Life History and Population Status of the Endemic Himalayan Aconitum naviculare

Bharat Babu Shrestha* and Pramod Kumar Jha

* Corresponding author: bhabashre@yahoo.com
Central Department of Botany, Tribhuvan University, Kirtipur, PO Box 5275, Kathmandu, Nepal

Open access article: please credit the authors and the full source.

Introduction

Given their minimal access to modern health care systems, people in the high mountains of Nepal have traditionally used >50% of locally available plant species for health care (Kunwar and Bussmann 2008). In addition, trade in medicinal plants collected from the wild has been an integral part of the livelihood of mountain people (Olsen and Larsen 2003), whereas market-driven collection of medicinal plants from the wild is largely unsustainable (Ghimire et al 2005). Although some medicinal plants in the Himalaya have been threatened because of unsustainable harvest from the wild for trade (Kala 2000; Ghimire et al 2005), others are naturally rare, and populations have been declining even when they have been used only for traditional health care (Kala 2005). Understanding life history and demography is essential for developing a scientific management plan (Murray et al 2002). However, except for a few high-profile taxa, population details are largely lacking for most Himalayan medicinal plants (Dhar et al 2000), and life history strategies have been studied only for a few species of Nepal Himalaya (Ghimire et al 2005).

Aconitum spp have been categorized as critically endangered in their natural habitats (CAMP 1998), but availability and life history strategies of this taxon have not been studied in Nepal Himalaya. Aconitum naviculare, endemic to Himalaya (Stainton 1997), is found from Bhutan to Nepal, including southern Tibet (Grierson and Long 1984; Liangqian and Kodata 2001; Ohba et al 2008). This plant species has been used in Tibetan medicine against colds, fever, and headache (Lama et al 2001; Bhattarai et al 2006; Liangqian and Kodata 2001). A. naviculare is the most preferred species in ethnomedicine in Manang, a trans-Himalayan dry valley in central Nepal (Shrestha et al 2007b). Any decline in the abundance of this species could have adverse effects on the local health care system in Manang, where people have little access to modern medicine.

In this article, we discuss germination, growth characters, reproductive output, and the plant’s adaptation to alpine environments to explain the distribution and abundance of this species in Manang Valley. The specific objectives of the study were (1) to understand variation in life history characters of A. naviculare among the populations, (2) to understand adaptation of this species to alpine environments, and (3) to explain the abundance of the species based on the life history characters and anthropozoogenic pressure.
Material and methods

Study site
The study area (28°41′–28°46″N, 83°57′–84°04″E, elevation 4050–4650 m) lies in the upper part of Manang district, central Nepal, which has a glacially formed U-shaped valley (3000–3400 m), traversed by the Marsyangdi River, and surrounded by high mountains (>6000 m) (Figure 1). The valley lies in a rain shadow area of the trans-Annapurna region, with a mean annual precipitation of 444 mm and temperature of 6.2°C (measured at 3420 m, Miehe et al. 2001). The area is covered by snow from November to March. Forest is mostly confined to the moist north-facing slope of Annapurna and the valley floor. The lower belt of the north-facing slope (3000–3500 m) has *Pinus wallichiana* and *Juniperus indica* forests, whereas the upper belt (3500–4200 m) has *Abies spectabilis* and *Betula utilis* forests (4200 m) (Shrestha et al. 2007a). On the southern slope, there is *Juniperus indica* forest up to 3800 m, whereas the alpine scrub has junipers (*Juniperus indica*, *Juniperus recurva*, *Juniperus squamata*), *Rhododendron lepidotum*, *Rosa* spp, *Berberis* spp, *Caragana Gerardiana*, *Ephedra Gerardiana*, *Cotoneaster microphyllus*, etc.

The sampling sites represented at least three fourths of the total area where *A. naviculare* occurred in the study area (Table 1). There were a few sites that were not easily accessible. The Ice Lake area, Khangsar, and Manang hill are nearer to the settlements and experience greater pressure from livestock grazing than the other 3 sites. There were no permanent settlement near Yak Kharka, Ledtar, and Phedi, but a few hotels for tourists were present.

Species studied
*A. naviculare* (Brühl) Stapf. (vernacular name: *ponkar/bongkar*; Fam. Ranunculaceae; Figure 2A–E) is a perennial herb with tuberous white roots; stems ascending, 10–30 cm; leaves mostly basal, palmately divided into 2–5 segments; flowers in loose raceme; sepals tinged dull reddish purple-violet blue, with dark purple veinlets, lower surface pubescent, persistent in fruits, helmet navicular; petals clawed; fruit of 5 follicles, sparsely pubescent (Ohba et al. 2008).

