 Effect of site exposure on the density and frequency of *Swertia chirayta* in the Sikkim Himalaya.



pliability; this is contrary to the general assumption that endangered species are often habitat specific and thus vulnerable to habitat deterioration (Brys et al 2005).

Anthropogenic pressures threatening chirayta availability in Sikkim include collection of non-timber forest products, fodder, and fuelwood; grazing; and habitat degradation during road clearing. Higher intensity of forest resource use and grazing results in trampling and damaging of chirayta plants or plant parts, thereby threatening the existence of the species. Change in land use, in particular the intensification of agriculture, is a major cause of declining plant populations, as chirayta plants are uprooted along with other weed species while preparing land for agriculture. This may increase the future threat to chirayta in those sites, because constant disturbance would prevent seedlings from maturing; habitat degradation is regarded as the major cause of species extinction in human-modified landscapes (Yokogawa et al 2013). Road clearing, especially along slopes, had an insignificant effect on chirayta availability, indicating its resilience to these disturbances, because such activities create open conditions suitable for the regeneration of important species (Yu et al 2008) like chirayta; however, this may also not guarantee the sustainability of the species in the longer run. For example, populations 7 and 8 (both occupying open grassy slopes near roads) recorded the highest chirayta density, but juveniles were more abundant than adults in both populations. If the proper conservation measures are not taken for these populations and the juveniles are destroyed before they complete their life cycle, the populations may become vulnerable to extinction in this area, and indeed elsewhere as well.

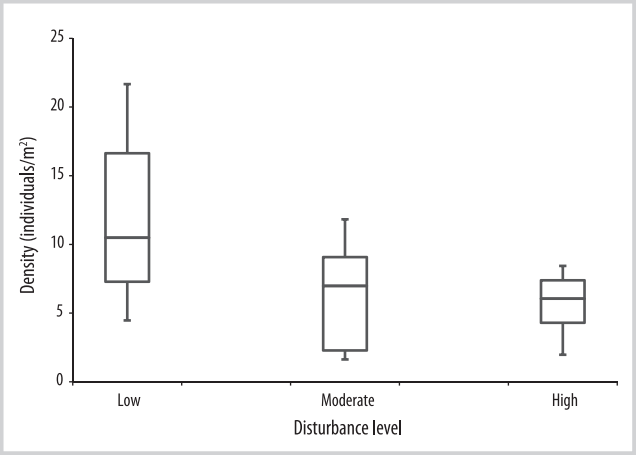
Our study indicated that past anthropogenic disturbances can also be a threat to chirayta, because human disturbances lead to faster replacement of native species by invasive species (Yan et al 2001; Kunwar 2003). The ban on grazing (1998) and medicinal plant collection (2001) by the state government, and the consequent removal of cattle from forest areas in Sikkim, promoted the growth of unpalatable species such as *Edgeworthia gardneri*, *A. adenophora*, *G. gigantea*, and *Osbeckia stellata*. These species invaded the open areas, a suitable niche for chirayta, restricting the species to small pockets and leading to population fragmentation, thus making the species more vulnerable to extinction, because chirayta is a comparatively slow-growing plant and cannot compete with the unpalatable species in the long run. Further, collection of chirayta for domestic use and illegal trade from these areas, without considering the individual plants' age, and collection of juveniles for nursery plantation has also led to population decline in areas closer to human settlements.

Natural factors such as landslides also contribute to the deterioration of chirayta in Sikkim (populations 11 and 13). There is a chance of increasing species abundance from current moderate levels to high in such landslide-affected areas if the landslide does not become active in the future and bury the juveniles and the dispersed seeds under deep soil in these populations.

Population 11, explored at the highest elevation (2841 masl) in north Sikkim, was completely isolated from other

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FIGURE 6 Effect of disturbance level on the density of *Swertia chirayta* in the Sikkim Himalaya.



populations. Such isolated populations are vulnerable to genetic drift and inbreeding, leading to decreased fitness of individuals (Hooftman et al 2004), and face increased risk of extinction (Colling and Matthies 2006). This particular population is very important, as the area remains under snow for almost 3 months a year; to overcome this, the species might have developed some special adaptive mechanisms and undergone genetic modifications that need detailed ecophysiological study. Adaptation of plants to a specific environment makes them susceptible to various environmental pressures (Korner 1999), suggesting that such populations need special conservation measures, and basic knowledge on reproductive biology and cytology is essential in formulating those measures (Chakraborty and Mukherjee 2009).

In this study, we observed that chirayta is not selective in forming associations; rather, it grows evenly with other species existing in the area and is not or is very little affected by their presence. Many studies report the negative effect of accumulation of litter on the seedling recruitment and survival of plants (Kalliovirta et al 2006), whereas our study indicated that good humus depth helps to maintain greater availability of chirayta.

Conclusion and recommendations

Sikkim offers high potential for and greater availability of chirayta compared to the central and northwestern Himalaya (Bhatt et al 2006). The identification of 14 microhabitats for chirayta in our study suggests that the species maintains high microhabitat pliability, and that is beneficial for its conservation and management. In the majority of the populations, chirayta was available near to human settlements or in areas where human interference exists. This indicates the resiliency of the species to minor habitat disturbances, but it can be affected by the complete degradation or modification of a habitat, which can be conceived as the only major ultimate threat to chirayta in the Sikkim Himalaya.

The relationship between habitat and population characteristics also needs to be considered in wider dimensions, especially when management steps are needed to enhance the regeneration of this threatened species (Kalliovirta et al 2006). The better performance of the species in nature and higher secondary metabolism content (alkaloid content) compared to in vitro-cultivated plants (Wawrosch et al 2005) suggests a primary focus on conservation in the species's natural habitat. However, artificial cultivation is also recommended, because the high market demand for the species calls for the development of improved strains to make cultivation and processing economically profitable (Raina et al 2013). Obtaining an improved strain requires understanding of the species's breeding system (Raina et al 2013), and this is strongly recommended for future study.

The following chirayta conservation and management steps are recommended:

1. Identify suitable habitats and healthy populations of *Swertia chirayta* through research and ensure its conservation and protection through policies and management practices.
2. Conserve and restore the degraded habitat through public participation and ensure that such restoration programs maintain or enhance the availability of chirayta in the area.
3. Develop cost-effective and feasible cultivation techniques for the species ensuring marketing and better economic returns to the local people, which will certainly reduce harvesting pressure on the wild populations.
4. Minimize human interference in the areas of chirayta's natural occurrence through legislation, which will help the species to regenerate without stress. Constant monitoring will ensure better growth and regeneration of the species.
5. Frame policies focusing on the major threats to natural habitat that lead to habitat degradation, fragmentation, and loss; ensure long-term survival of the species in the area through proper habitat management and conservation.

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Supplemental material

TABLE S1 Characteristics of *Swertia chirayta* population sites and their broader habitats in the Sikkim Himalaya.
TABLE S2 Phytosociological attributes of populations of *Swertia chirayta* in the Sikkim Himalaya.

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