CHAPTER 4

Population Studies and Habitat Assessment

4.1 Introduction

In recent decades, the use and collection of medicinal plants have gone up from the subsistence level to large scale commercial extraction endangering their natural populations (Ghimire *et al.*, 2008; Badola and Aitken, 2003, 2010). In addition, overgrazing, pathogens, herbivores, seed predation (Albert *et al.*, 2005), etc., are also responsible for the reduction in population size of important medicinal plant species. Natural disturbances such as landslides and avalanches cause habitat alteration, degradation and fragmentation, leading to population isolation and reduction in population size or loss in case of rare plants in mountains (Badola and Pradhan, 2010) particularly for the species having small populations (Coates *et al.*, 2006). Habitat degradation may cause inbreeding and genetic drift in plant species thereby affecting their population viability as well as the survival probabilities of rare species (Hooftman and Diemer, 2002; Hooftman *et al.*, 2004). At the same time, plant fecundity may be reduced due to habitat degradation, fragmentation and destruction of plant populations (Brys *et al.*, 2003). In majority of cases in high value medicinal plants, the unsustainable *in-situ* harvesting to meet raw material demand of pharmaceuticals (Badola and Pal, 2002; Badola and Aitken, 2003, 2010; Butola and Badola, 2008a) has resulted into habitat loss and/or habitat degradation, population fragmentation/isolation, and loss of genetic diversity. Despite of these facts, the studies on the population ecology of important medicinal plants are least considered especially on Himalayan taxa (Ghimire *et al.*, 2008).

The successful conservation and effective management planning of the threatened plant species largely depends on an understanding of the effects of the natural and/or man-made changes on habitats (Hegland *et al.*, 2001), their ecological requirements and demography of the existing populations (Kalliovirta *et al.*, 2006), and their responses to disturbances (Ticktin, 2004). The microhabitat of the site plays a significant role in the successful regeneration of plant species (Tilman, 1993; Hegland *et al.*, 2001; Jensen and Meyer, 2001; Overbeck *et al.*, 2003) and identification of which is very important for the species conservation (Sypros *et al.*, 2008). The nature of microhabitats is significantly related to the seed viability potential, which in turn decides the regeneration future of a population (refer chapter 6). Insufficient knowledge regarding the effects of disturbance on plant communities and plant populations are the main constraints in designing appropriate management plans, which complicate the conservation initiatives (Fidelis *et al.*, 2008). Envisaging the extinction risk and the future population size based on current population structure, growth and fecundity is the most suitable practical approach in assessing the impact of exploitation (Guedje *et al.*, 2003); which can be used as an appropriate tool in designing future conservation and management planning for threatened species.

Swertia chirayita (Roxb. ex Fleming) H. Karst (family Gentianaceae), a critically endangered medicinal plant species of the temperate Himalaya (Badola and Pal, 2002), bears high pharmacological importance (Joshi and Dhawan, 2005); the whole plant is used in traditional medicine (Kirtikar and Basu, 1984; Pradhan and Badola, 2008). Further, the plant is practiced in the preparation of herbal drug: Diabecon (Kohli *et al.*, 2004), D-400 (Sundaram *et al.*, 1996), Himoliv (Bhattacharya *et al.*, 2003); Melicon V (an herbal antiseptic and antifungal Veterinary ointment).

S. chirayita have been extracted traditionally both for domestic use, and rigorously for the commercial benefits especially in recent decades from different parts of Himalaya (Badola and Pal, 2002; Dutta, 2004; Olsen, 2005) leading to tremendous pressure on its natural populations. Despite very high conservation value of the species, there have been no efforts to replenish its source. The categorization of this important species as critically endangered (IUCN), endangered (Indian Red Data Book), critically rare and virtually endemic to Himalaya (Samant *et al.*, 1998), and vulnerable to Sikkim (Ved *et al.*, 2003a) has led the biodiversity conservationists internationally to come together to develop concern over the species. As an initiative, a forum of international experts had prioritized conservation of *S. chirayita* through cultivation at the top (Badola and Pal, 2002). However, so far, no initiative for systematic evaluation of the species in its natural habitats has been taken up, except targeting five populations for central and north-western Himalaya (Bhatt *et al.*, 2006). Further, the documentation on quantitative investigation relating to the impact of such exploitation on population dynamics of targeted taxa is very poor. There is hardly any literature available, including those from north-eastern Himalaya on the populations, community associations and micro-habitat diversity of the species hindering the suitable conservation framework. A complete lack of substantial population data pose a question on, hitherto, a perceived estimated assessment for categorization of *S. chirayita* under threatened status. Therefore, it is essential to have appropriate and sufficient data on populations representing species availability in Himalayan regions before exact criteria is fixed towards conservation status of this important species. At the same time, it would be vital to have micro level assessment of habitats of the species. It would equally be important to know whether different sites have *S. chirayita* as dominant species in represented communities or not. Whether some associates in a community are invasive and their quantitative presence may be detrimental to future regeneration of *S chirayita*, as vital clues to conservation planning? Also, it would be important to assess the site specific population data, with those covering micro-habitats and identifying communities and potential conservation threats. Such studies are imperative in understanding the relationship between the species to its community and habitats (Zotz and Schmidt 2006), and will be helpful in sustainable use as well as designing effective conservation management approaches for *in-situ* conservation of *S. chirayita* as a model species.

The objectives of the present study on *S. chirayita* in Sikkim Himalaya were to, (1) evaluate the status of populations of targeted taxa and associated potential threats; (2) assess the population structures and associates of *S. chirayita* in nature; and (3) identify the microhabitat characteristics and community structures of *S. chirayita*.

4.2 Materials and Methods

4.2.1 Study area

The present study was conducted in Sikkim Himalaya (Figure 2), India, which lies between 27^{0}04'46" and 28^{0}07'48" North latitudes and 88^{0}58" and 88^{0}55'25" East longitude in the altitudinal range of 220m asl to 8,598m asl, covering an area of 7,096 sq. km. (0.2% of the Indian sub-continent). It shares border with countries like Bhutan (*ca.* 30 km long represented by Pangolakha range in the east); Tibetan Autonomous Region of China (*ca.* 220 km long represented by Chola range in the east and Trans-Himalaya region in the north) and Nepal (*ca.* 100km long represented by Singhalila range in the west); however, towards the south, it shares border of *ca.* 80 km with Darjeeling district (West Bengal) of the Indian Union. The Sikkim is further represents two major river system viz., Tista and Rangit. It has peculiar climatic condition, as such; the temperature conditions vary from sub-tropical in the southern lower parts to cold deserts towards northern part. It lies very close to Bay of Bengal and is directly affected by moisture laden southwest monsoon making Sikkim one of the most humid places in the whole Indian Himalaya range.

4.2.2 Data collection

Initially, available literatures were reviewed thoroughly to generate idea on the distribution of the species in Sikkim Himalaya. Interaction with field personnel of state forest department, villagers and local folks helped focusing possible areas of species availability and accessibility for targeting the field studies. On the basis of extensive field surveys and accessibility to different sites for data collection, 22 populations along the Tista and Rangit river basins were identified within altitudinal range of 1500m asl to 3000m asl, lying between $27^0$09'58.2"and $27^0$44'34.7" N latitude and $88^0$06'35.2" and $88^0$38'28.08" E longitude in different parts of Sikkim Himalaya. Populations of *Swertia chirayita* were considered different primarily based on their non-continuity with each other by isolation, or by physical barriers such as rivers, mountain and aspects, and longer distances. Secondly, a site of the species located at least 500 m distance apart from other population was considered as different population (Osunkoya, 1999).

For each population, sampling was conducted through vertical belt transects methods following Michael (1990), in which a 20m x 150m long transect was marked as sufficiently large size to sustain a population (based on first hand experiences in Sikkim for the species). Each transect was sub-divided into three stands (20m x 50m), as lower, middle and upper stand. In each population, density of *Swertia chirayita* was determined by using random 30 quadrats of 1m x 1m size targeting 10 quadrates for each of 03 sub-sites or a stand in which presence and abundance of *S. chirayita* was recorded and counted. The associated species were also enumerated and the number of individuals was counted within each quadrat; the type of microhabitat in each quadrat was also identified and noted. The microhabitat characteristics were used for estimating microhabitat preference of *S. chirayita*. In addition, broad vegetation type at each major site was identified. At each sample site, altitude and coordinates were recorded using hand held GPS (Garmin *etrex*, USA); aspect and slope was recorded using inclinometer (Suunto, Finland). The humus depth was measured using standard ruler, taking 10 samples per stand.

4.2.3 Statistical analysis

Analytical features such as density, frequency percentage (Mishra, 1968), relative density, relative frequency (Jain and Rao, 1977), Importance Value Index (IVI) as a sum of relative density and relative frequency (Michael, 1990) was calculated focusing the ground vegetation only. Diversity index (Shannon and Weiner, 1963) was calculated to observe variability of associated species along different altitudes, which, were later used to relate with the density and availability of the targeted species. Pearson's correlation was used to assess the relation of different parameters amongst themselves and with the altitude. IVI value was used to identify the plant community structure in different population sites of *S. chirayita*. One way ANOVA ($\alpha = 0.05$) was used to compare the differences in means of density between the different population and microhabitats. If the differences was significant, Bonferroni test ($p<0.05$) was applied, and if the difference was non-significant, further testing was avoided.

The abundance to frequency ratio was used to interpret the distribution pattern of the species (Whiteford, 1949). The value <0.025 indicated regular distribution, 0.025 to 0.05 indicated random distribution and >0.05 indicated contagious distribution (Curtis and Cottam, 1956). The patchiness of the population was analyzed indirectly based on density and frequency. If the population has high density but low distribution frequency, then the population is considered to be patchy in nature, but if the population has high frequency then it is considered to be non-patchy in nature (Rokaya and Ghimire, 2004). On the basis of the availability, the density was classified as: nil (0 individual), low (<5 ind/m^2), medium (5 to 10 ind/m^2), high (10 to 20 ind/m^2), and very high (>20 ind/m^2).

4.3 Results

A total of 22 populations, along 1500 to 3000m asl, were identified for *Swertia chirayita* under present study in Sikkim Himalaya (Table 1). These sites represented the ridges, forest gaps, forest shrubberies/pastures, rocky slopes, open slopes, shrubberies, landslide debris, etc., having varied terrains / diverse landscapes (Photo Plate I). Broad habitats of these study sites were further characterized by the different types of temperate broad leaved mixed forests, with the presence of single conifer elements in some population sites except for Sc11, which represented the steep open rocky slope in temperate coniferous forest (Table 1). The *Castonopsis tribulides, Alnus nepalensis, Michelia lanuiginosa, Quercus lamellose,* etc were the dominant broadleaf tree species; the dominant conifer element represented the *Cryptomeria japonica* only. The ground associates of *S. chirayita* varied along the change in altitude of the population sites, but in general, the prominent ground associates were *Gleichinia gigantean, Osbeckia sikkimensis, Anaphalis* sp., *Eupatorium cannabinum, Dichroa febrifuga, Artemesia vulgaris, Hedychium spicatum, Eragrostis atrovirens, Swertia bimaculata,* etc. In Sc20 population (altitude: 2332 m), *Anaphalis* sp., was the only ground associates. Of these associates, *Gleichinia gigantean, Osbeckia sikkimensis, Eupatorium cannabinum, Artemesia vulgaris, Anaphalis* sp., were prevalent in majority of the population sites (Table 2). Under all sampling quadrats for 22 population sites for *S. chirayita*, 37 different associate species were recorded. The general slopes of the sites ranged between 25^0 and 65^0. The humus depth increased with increasing altitude of the population sites; whereas, the soil pH exhibited significant (r = -0.454; $p<0.05$) negative correlation with the altitude of the same.

Photo Plate I. Broad habitat of *Swertia chirayita* in Sikkim
A: Forest shrubberies; B: Forest-agriculture margin; C: Along/near the road;
D: Forest slope; E: Landslide area; F: Open grassy slope

The lowest species richness was recorded for the population Sc20 (at 2332m altitude), while the Sc2 population (1948 m altitude) exhibited highest species richness (Table 3). However, a negative correlation was established between the species richness and altitude of the population sites (r = -0.027). In general, all the populations showed low community plant density, which was maximum for Sc8 and minimum for Sc14 followed by Sc18 (Table 3). Further, the community plant density was significantly declined with increasing altitude (r = -0.406; $p<0.10$). The species diversity was recorded highest for the Sc6 and the lowest for Sc15 followed by Sc1 and Sc16 (Table 3), which showed insignificant negative correlation with the altitude of the population sites (r = -0.342). Observations revealed that the *S. chirayita* occurred at the margin of the forest or in the forest gaps and was barely noticed inside deep forest except few populations.

Variability in *S. chirayita* density in different population sites (Figure 3) and sub-sites within a population (Figure 4) was recorded. The existing differences in plant density within a sub-site in a population were high for some of the populations (Figure 4) indicating the patchy or clustered or fragmentary nature of distribution of *S. chirayita*. The plant density decreased insignificantly with the increasing altitude of the population sites; while, the degree slope and soil pH had insignificant positive effect on the average density of *S. chirayita*; however, the effect of humus depth was poorly significant (r = 0.372; $p<0.10$). Populations, viz., Sc5, Sc6, Sc10, Sc14 and Sc18 recorded very low average *S. chirayita* density (Figure 3); amongst different populations, the lowest and the highest average density was recorded for Sc10 (1.63 $\pm$ 0.69 ind/m^2) and Sc8 (21.67 $\pm$ 8.62 ind/m^2); Sc7 (18.40 $\pm$ 14.58 ind/m^2) followed Sc8 in plant density. Population sites such as Sc5, Sc6 and Sc18 were located near to the human habitation where different type of land use practices such as agriculture, fodder/fuel hood collection, grazing, NTFP collection, etc., were prevalent; however, Sc7, Sc8 and Sc10 were located near or along the road side where frequent disturbance in the form of road clearing/cleaning were common; and Sc14 was located near to the sacred wetland which experiences frequent human visits. Populations, viz., Sc2, Sc4 and Sc12 also recorded good availability of *S. chirayita* (Figure 3). Sc2 and Sc12 were located near to the human habitation while Sc4 was located in the forest area; however, all the three sites had a history of land use for grazing, fodder collections, etc., as well as collection of *S. chirayita* for domestic use and nursery plantation in the past. Populations namely, Sc3 and Sc22 recorded 9.63 $\pm$ 6.39 ind/m^2 and 9.63 $\pm$ 7.15 ind/m^2 respectively (Figure 3). Both these sites were located away from human habitation; however, they were under the immense anthropogenic pressure in the form of grazing, illegal tree felling, etc., in the recent past. Sc4 still faces human pressure because this site lies along the heavily used trail. Other populations such as Sc1, Sc9, Sc17, Sc19 and Sc20 recorded moderate average density of *S. chirayita* (Figure 3). Sc1 and Sc9 were located in the forest area close to the villages and are still frequently exploited for the collection of fodder and NTFP. Population Sc17 was also located in the open forest area where the site was recovering from the old land slide. Population Sc19 and Sc20 existed on the same vertical slope, but both the populations had peculiar characteristics and the nature of disturbances were different. Of all the populations, Sc11 with plant density of 6.50 $\pm$ ind/m^2 was distinct because it was located in the highest altitude (2841 m asl) of the study sites near or along the road where the developmental activities such as road extension / maintenance is continuous phenomena. The types and level of existing disturbance in different sites are shown in Table 4. In general, the average density of *S. chirayita* were negatively correlated with the species richness (r = -0.04) but positively correlated with species diversity (r = 0.17).

Phytosociological analysis indicated that the relative density of *S. chirayita* to overall stand density was high in majority of the populations, which ranged between 8.27% (Sc6) and 78.38% (Sc12) [Table 2]. Relative density of *S. chirayita* exceeded the value recorded for the associate species in majority of the populations; while in some case, the relative density was lower than the value recorded for some of the associates at the site (Table 2). The dominant associates varied amongst the populations; however, *Eupatorium cannabinum, Gleichenia gigantean, Anaphalis* sp., *Artemesia vulgaris* were the main dominant associates of *S. chirayita*. Interestingly, the *Eupatorium cannabinum* showed greater ecological amplitude and grows in majority of the sites (15 sites) where *S. chirayita* was recorded and in 7 populations, it recorded higher relative density over *S. chirayita* (Table 2). The relative density of *S. chirayita* showed positive correlation with the altitude (r = 0.511, $p<0.02$; Figure 5); whereas, the degree slope showed insignificant effect on *S. chirayita* availability (r = 0.021) and its frequency of occurrence (r = 0.181).

Of the total 22 populations sites, 13 showed 100% frequency of occurrence of *S. chirayita*, whereas, for the remaining 9 sites, the frequency ranged between 33.3% and 70% (Table 2), which increased with ascending altitude (r = 0.423; $p<0.05$). Highest relative frequency for *S. chirayita* was recorded in Sc19 followed by Sc7 and Sc4; while, the lowest was recorded for Sc1 followed by Sc10 and Sc21 (Table 2). Relative frequency showed insignificant increase with increasing altitude, humus depth and soil pH of the population sites. Comparatively, IVI value was higher for the *S. chirayita* than other associates in majority of the populations, thus forming communities with the domination of *S. chirayita*, the maximum of which was recorded for Sc4 followed by Sc7 and Sc8 (Table 3). Based on the IVI value for different species, 11 different types of ground community structures were identified in 22 population sites of *S. chirayita*, **(1)** *Gleichenia gigantean* – *S. chirayita* (Sc1); **(2)** *S. chirayita* – *G. gigantean* (Sc2, Sc14); **(3)** *S. chirayita* - *Osbeckia sikkimensis* - *Anaphalis* sp. (Sc3); **(4)** *S. chirayita* (Sc4. Sc9, Sc11, Sc12, Sc19); **(5)** *Eupatorium cannabinum* – *S. chirayita* (Sc5, Sc6, Sc10, Sc18, Sc21); **(6)** *S. chirayita* – *E. cannabinum* (Sc7, Sc8, Sc17); **(7)** *S. chirayita* – *Osbeckia sikkimensis* – *E. cannabinum* (Sc13); **(8)** *S. chirayita* – *S. bimaculata* (Sc16); **(9)** *S. chirayita* – *Artemesia vulgaris* – *E. cannabinum* (Sc7); **(10)** *S. chirayita* – *Anaphalis* sp. (Sc20); **(11)** *S. chirayita* – *Eragrostis atrovirens* (Sc22). Of the 11 plant community structure identified, *S. chirayita* was dominant over other species in 8 community structure in 11 population sites; however, in Sc4, Sc9, Sc11, Sc12 and Sc19 *S. chirayita* formed the pure community with smaller share of other associates (Table 2). In total, *S. chirayita* was dominant in 16 populations indicating its high availability in Sikkim. As regard to distribution pattern, broadly, the *S. chirayita* was found to be patchy in nature since none of the population sites revealed the even distribution for the same (Figure 4). On the basis of abundance to frequency ratio, *S. chirayita* showed contagious/clustered distribution in majority of the populations except for Sc5 and

Sc10, which showed random distribution (Table 2). However, none of the site showed regular distribution for *S. chirayita.*

S. chirayita was found growing in a diverse microhabitat conditions viz. boulders/stony areas, rock crevices, moss covered/grassy slopes, tree/root base, tree/bamboo canopy, along streams, rotten logs, shrubberies etc (Photo Plate II). Present study identified a total of 14 microhabitats for *S. chirayita* in 22 population sites along different altitude (Figure 6). Of the 22 populations studied, Sc3 recorded the highest and Sc10, Sc11 and Sc18 had the lowest number of microhabitat niches for *S. chirayita* (Table 3). The number of microhabitats decreased with the increasing altitude (r = -0.158) of the population sites. Amongst the 14 microhabitats identified, open grassy slope recorded significantly ($p<0.05$) highest density (37.57 $\pm$ 16.24 ind/m^2; 21.94%) of *S. chirayita* compared to shrubberies, rotten logs/burn/tree stumps, between tree saplings, marshy grassy slope, old landslide/debris and bamboo canopy. The other microhabitats which recorded good density of *S. chirayita* were rock crevices / boulders / stony areas (29.23 $\pm$ 16.45 ind/m^2; 17.08%) and below tree canopy (26.73 $\pm$ 9.17 ind/m^2; 15.62%); however, marshy grassy slope had the lowest plant density (1.63 $\pm$ 0.69 ind/m2; 0.95%) followed by shrubberies (2.43 + 2.50 ind/m2; 1.42%) [Figure 7]. On individual quadrat basis, the 'open grassy slope' (22.51%) followed by 'below tree canopy' (16.79%) were the most frequently occurring microhabitats, while, 'between tree saplings' was amongst the least frequent (1.66%) occurring microhabitat (Figure 8). On per site basis, 'along tree root base' was the most prominent microhabitat (17.14%) followed by 'open grassy slope' (16.19%); whereas 'bamboo canopy', 'marshy grassy slope' and 'rocky slope' appeared in single population site each (Figure 8). Aspect, cumulatively for the entire study sites, had influenced the availability of *S. chirayita*; the maximum average plant density was recorded along west facing slope (20.03 ind/m^2); whereas, cumulatively, the highest (100%) frequency of occurrence for *S. chirayita* was recorded along the north facing slope (Figure 9).

Photo Plate II. Microhabitat of *Swertia chirayita* in Sikkim
A: Rocky slope; B: Tree base; C: Rotten logs; D: Along stream;
E: Shrubberies; F: Stoney areas

4.4 Discussion

The present study reveals an overall availability of *S. chiraiyta* to be relatively high in Sikkim Himalaya. Of the total 22 populations, 16 populations recorded medium (5 to 10 ind/m^2) to high (10 to 20 ind/m^2) to very high average (>20 ind/m^2) density of *S. chirayita* plants; only 6 populations had low density of >5 ind/m^2 compared to very few reports in western and central Himalaya (Bhatt *et al.*, 2005), where the species density ranged between 1.65 ind/m^2 and 2.35 ind/m^2. However, the variation in *S. chiraiyta* plants' availability was observed amongst the populations and within the stands in a population in the present study. Here, the *S. chirayita* showed either contagious or random distribution indicating its patchy or scattered or fragmented distribution, as reported in *Podophyllum hexandrum*, an another endangered Himalayan herb (Airi *et al.*, 1997). In such case, the analysis of patchiness nature on the basis of frequency and density could not be applied as suggested by Rokaya and Ghimire (2004), because, even though the species revealed high average density and frequency in majority of the sites, *S. chirayita* was available in patches, the size of which varied amongst the population sites.

The lowest species richness recorded in Sc20 site was might be due to its location near to the road side where frequent road cleaning and clearing process and other disturbances restricted the regeneration of the other ground flora; while the highest species richness in Sc2 could be related to increased intensity of fodder collection as a consequence of ban imposed on animal grazing from forest lands vide Notification No.426/F, dated 17.07.1995, the former activity is known to increase the species richness (Dzwonko and Loster, 2007). The highest species diversity recorded at population site Sc6, which could be due to its low altitude as the species diversity reduces with increasing altitude (Pavon *et al.*, 2000; Wang *et al.*, 2007). In addition, the site is located in the private agricultural field where grazing, fodder/fuel hood collection, land clearing, etc., were very common creating open spaces suitable for regeneration of the ground species (Aikens *et al.*, 2007). While, comparatively the low species diversity in Sc15 could be related to its higher altitude location, compared to Sc6, and further, to its abandoned status created by the cattle herders which gave an opportunity to growth of unpalatable species especially shrubs suppressing the regeneration of the other herb species. Population Scl and Sc16 was located in the forest area where the minimum light penetration to the ground prohibited the survival of monocarpic (light loving) ground species (Gaudio *et al.*, 2011) resulting in low species diversity. Decreasing plant density with increasing altitude is a natural phenomenon as observed in the present study with *S. chirayita. S. chirayita* performs well on the slopes as the gradients often do not allows accumulation of water; higher the degree of slope, more is the seedling emergence or plant density as observed in the present study.

The low availability of *S. chirayita* in populations, viz., Sc5, Sc6, Sc10, Sc14 and Sc18 could be possibly due to its proximity to the human habitation. As the Sc5 experiences frequent visitors for fodder/fuel hood collection thus creating open condition/gaps where the individuals of *S. chirayita* can easily be sighted. During such activities, collection of *S. chirayita* plants without considering their age has been observed, for the domestic use, prior to flowering and fruiting. Such practice allowed very few individuals to complete the reproductive phase resulting in low regeneration of *S. chirayita*. Further, major portion of the site had rocky habitat which could restrict the species to crevices and holes creating competitive environment for the species. The Sc6 population site was located along the periphery of the privately owned agricultural field where the species faced tremendous pressure in terms of different land use practices. The plants gets trampled or uprooted along with the other weed species during the clearing / preparation of land to sow crops, as change in land use, in particular the intensification of agriculture is the one of the major cause for the decline in the number of plant populations (Korneck and Sukopp, 1988) as the alteration in demographic rates may rapidly affects population size (Schemske *et al.*, 1994; Fischer and Matthies, 1998). Sometimes, the cattle are left in the field for grazing; being bitter in taste, the *S. chirayita* is not preferably grazed but may result in damage of the whole plant or part of it by trampling which affects the species abundance (Yu *et al.*, 2008) as well as its regeneration. Nonetheless, such activities may further augment the threat of existence to *S. chirayita* in those sites in future because constant disturbance would prohibit the seedlings / saplings to mature leading to disappearance of the species from the sites as the habitat degradation is regarded as the major cause of species extinction in human modified landscapes (Andren, 1994).

The lowest availability of *S. chirayita* in Sc10 could be possibly due to its closeness to the roadside as well as availability of single microhabitat condition which experiences frequent soil erosion due to marshy habitat. Such condition offers chances of uprooting of the seedlings / saplings, as well as the washing away of the seeds, resulting in low density as well as accumulation of available *S. chirayita* plants in lower and middle stand. Also, the frequent soil erosion prohibited the humus accumulation required for the seedling emergence and growth affecting the availability of *S. chirayita* in Sc10, as the health of a forest floor plays a significant role in plant growth and survival. High moisture availability increases the seedling mortality by increasing the chances of fungal attack (Fidelis *et al.*, 2008). This might be the probable reason for the low availability of *S. chirayita* in Sc14, as the site is located in the vicinity of the wetland. In addition, the wetland being sacred, experiences frequent human visits which cause disturbances to its habitat thereby resulting in lower availability of *S. chirayita* in Sc14. Being closer to the settlement, harvesting of *S. chirayita* for domestic use is also a common practice at this site; further the site is exploited for other forest resources aggravating the problem of habitat deterioration, which lessened the species availability. Similarly, being closer to the villages, population site Sc18 is exploited for fodder/fuel hood as well the collection of *S. chirayita* for personal use. There have been instances where *S. chirayita* juveniles were collected for plantation in the nursery and the harvesting of the adults, before maturing, for trade at the site. This has led to low availability of the species at the site. Further, the site recorded single microhabitat and appeared much vulnerable to deterioration as a result of human interferences; and microhabitat loss results in decrease in species abundance (Goode *et al.*, 1995) ultimately leading to species extinction.

Populations, viz. Sc7 and Sc8 being located nearer to the road are easily accessible and even though they were found to be constantly degraded during the road extension / repairing / cleaning process, both the sites had good availability of *S. chirayita* and recorded highest density of the same indicating that the species being adapted to such disturbances, as the effect of habitat deterioration on the persistence of plants may strongly differ among species (Brys *et al.*, 2005). At the same time, the sites provided suitable niche (open condition) for the regeneration of the species (Yu *et al.*, 2008). *S. chirayita* showed high availability in lower stand and its availability decreased in middle stand and was completely absent from upper stand in Sc7, as the population was situated in the forest margin, indicating its patchy or contagious distribution at the site; even though, the species showed high availability in all the three stands at site Sc8; the distribution was random in nature. The greater availability of *S. chirayita* in both the sites could also be attributed to the larger number of microhabitats as microhabitat diversity significantly affects species richness and abundance (Yu *et al.*, 2008; De Souza and Eterovick, 2010). However, both the sites had abundance of juveniles and the adult plants were very scarce which signals towards the requirement of high conservation measures because if juveniles are destroyed before they reaches the adult stage and complete its life cycle, the population may become vulnerable to extinction. Populations, viz. Sc3, Sc4 and Sc22 were located in the forest areas in the gaps in similar range of altitude (ca. 2100 – 2200 m asl). All the three population sites were under immense anthropogenic pressure in the form of grazing, NTFP collection, building of cattle sheds, land clearings, etc. Nevertheless, ban in grazing by the state government and the removal of cattle from the forest areas in Sikkim promoted *S. chirayita* to flourish in those areas where open conditions were available. Besides, higher number of microhabitats in all the three population sites proved advantageous (Yu *et al.*, 2008; De Souza and Eterovick, 2010) for the growth of *S. chirayita* leading to high availability of the plants in those sites. Nonetheless, growth of unpalatable species have been observed in abandoned areas in other sites which may become a problem for regeneration of *S. chirayita* in the future leading to species disappearance from those sites

Over 50% of the population site Sc2 was observed as open grassy slope and under continuous pressure for the fodder and NTFP collection due to its closeness to the human habitation. Also, the site had a history of grazing which could be attributed to openness and high species richness at the site. The site also recorded greater number of microhabitats in addition to the presence of unpalatable species such as *Edgeworthia gardenerii, Gleichenia gigantean* and *Osbeckia sikkimensis,* which act as a buffer protecting *S. chirayita* from many disturbances. This looks promising for *S. chirayita* at present; however in the long run, species such as *Osbeckia sikkimensis,* which has a tendency to invade, might cover entire area restricting *S. chirayita* to small pockets. On the other hand, entire slope in Sc12 is completely open; this might be due to mass felling of trees in the past for township development in the nearby area or due to huge landslide that might have occurred in the geological past. In addition, the site recorded varied microhabitats and very low density for the associated species. Further, the presence of unpalatable species like *Osbeckia sikkimensis* and *Rubus ellipticus* protects the species from disturbances like trampling, etc. The abrupt ban on grazing has promoted the species like *Aconogonum molle, Osbeckia sikkimesis, Dichroa fenrifuga,* etc., to spread covering wide area under which *S. chirayita* cannot be sighted easily and escapes ruthless harvesting thereby resulting in good availability in the area. At present, though the *S. chirayita* seems dominant over other species at the site; but, uncontrolled growth of other species makes this species vulnerable to population fragmentation and extinction because *S. chirayita* is a slow growing species, compared to other associated species, which have tendencies to become invasive, and *S. chirayita* cannot withstand them in longer run.

The Sc11 population was explored at the highest altitude (2841m asl) located entirely on the rocky slope and with complete isolation from other populations. Isolation of populations results in the reduced fitness of plants and further decline in population size (Lienert, 2004; Hensen *et al.*, 2005). *S. chirayita* was highly concentrated in the upper stand while it showed medium availability in lower and middle stands thereby resulting in contagious distribution. Though, it had good availability of *S. chirayita*; nevertheless, the population might face risk of extinction in future because the area is prone to landslides / rockslide etc., caused by the developmental activities such as road extension / maintenance. This particular population is very important as the entire area remains under snow cover for almost 3-4 months in a year; to overcome the severity of the climatic condition, the species might have developed special adaptive features such as shorter plant height (refer chapter 5), production of highly viable seeds (refer chapter 7), healthy seedlings, nectars very rich in sugars attracting insects etc., which needs detailed eco-physiological studies to determine its adaptive mechanism better. However, specialization of plants to specific environment makes them susceptible to various environmental pressures (Korner, 1999), suggesting that the population should be provided special conservation measures.

The association of *S. chirayita* and *Eupatorium cannabinum* was common amongst Sc1, Sc9 and Sc17 populations. These three sites recorded moderate availability of *S. chirayita* and are potential population sites. In the first two sites, *S. chirayita* was dominant over *E. cannabinum* and vice versa in Sc17. All the threes sites were located in the forest area either in the gaps or in the fringe of the forest. The governmental ban imposed on collection of medicinal plants (Exim Bank, 2009) allowed good growth and regeneration of *S. chirayita* in population site Sc1, supported by 100% frequency of occurrence. The site has a history of *S. chirayita* collection for trade in the past; however, ban on grazing has limited the human intervention in population site Sc1 but has permitted the growth of several unpalatable plant species thus threatening the availability of *S. chirayita* at the site. Higher intensity of forest resource use such as fodder/fuel hood, NTFPs, etc., at population site Sc9 resulted in trampling as well as damaging of *S. chirayita* plants or its parts during fodder collection process along with other fodder elements. This site could be a promising population if conservation measures are taken. Population Sc17 is situated in distant location in open slope and the frequency of disturbance was very low; however, the population was available on the land slip area with over 70% adult plant. There is a chance of increase in abundance of the species from moderate at present to high in the future if the landslide does not become active and burry the juveniles and the dispersed seeds under the deep soil. The major threat at the existing population site is the dominance and uncontrolled growth of a weed species, *Eupatorium cannabinum,* which may cover entire area in the future suffocating the growth and regeneration of *S. chirayita.* Sc19 was lying in the margin of agricultural field and the forest area and faced higher degree of disturbances such as grazing fodder/fuel hood collection, land clearing for agriculture purpose, NTFP collection, etc. The increasing density from lower to upper stand reveals higher intensity of pressure at the side nearer to agricultural field. This will restrict the distribution of the species in a pocket in future at the population site. Population Sc20 was located in the forest area along or near to the road where it encounters disturbances like road cleaning/clearing, chirayita collection for the domestic purpose, etc. Likewise in the previous population, Sc20 had high availability of *S. chirayita* in the upper stand and low availability in the lower and the middle stand indicating increasing threat on the species leading its restriction wtihin small patch in the future. Both the site can be considered a potential population and needs meager conservation initiatives for long term sustainability of the population.

Swertia chirayita, for its higher density and higher relative density, emerged dominant over other associated species in 16 of the total 22 populations. *S. chirayita* is not selective in forming associations; rather, the species grows evenly with other species existing in the population sites. However, *S. chirayita* being slow growing species, its domination over other species might get affected in future because some of the associated species like *Eupatorium cannabinum, Osbeckia sikkimensis, Aconogonum molle*, etc., have a tendency to become an invasive element thereby endangering the existing populations of *S. chirayita* .

During the study, it was also observed that the availability of *S. chirayita* being affected by increasing number of associate species (r = -0.040), as reported by Fidelis *et al.*, (2008) in *Eryngium horridum*. The possible reasons could be the low light penetration, increased competition, high moisture climate leading to fungal attack, etc., affecting both germination and establishment of seedlings (Tilman 1993; Foster and Gross 1998; Xiong and Nilsson, 1999; Moles and Westoby, 2004a,b) thereby causing increased seedling mortality (Fidelis *et al.*, 2008). Litter may favour seed germination and establishment. Higher density of plants with increasing humus depth ($r = 0.372$; $p<0.10$) in the current study indicates that the good humus availability helps to maintain greater plant availability of *S. chirayita*. However, negative effect of accumulation of litter on the seedling recruitment, survival of plant populations (Kalliovirta *et al.*, 2006), species richness and vegetation (Sydes and Grime 1981a,b; Colling *et al.* 2002; Dzwonko and Gawronski 2002) has been reported in several studies. Decline in species richness with the increasing altitudes due to various phenomenon viz., dry weather condition, decrease in precipitation, short photo period, less soil nutrient, etc., has been indicated in several studies (Hamilton 1975; Gentry 1988; Kitayama 1992; Stevens 1992; Vazquez and Givnish 1998; Odland and Birks 1999). Similar decrease in the species richness along increasing altitudes in the present study has been observed as promising advantageous for the important taxa like *S. chirayita* by providing sufficient area for it to boon.

Quality of habitat/micro-site plays a significant role in the seedling recruitment, establishment and better performance of the species (Turnbull *et al.*, 2000; Kalliovirta *et al.*, 2006). The present study discovered that, *S. chirayita* is not habitat specific, suggesting the species offers high microhabitat niche pliability, in contrary to general assumption that the endangered species are often habitat specific. However, species performs well in the microhabitats characterized by less prevalence of competitor species such as open grassy slope, old landslide debris, rock crevices / boulders / stony areas, tree canopy, open moss covered slope, moist moss laden rocks, etc., as recorded in the present study. Under such habitat conditions, competition pressure for sunlight, precipitation and nutrients is reduced thereby helping *S. chirayita* to flourish. Trapping of soil and organic matter in the bedding/fault planes at the base of the large rock outcrops/on rock outcrops/rock crevices/gaps enabling good germination of seeds can be the possible reason for high density of *S. chirayita* in such microhabitat conditions where the plants were observed in numerous clusters. Tree canopy intercepts the abiotic factors necessary for the growth and survival of many under storey vegetation (Dobrowolska, 2008; Valladares and Niinemets, 2008), which results in high emergence of plant species like *S. chirayita* under such habitat condition in the absence of competitors. The water logging in the soil leading to decomposition of the underground part followed by the complete drying of the above ground part was observed in some of the population viz., Sc4, Sc9, indicating and emphasizing the less water requirement by the species for the growth and survival (refer chapter 8). Bamboo groove acts as a barrier to the human as well as the grazing animals thereby the species like *S. chirayita* acquires protection and an opportunity for the seeds to emerge in high number as seen in the case of Sc18.

4.5 Conclusion

The present study concludes that, Sikkim Himalaya offers a high potential and greater availability of *Swertia chirayita* compared to central and northwestern Himalaya (Bhatt *et al.*, 2006), where species is regarded as critically rare / critically endangered. Also, the identification of 14 microhabitats in the present study suggests the species maintains high micro-habitat pliability and that is important for its conservation and management, as a newer finding. However, the distribution is patchy in nature. Study further revealed that the commercial extraction of *S. chirayita* is not common in Sikkim and cannot be consider as a threat because of the governmental ban imposed on its collection from the wild. However, in cases, the impact of past harvesting could be witnessed. The use of the species as a home remedy cannot be considered as a threat to the species. Such practices are necessary to conserve the traditional knowledge (Pradhan and Badola, 2008; Badola and Aitken, 2010), which is also a very important issue. The present study suggests that the only threat to the species is the man made habitat modification or degradation in Sikkim Himalaya. In majority of the population sites, *S. chirayita* was available near to human settlement or in the areas where human interference exists, which indicate that its existence is not affected by minor habitat disturbances caused by the humans but is affected by complete degradation or modification of the habitat. Apart from these threats, natural disturbances viz., landslide, forest fire, etc., are also responsible for the species endangerment which makes it vulnerable as categorized (Ved *et al.*, 2003a), and has no remedy except preservation of the gene pool through *ex-situ* mechanisms (Badola and Pal, 2002).

The necessary steps in the context of conservation of *S. chirayita* would be the (i) identification and conservation of suitable habitat condition and elite populations, (ii) supplementary researches to discover and study more populations in other possible localities, (iii) the development of the cost effective *ex-situ* cultivation packages and improved agro-techniques for mass scale cultivation of the species (refer chapter 8), (iv) development of the *ex-situ* conservation strategies especially in a scenario when harvesting potential from the wild falls short of the demand for the commercial exploitation (Badola and Pal, 2002; Badola and Aitken, 2010).

At the same time, the relationship between the habitat and population characteristics needs to be considered in wider dimensions, especially when planning management activities need to be placed in order to enhance the regeneration of this threatened species (Kalliovirta *et al.*, 2006). The better performance of the species in nature and difference in secondary metabolism content in comparison to *in-vitro* cultivated plants (Wawrosch *et al.*, 2005), suggest primarily focuses of *in-situ* over *ex-situ* conservation, though later is equally supportive. The insignificant difference in major phytochemicals (amarogentin, mangiferin, swerchirin) between extracts of wild and cultivated plants strengthens the validity of cultivated *S. chirayita* for medicinal purpose and trade (Phoboo *et al.*, 2010) which would be an important direction towards *in-situ* conservation of *S. chirayita* (Badola and Pal, 2002). Future studies should focus on monitoring the populations and estimating the population growth rate to address the best management system of the species (Kusuma and Astuti, 2009).

Table 1. Site characteristics of selected populations of *Swertia chirayita* in Sikkim

Site code	Site Name	Altitude (m asl)	Aspect	Slope (^{0})	GPS		Broad habitat
					Latitude (N)	Longitude (E)	
Sc1	Luing (ES)	2126	NE	60	27^{0}21'47.60"	88^{0}34'12.17"	Ridge, mixed forest of *Cryptomeria japonica* and *Castanopsis tribuloides*
Sc2	Railgaon (ES)	1948	NE	25	27^{0}21'52.71"	88^{0}33'47.07"	Shrubberies with scattered tree species of *Cryptomeria japonica* and *Castanopsis tribuloides*
Sc3	Upper Pangthang (ES)	2176	SW	50	27^{0}21'13.54"	88^{0}33'53.37"	Forest-shrubberies of *Quercus lamellose* and *Castanopsis tribuloides*
Sc4	Guransey dara (ES)	2107	SE	55	27^{0}20'51.02"	88^{0}34'07.92"	Moist mixed Forest with the domination of *Cryptomeria japonica* and *Rhododendron* sp.
Sc5	Jaunbari (SS)	1651	SW	45	27^{0}11'47.20"	88^{0}23'33.60"	Moist forest-shrubberies with *Alnus nepalensis* and *Michelia lanuigilosa*
Sc6	Upper Chamgaon (SS)	1583	NW	50	27^{0}11'03.80"	88^{0}22'26.20"	Forest-shrubberies with *Alnus nepalensis* and *Schima wallichi*
Sc7	Tiffin dara1 (SS)	1667	W	55	27^{0}11'14.8"	88^{0}22'46.01"	Moist grassy slope with *Cryptomeria japonica* and *Alnus nepalensis*
Sc8	Tiffin dara2 (SS)	1744	W	55	27^{0}11'12.1"	88^{0}22'45.8"	Forest-shrubberies with *Cryptomeria japonica* and *Alnus nepalensis*
Sc9	Upper Changrang (ES)	2055	S	60	27^{0}21'51.97"	88^{0}35'20.31"	Forest-shrubberies with *Machilus* sp. and *Castanopsis tribuloides*
Sc10	Phinsyonala (NS)	1761	NE	50	27^{0}37'01.6"	88^{0}37'26.2"	Forest-shrubberies of *Alnus nepalensis*
Sc11	Zema1 (NS)	2841	NE	65	27^{0}44'34.7"	88^{0}32'48.0"	Rocky steep slope with *Selenium* sp. and *Artemesia* sp.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Moist mixed forest with the dominance of *Cryptomeria japonica*
Sc13	B2 (ES)	1694	N	55	27^{0}22’54.12”	88^{0}38’28.08”	Forest-Shrubberies with persisting landslide with the domination of *Alnus nepalensis*
Sc14	Khecheopalri (WS)	1867	SW	50	27^{0}21’06.7”	88^{0}11’21.6”	Moist mixed forest of *Quercus* sp. and *Castanopsis tribuloides*
Sc15	Fring dara (WS)	2030	SW	40	27^{0}20’53.2”	88^{0}10’51.5”	Shrubberies of *Osbeckia* sp.
Sc16	Yuksam (WS)	1948	SW	65	27^{0}23’26.2”	88^{0}13’09.8”	Mixed forest of *Quercus lamellosa* as dominant
Sc17	Deewani taar (WS)	2055	SE	55	27^{0}11’41.3”	88^{0}13’23.9”	Forest-Shrubberies with the dominance of *Alnus nepalensis*
Sc18	Gumpa dara (WS)	1978	SE	55	27^{0}10’13.6”	88^{0}11’03.9”	Forest –shrubberies of *Cryptomeria japonica-Alnus nepalensis*
Sc19	Hilley (WS)	2697	S	60	27^{0}10’44.5”	88^{0}07’05.4”	Forest-shrubberies with *Lithocarpus pachyphylla* and *Arundinaria maling*
Sc20	Ribdi (WS)	2332	S	60	27^{0}09’58.2”	88^{0}06’35.2”	Moist forest of *Cryptomeria japonica*
Sc21	Tendong (SS)	2099	S	50	27^{0}13’45.0”	88^{0}23’37.0”	Forest-shrubberies with *Castanopsis tribuloides* and *Quercus* sp as dominant
Sc22	Ravangla (SS)	2160	S	45	27^{0}18’58.6”	88^{0}22’20.6”	Mixed forest of *Castanopsis tribuloides, Quercus lamellose, Machilus edulis* and *Cinnamomum* sp.

ES: East Sikkim; SS: South Sikkim; NS: North Sikkim; WS: West Sikkim

Table 2. Phytosociological attributes of *Swertia chirayita* and its associates in Sikkim

Site code	Species	RD (%)	Freq (%)	RF (%)	IVI	Ab	A/F ratio
Sc1	*Swertia chirayita*	23.30	100.00	24.79	48.09	7.30	0.073
	Anaphalis sp.	7.34	36.67	9.09	16.43	6.27	0.056
	Clematis buchananiana	0.64	13.33	3.31	3.94	1.50	0.150
	Eupatorium cannabinum	10.43	30.00	7.44	17.86	10.89	0.225
	Gleichenia gigantean	37.23	50.00	12.40	49.63	23.33	0.171
	Osbeckia sikkimensi	14.15	100.00	24.79	38.94	4.43	0.044
	Swertia bimaculata	6.38	60.00	14.88	21.26	3.33	0.467
	Symplocos glomerata	0.21	6.67	1.65	1.87	1.00	0.113
	Symplocos theifolia	0.32	6.67	1.65	1.97	1.50	0.363
Sc2	*Swertia chirayita*	42.21	100.00	32.26	74.47	11.83	0.118
	Anaphalis sp.	9.16	43.33	13.98	23.13	5.92	0.087
	Edgeworthia gardenerii	0.12	3.33	1.08	1.19	1.00	0.384
	Elaeocarpus lanceaefolius	0.12	3.33	1.08	1.19	1.00	0.133
	Eurya acuminata	0.36	3.33	1.08	1.43	3.00	0.137
	Gleichenia gigantean	34.01	36.67	11.83	45.84	26.00	0.083
	Osbeckia sikkimensis	5.59	43.33	13.98	19.57	3.62	0.709
	Pieris ovalifolia	0.12	3.33	1.08	1.19	1.00	0.900
	Swertia bimaculata	3.45	33.33	10.75	14.20	2.90	0.300
	Symplocos glomerata	3.80	16.67	5.38	9.18	6.40	0.094
	Symplocos theifolia	0.48	10.00	3.23	3.70	1.33	0.300
	Zanthoxylum alatum	0.59	13.33	4.30	4.90	1.25	0.300
Sc3	*Swertia chirayita*	56.67	70.00	31.82	88.48	13.76	0.197
	Anaphalis sp.	16.86	30.00	13.64	30.50	9.56	0.042
	Gleichenia gigantean	13.53	16.67	7.58	21.11	13.80	0.046
	Osbeckia sikkimensis	7.65	53.33	24.24	31.89	2.44	0.828
	Rhododendron dalhousie	2.55	16.67	7.58	10.12	2.60	0.319
	Swertia bimaculata	2.75	33.33	15.15	17.90	1.40	0.156
Sc4	*Swertia chirayita*	66.93	100.00	60.00	126.93	11.33	0.113
	Eupatorium cannabinum	16.93	13.33	8.00	24.93	21.50	0.200
	Eurya japonica	3.35	6.67	4.00	7.35	8.50	1.613
	Gleichenia gigantean	5.71	6.67	4.00	9.71	14.50	0.111
	Osbeckia sikkimensis	5.91	30.00	18.00	23.91	3.33	1.275

	Swertia bimaculata	1.18	10.00	6.00	7.18	2.00	2.175
Sc5	*Swertia chirayita*	12.85	70.00	58.33	71.18	3.29	0.047
	Eupatorium cannabinum	86.59	36.67	30.56	117.15	49.00	1.336
	Golchidion acuminatum	0.56	13.33	11.11	11.67	2.25	0.169
Sc6	*Swertia chirayita*	8.27	46.67	35.90	44.17	3.93	0.084
	Engelhardtia spicata	0.30	16.67	12.82	13.12	1.20	1.067
	Eupatorium cannabinum	90.23	46.67	35.90	126.12	49.79	2.100
	Hedychium spicatim	1.05	3.33	2.56	3.62	7.00	0.072
	Machiliu edulis	0.15	16.67	12.82	12.97	1.60	0.096
Sc7	*Swertia chirayita*	61.81	53.33	61.54	123.35	34.50	0.647
	Betula alnoides	0.56	10.00	11.54	12.10	2.33	2.957
	Eupatorium cannabinum	37.63	23.33	26.92	64.55	69.00	0.233
Sc8	*Swertia chirayita*	51.88	100.00	71.43	123.30	21.67	0.217
	Eupatorium cannabinum	47.73	33.33	23.81	71.53	59.80	1.794
	Hedychium spicatum	0.24	3.33	2.38	2.62	3.00	0.900
	Maesea chisia	0.16	3.33	2.38	2.54	2.00	0.600
Sc9	*Swertia chirayita*	50.44	100.00	51.72	102.16	7.67	0.077
	Artemesia vulgaris	3.73	10.00	5.17	8.90	5.67	3.300
	Eupatorium cannabinum	21.71	10.00	5.17	26.88	33.00	0.567
	Gleichenia gigantean	0.88	3.33	1.72	2.60	4.00	0.133
	Osbeckia sikkimensis	19.74	50.00	25.86	45.60	6.00	0.120
	Polygonum molle	3.51	20.00	10.34	13.85	2.67	1.200
Sc10	*Swertia chirayita*	13.92	60.00	25.71	39.63	2.72	0.045
	Artemesia vulgaris	5.68	50.00	21.43	27.11	2.13	0.250
	Astilbe rivularis	3.41	46.67	20.00	23.41	1.57	0.043
	Eupatorium cannabinum	76.99	76.67	32.86	109.85	19.17	0.034
Sc11	*Swertia chirayita*	61.71	100.00	46.88	108.58	6.50	0.065
	Artemesia vulgaris	27.85	40.00	18.75	46.60	7.33	0.183
	Astilbe rivularis	1.27	10.00	4.69	5.95	1.33	0.133
	Selenium sp.	9.18	63.33	29.69	38.86	1.53	0.024
Sc12	*Swertia chirayita*	78.38	100.00	43.48	121.86	10.63	0.106
	Aconogonum molle	8.60	33.33	14.49	23.09	3.50	0.150
	Astilbe rivularis	2.21	20.00	8.70	10.91	1.50	0.075
	Dichroa febrifuga	0.49	6.67	2.90	3.39	1.00	0.044
	Osbeckia sikkimensis	8.11	50.00	21.74	29.85	2.20	0.105

	Rubus ellipticus	2.21	20.00	8.70	10.91	1.50	0.075
Sc13	*Swertia chirayita*	44.64	100.00	47.62	92.26	6.67	0.067
	Artemesia vulgaris	4.24	10.00	4.76	9.00	6.33	0.731
	Eupatorium cannabinum	24.55	23.33	11.11	35.66	15.71	0.112
	Osbeckia sikkimensis	16.29	46.67	22.22	38.52	5.21	0.084
	Pteris biaurita	8.71	13.33	6.35	15.05	9.75	0.633
	Rubus ellipticus	1.56	16.67	7.94	9.50	1.40	0.673
Sc14	*Swertia chirayita*	43.38	33.33	38.46	81.84	5.90	0.177
	Gleichenia gigantean	25.00	13.33	15.38	40.38	8.50	0.100
	Hedychium spicatum	5.88	3.33	3.85	9.73	8.00	0.975
	Osbeckia sikkimensis	2.94	3.33	3.85	6.79	4.00	2.400
	Pteris biaurita	9.56	6.67	7.69	17.25	6.50	0.450
	Swertia bimaculata	8.82	20.00	23.08	31.90	2.00	0.638
	Utrica diocia	4.41	6.67	7.69	12.10	3.00	1.200
Sc15	*Swertia chirayita*	36.36	100.00	33.33	69.70	5.07	0.051
	Artemesia vulgaris	21.53	26.67	8.89	30.42	11.25	0.041
	Dichroa febrifuga	1.44	10.00	3.33	4.77	2.00	0.067
	Eupatprium cannabinum	5.26	6.67	2.22	7.49	11.00	0.104
	Heracleum wallichii	0.24	3.33	1.11	1.35	1.00	1.650
	Osbeckia sikkimensis	10.53	46.67	15.56	26.08	3.14	0.200
	Rumex nepaulensis	10.05	36.67	12.22	22.27	3.82	0.422
	Swertia bimaculata	14.59	70.00	23.33	37.93	2.90	0.300
Sc16	*Swertia chirayita*	33.58	100.00	35.29	68.87	6.17	0.062
	Aconogonum molle	9.62	26.67	9.41	19.03	6.63	0.332
	Arisaema sp.	2.18	23.33	8.24	10.41	1.71	0.073
	Artemesia vulgaris	25.77	46.67	16.47	42.24	10.14	0.056
	Eupatorium cannabinum	24.32	36.67	12.94	37.26	12.18	0.167
	Rubus ellipticus	0.91	10.00	3.53	4.44	1.67	0.248
	Rumex nepaulensis	2.72	30.00	10.59	13.31	1.67	0.167
	Utrica diocia	0.91	10.00	3.53	4.44	1.67	0.217
Sc17	*Swertia chirayita*	37.19	100.00	43.48	80.66	8.90	0.089
	Anaphalis sp.	12.12	30.00	13.04	25.16	9.67	0.357
	Artemesia vulgaris	0.28	3.33	1.45	1.73	2.00	0.333
	Astilbe rivularis	0.28	6.67	2.90	3.18	1.00	0.322
	Eupatorium cannabinum	42.48	53.33	23.19	65.67	19.06	0.150

	Rubus ellipticus	2.21	20.00	8.70	10.91	1.50	0.075
Sc13	*Swertia chirayita*	44.64	100.00	47.62	92.26	6.67	0.067
	Artemesia vulgaris	4.24	10.00	4.76	9.00	6.33	0.731
	Eupatorium cannabinum	24.55	23.33	11.11	35.66	15.71	0.112
	Osbeckia sikkimensis	16.29	46.67	22.22	38.52	5.21	0.084
	Pteris biaurita	8.71	13.33	6.35	15.05	9.75	0.633
	Rubus ellipticus	1.56	16.67	7.94	9.50	1.40	0.673
Sc14	*Swertia chirayita*	43.38	33.33	38.46	81.84	5.90	0.177
	Gleichenia gigantean	25.00	13.33	15.38	40.38	8.50	0.100
	Hedychium spicatum	5.88	3.33	3.85	9.73	8.00	0.975
	Osbeckia sikkimensis	2.94	3.33	3.85	6.79	4.00	2.400
	Pteris biaurita	9.56	6.67	7.69	17.25	6.50	0.450
	Swertia bimaculata	8.82	20.00	23.08	31.90	2.00	0.638
	Utrica diocia	4.41	6.67	7.69	12.10	3.00	1.200
Sc15	*Swertia chirayita*	36.36	100.00	33.33	69.70	5.07	0.051
	Artemesia vulgaris	21.53	26.67	8.89	30.42	11.25	0.041
	Dichroa febrifuga	1.44	10.00	3.33	4.77	2.00	0.067
	Eupatprium cannabinum	5.26	6.67	2.22	7.49	11.00	0.104
	Heracleum wallichii	0.24	3.33	1.11	1.35	1.00	1.650
	Osbeckia sikkimensis	10.53	46.67	15.56	26.08	3.14	0.200
	Rumex nepaulensis	10.05	36.67	12.22	22.27	3.82	0.422
	Swertia bimaculata	14.59	70.00	23.33	37.93	2.90	0.300
Sc16	*Swertia chirayita*	33.58	100.00	35.29	68.87	6.17	0.062
	Aconogonum molle	9.62	26.67	9.41	19.03	6.63	0.332
	Arisaema sp.	2.18	23.33	8.24	10.41	1.71	0.073
	Artemesia vulgaris	25.77	46.67	16.47	42.24	10.14	0.056
	Eupatorium cannabinum	24.32	36.67	12.94	37.26	12.18	0.167
	Rubus ellipticus	0.91	10.00	3.53	4.44	1.67	0.248
	Rumex nepaulensis	2.72	30.00	10.59	13.31	1.67	0.167
	Utrica diocia	0.91	10.00	3.53	4.44	1.67	0.217
Sc17	*Swertia chirayita*	37.19	100.00	43.48	80.66	8.90	0.089
	Anaphalis sp.	12.12	30.00	13.04	25.16	9.67	0.357
	Artemesia vulgaris	0.28	3.33	1.45	1.73	2.00	0.333
	Astilbe rivularis	0.28	6.67	2.90	3.18	1.00	0.322
	Eupatorium cannabinum	42.48	53.33	23.19	65.67	19.06	0.150

	Osbeckia sikkimensis	1.39	10.00	4.35	5.74	3.33	0.600
	Pteris biaurita	5.57	20.00	8.70	14.27	6.67	0.333
	Rhododendron. cilliatum	0.70	6.67	2.90	3.59	2.50	0.375
Sc18	*Swertia chirayita*	29.91	33.33	33.33	63.24	6.70	0.201
	Anaphalis sp.	16.52	13.33	13.33	29.85	9.25	0.297
	Eupatorium cannabinum	44.20	33.33	33.33	77.53	9.90	0.467
	Strobilanthus sp.	3.13	10.00	10.00	13.13	2.33	0.694
	Utrica diocia	6.25	10.00	10.00	16.25	4.67	0.233
Sc19	*Swertia chirayita*	69.87	100.00	65.22	135.08	7.03	0.070
	Anaphalis sp.	25.83	33.33	21.74	47.57	7.80	0.131
	Rhododendron sp.	1.99	6.67	4.35	6.33	3.00	0.234
	Rubus ellipticus	2.32	13.33	8.70	11.01	1.75	0.450
Sc20	*Swertia chirayita*	55.97	100.00	50.00	105.97	8.43	0.084
	Anaphalis sp.	44.03	100.00	50.00	94.03	6.63	0.066
Sc21	*Swertia chirayita*	13.23	70.00	27.63	40.86	6.38	0.091
	Anaphalis sp.	4.44	16.67	6.58	11.02	9.00	0.519
	Eragrostis atrovirens	18.26	50.00	19.74	38.00	12.33	0.133
	Eupatorium cannabinum	61.60	63.33	25.00	86.60	32.84	0.120
	Osbeckia sikkimensis	0.39	10.00	3.95	4.34	1.33	0.247
	Pteris biaurita	0.99	16.67	6.58	7.57	2.00	0.113
	Rubus ellipticus	0.49	13.33	5.26	5.76	1.25	0.094
	Strobilanthus sp.	0.59	13.33	5.26	5.86	1.50	0.540
Sc22	*Swertia chirayita*	77.07	70.00	53.85	130.91	13.14	0.188
	Aconogonum molle	0.27	3.33	2.56	2.83	1.00	0.215
	Anaphalis sp.	1.87	6.67	5.13	6.99	3.50	0.300
	Eragrostis atrovirens	15.47	30.00	23.08	38.54	6.44	0.150
	Eupatorium cannabinum	2.13	6.67	5.13	7.26	4.00	2.700
	Osbeckis sikkimensis	0.27	3.33	2.56	2.83	1.00	0.300
	Pteris biaurita	2.40	3.33	2.56	4.96	9.00	0.525
	Rubus ellipticus	0.53	6.67	5.13	5.66	1.00	0.600

RD: relative density; RF: relative frequency; IVI: important value index; Ab: abundance; A/F: abundance to frequency ratio

Table 3. Diversity and dominance pattern of *Swertia chirayita* pockets in Sikkim

Site code	Species richness	Community density (ind/m^2)	Shannon - Wiener diversity Index	No. microhabitat / site
Sc1	9.0	31.33	0.71	6.0
Sc2	12.0	28.03	0.89	5.0
Sc3	6.0	17.00	1.20	8.0
Sc4	6.0	16.93	1.82	7.0
Sc5	3.0	20.57	6.52	6.0
Sc6	5.0	25.76	8.75	4.0
Sc7	3.0	34.73	1.44	5.0
Sc8	4.0	41.77	1.44	5.0
Sc9	6.0	15.20	1.02	6.0
Sc10	4.0	18.13	3.93	1.0
Sc11	4.0	10.53	1.54	1.0
Sc12	6.0	13.56	3.30	7.0
Sc13	6.0	14.94	0.87	5.0
Sc14	7.0	4.54	0.82	4.0
Sc15	8.0	13.94	0.69	7.0
Sc16	8.0	18.37	0.73	4.0
Sc17	8.0	23.93	0.95	7.0
Sc18	5.0	7.46	0.91	1.0
Sc19	4.0	10.06	2.15	4.0
Sc20	2.0	15.06	1.50	2.0
Sc21	8.0	33.77	1.46	5.0
Sc22	8.0	12.50	3.06	6.0

Table 4. Types and intensity of existing disturbances in different populations of *Swertia chirayita* in Sikkim Himalaya

Sites	Types of disturbance																										
	Grazing			**Fodder collection**			**Fuel hood collection**			**NTFP collection**			**Agriculture**			**Road cleaning / clearing**			**Human movement**			**Chirayita collection**			**Others (landslides, etc)**		
	Intensity of disturbance																										
	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
1				●						●									●								
2						●				●											●	●					
3										●										●							
4											●									●							
5						●			●			●									●		●				
6		●				●			●						●						●						
7																		●			●						
8																		●			●						
9						●			●		●										●						
10																		●			●		●				
11																		●									●
12				●				●				●									●		●				
13										●								●									●
14						●			●			●		●							●			●			
15	●			●			●				●								●			●					
16					●			●				●									●			●			
17							●														●				●		
18						●			●	●									●					●			
19		●				●			●		●				●						●		●				
20						●			●			●						●			●		●				
21																			●								
22												●							●			●					

L = low, M = moderate, H = high

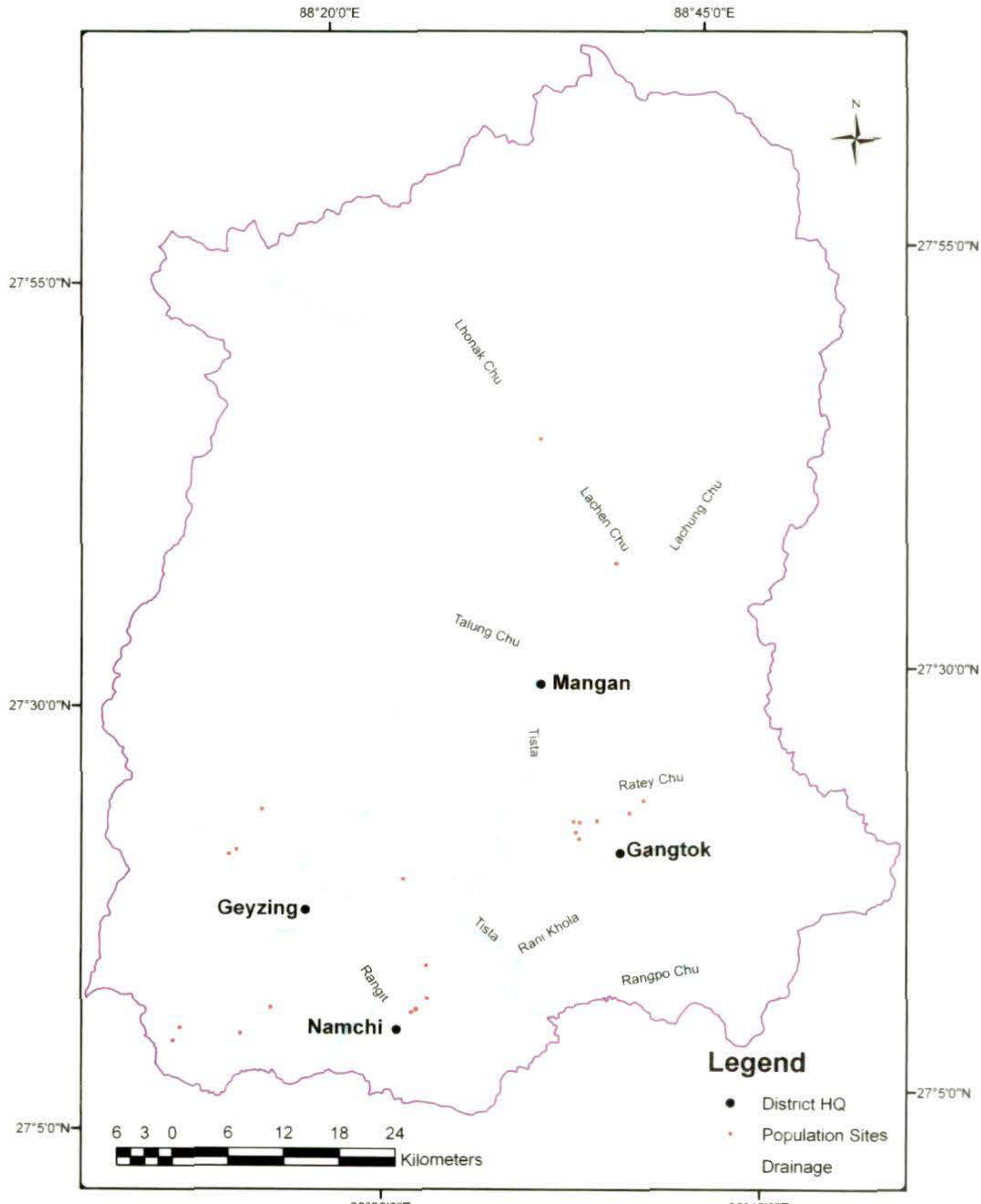

Figure 2. Map showing the studied sites for *Swertia chirayita* in Sikkim, India

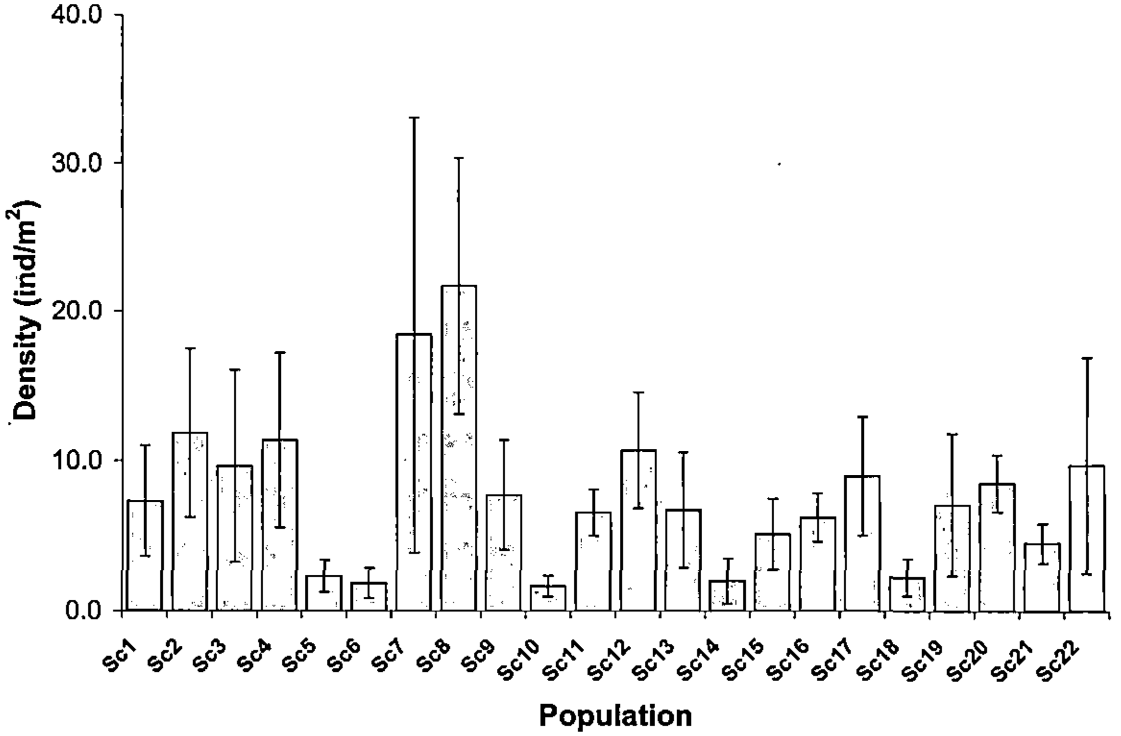

Figure 3. Distribution pattern of *Swertia chirayita* in selected population in Sikkim

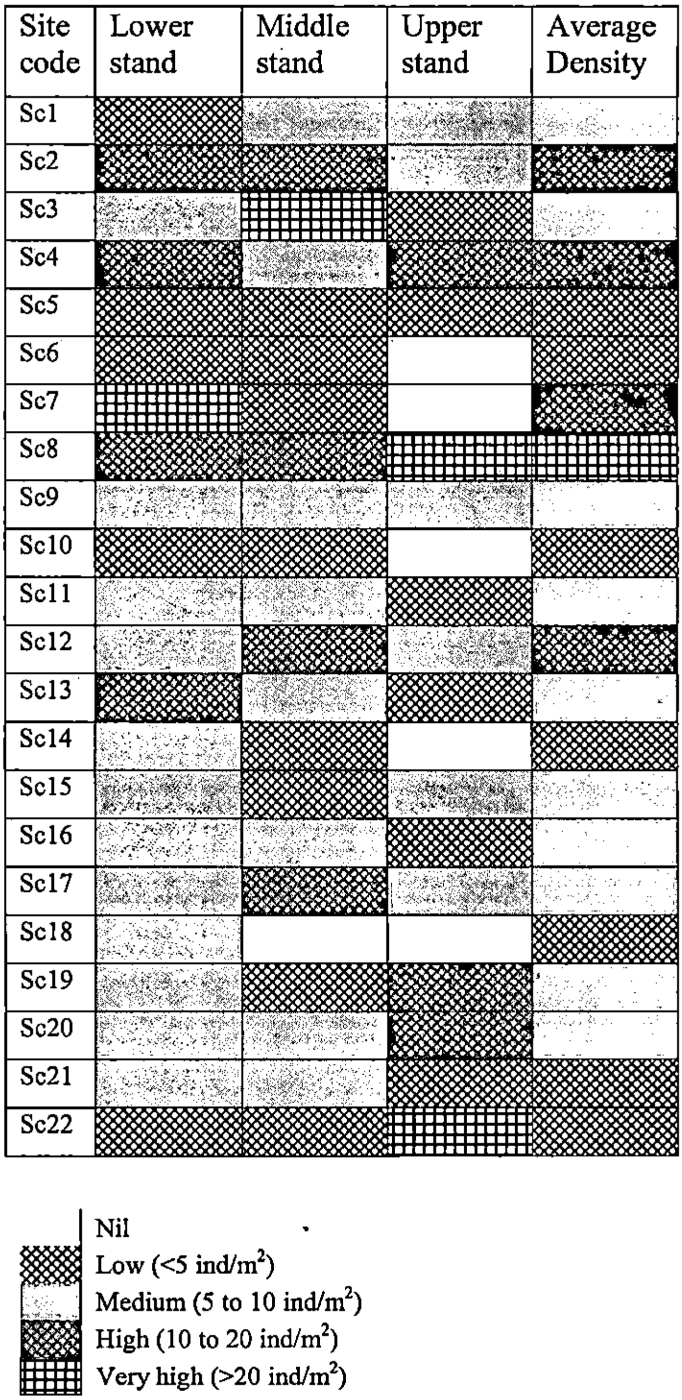

Figure 4. Distribution pattern of *Swertia chirayita* in selected population in Sikkim

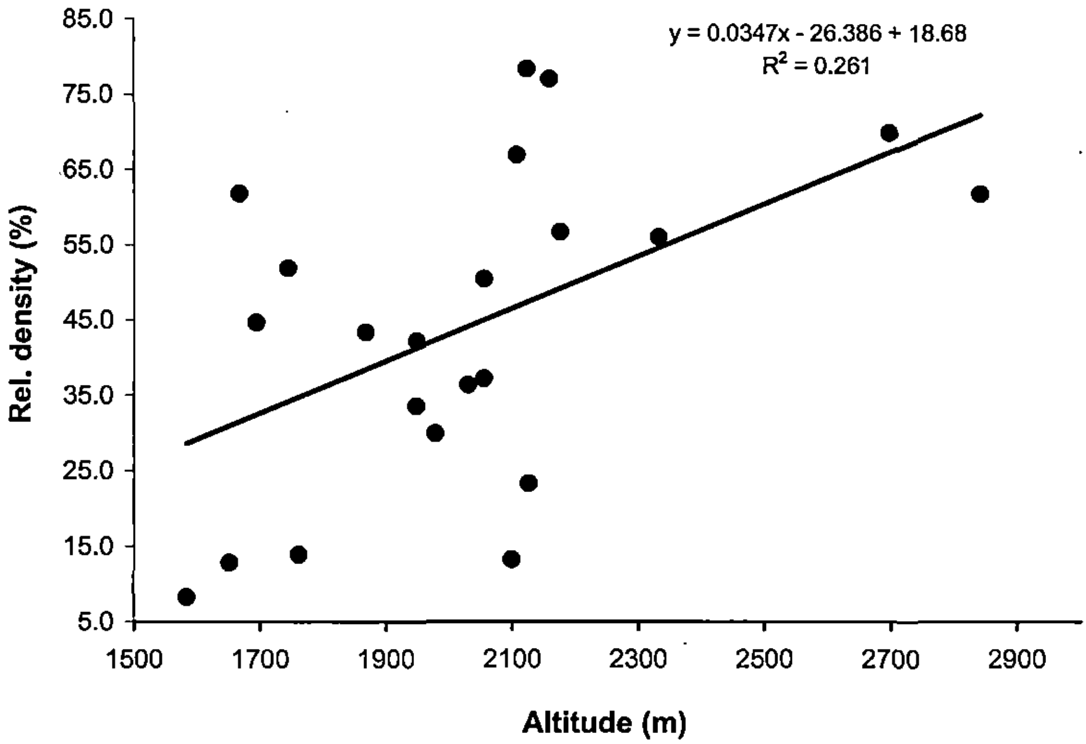

Figure 5. Availability of *Swertia chirayita* along altitudinal gradient in Sikkim

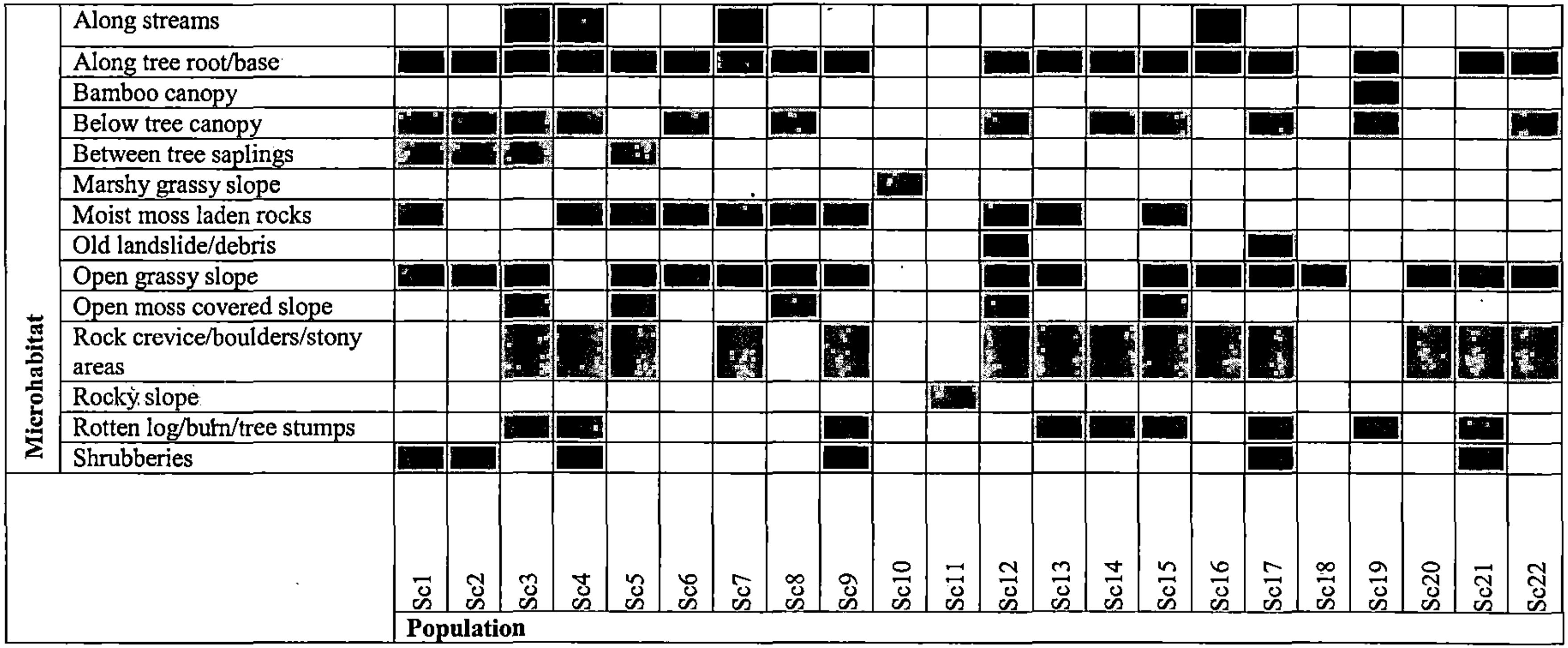

Figure 6. Occurrence of microhabitat of *Swertia chirayita* in different populations of Sikkim

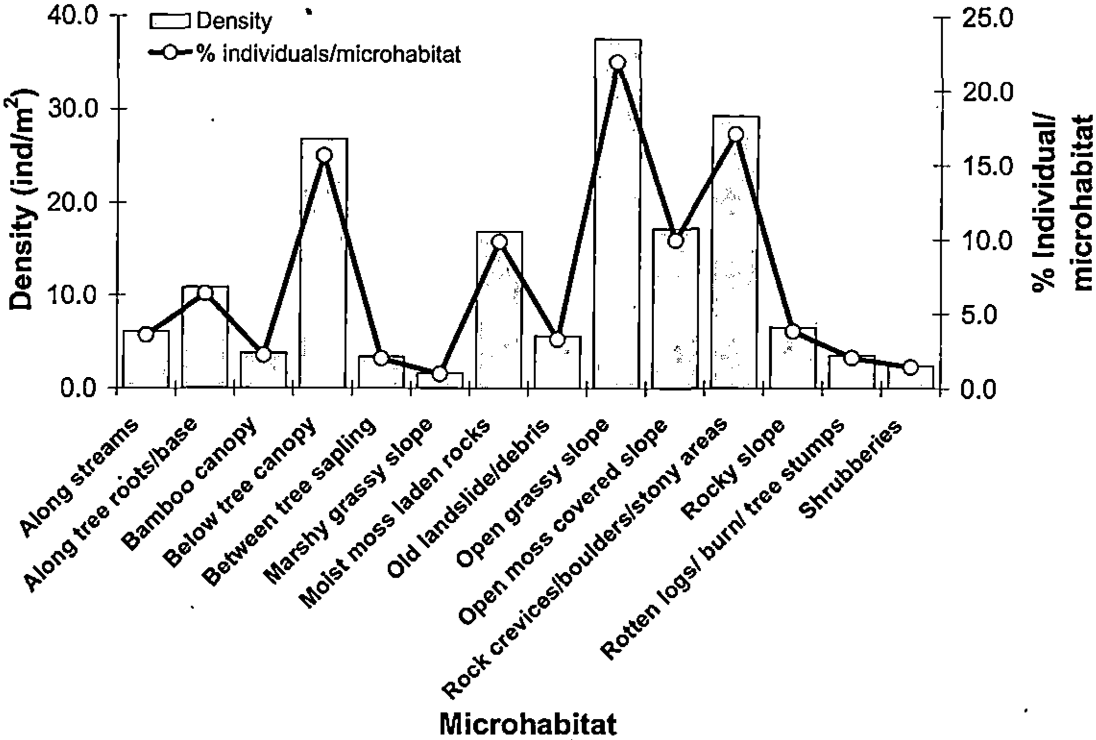

Figure 7. Distribution pattern of *Swertia chirayita* in identified microhabitats in Sikkim

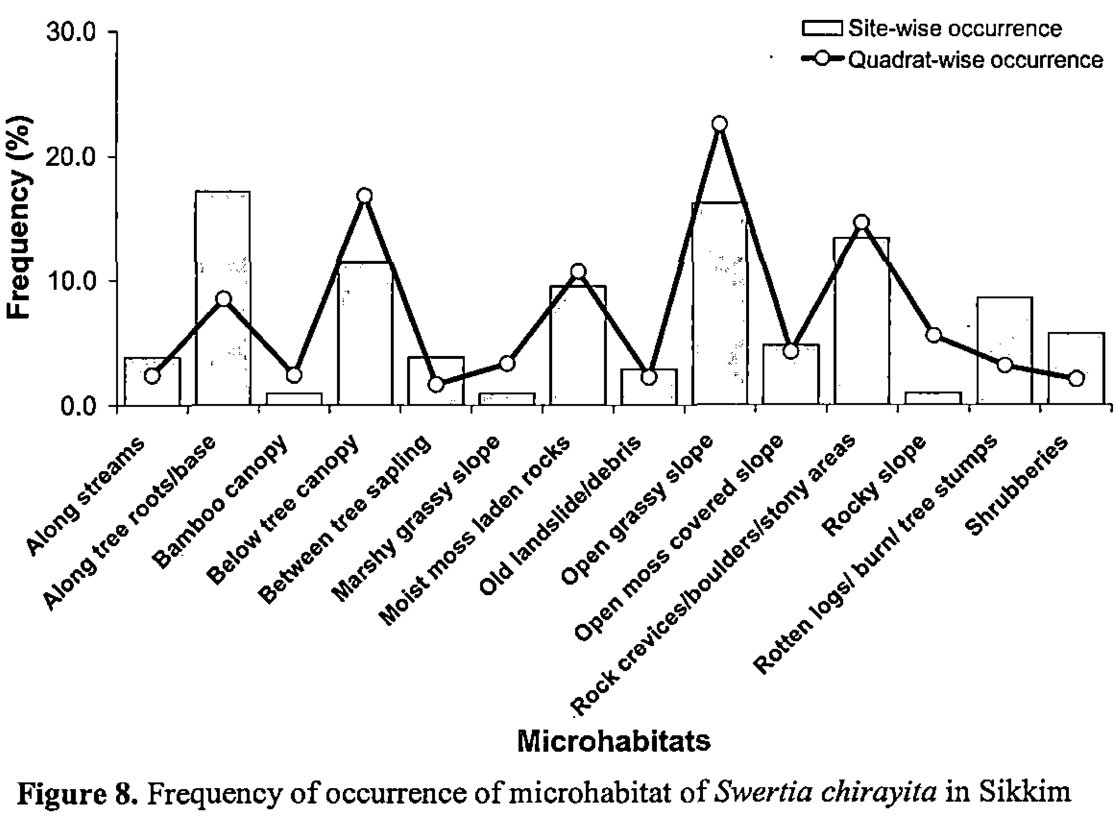

Figure 8. Frequency of occurrence of microhabitat of *Swertia chirayita* in Sikkim

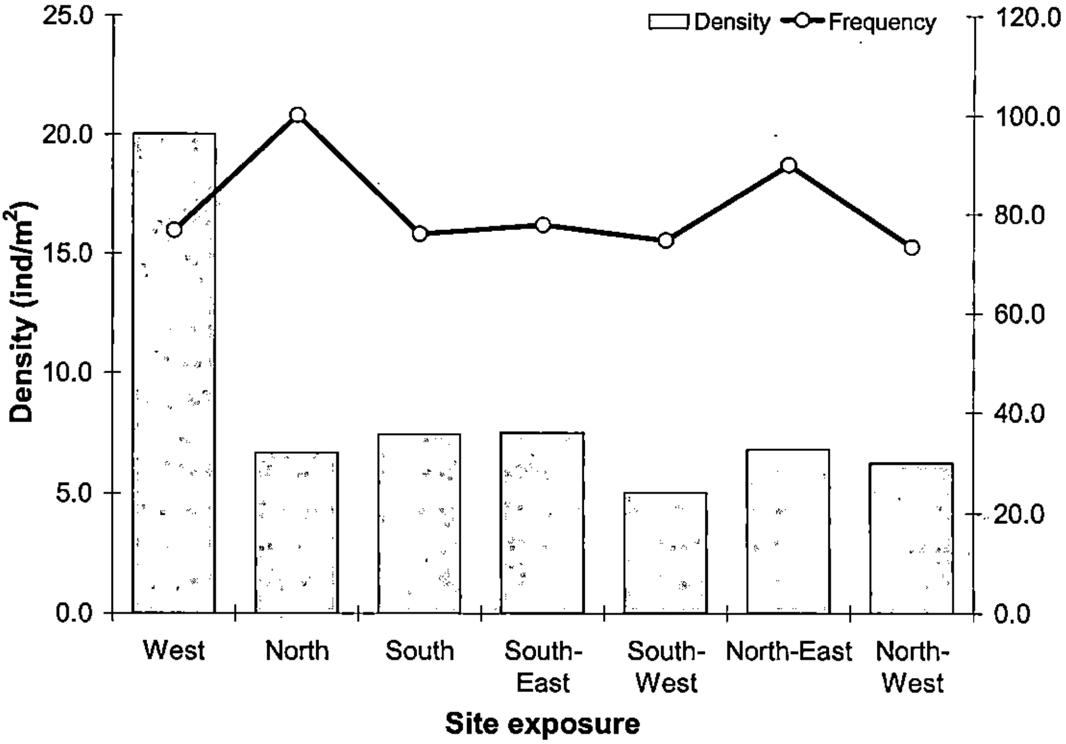

Figure 9. Effect of site exposure on the availability of *Swertia chirayita* in Sikkim