Sampling procedure
We sampled 240 quadrats (1 m × 1 m) lying within 30 large plots (10 m × 10 m) during September 2005. Each large plot was divided into 4 quarters (5 m × 5 m), and 2 quadrats were studied in each quarter. In each quadrat, individuals of *A. naviculare* were counted to determine density (pl/m²). Major associated shrub species were recorded. Because of patchy distribution of *A. naviculare*, sampling plots were subjectively located at localities where the species was relatively common and covered an area >100 m². Thus, calculated density should be considered as the maximum density in its habitat. To determine above-ground biomass, all the individuals of *A.
*naviculare* (excluding seedlings and saplings) were collected from the single most densely populated quadrat within the large plot. Of 30 large plots, we did not sample 5 plots (2 at Manang hill and 3 at Khangsar) for above-ground biomass because of rarity of the plant at the sampling sites.

The single most vigorous individual was completely uprooted from each quarter to measure tuber and stem mass. About 100 g of soil was collected from the rooting depth (5–10 cm) of the collected plant. The plant and soil samples were air-dried under shade. At each site, the area of occupancy of *A. naviculare* was visually estimated.

Because of unequal population size, the number of plots studied was not equal; 3 plots were sampled in the Ice Lake area, 5 each at Manang and Khangsar hills, and 17 at Ledtar. We did not sample the Yak Kharka and Thorong Phedi areas for density and above-ground biomass during the first visit because there had been heavy collection of this plant before we reached the area. During the second visit in October 2006, we sampled individual plants again to measure growth characters (tuber and stem mass, plant height, petiole length) and reproductive outputs (number of flowers borne by each individual plant (flowers/plant) as well as number of seeds in each follicle (seeds/follicle). Mature seeds were collected from each sampling site to determine seed mass and germination behavior.

### Laboratory analysis

Air-dried plant materials were oven dried (60°C for 72 hours), and the biomass was measured to 0.001 g. Soil samples were air-dried in shade under laboratory conditions, and the dried soil was passed through a fine sieve (0.5 mm). Soil organic carbon (OC; Walkley and Black method) and total nitrogen (N; micro-Kjeldahl method) were determined by following the methods described by Gupta (2000).

**Germination experiment:** The seeds were stored at 4°C before germination. Germination experiments were carried out 3 times: after 10, 15, and 20 weeks of seed collection. Each time, 100 seeds were selected from each sampling site and divided randomly into 5 groups of 20

### Table 1

| Sites       | WD | Elevation (m) | Slope (°) | Aspect (°) | RRI          | Associated shrub species                                      |
|-------------|----|---------------|-----------|------------|--------------|--------------------------------------------------------------|
| Ice Lake    | 3  | 4400–4550     | 32 ± 3    | 193 ± 20 SW| 0.980 ± 0.015| Caragana gerardiana Royle                                    |
| Manang      | 2  | 4150–4450     | 30 ± 8    | 237 ± 37 SW| 0.859 ± 0.107| Spiraea arcuata Hook. f., Rosa spp, Berberis spp, Ephedra gerardiana Wall. ex. Stapf |
| Khangsar    | 2  | 4400–4650     | 29 ± 7    | 208 ± 50 SW| 0.908 ± 0.149| Juniperus squamata Buch. – Ham. ex. D.Don, Cotoneaster microphyllus Wallich ex. Lindley |
| Yak Kharka  | 4  | 4090–4270     | 36 ± 1    | 239 ± 21 SW| 0.847 ± 0.077| Spiraea arcuata Hook. f., Berberis spp, Cotoneaster microphyllus Wallich ex. Lindley |
| Ledtar      | 5  | 4200–4500     | 28 ± 5    | 240 ± 24 SW| 0.873 ± 0.093| Juniperus squamata Buch. – Ham. ex. D.Don, Spiraea arcuata Hook. f., Berberis spp |
| Thorong Phedi| 6  | 4350–4450     | 38 ± 7    | 108 ± 13 SE| 0.778 ± 0.073| Spiraea arcuata Hook. f., Berberis spp |
| Mean*/range**|   | 4090–4650**   | 30 ± 6*   | 227 ± 42 SW*| 0.870 ± 0.098*| – |

*WD, walking distance in hours from traditional settlements; RRI, relative radiation index.
Because of the large population, 200 seeds were taken from Ledtar for germination. After the mass of each group was taken, the seeds were placed in petri dishes (diameter 10 cm) with double-layered blotting papers saturated with distilled water. Seeds were examined every 4 days over 32 days to analyze germination. The internal environment of petri dishes was kept saturated with moisture by frequently adding distilled water. The experiment was done under laboratory conditions with natural photoperiod (11–12 hours of light/12–13 hours of dark), mid-day temperature from 16 to 22°C, and relative humidity of 36 to 50%. Because most of the alpine plants need light for seed germination (Bliss 1958), the Petri dishes were placed near a window; thus, they received direct sunlight for about 4 hours a day.

**Numerical analysis**

From the values of aspect (Ω), slope (β), and latitude (Φ), the relative radiation index (RRI; Oke 1987) of each large plot was calculated by using the following formula:

$$\text{RRI} = \{ \cos(180 - \Omega) \sin \beta \sin \Phi \} + \cos \beta \cos \Phi$$

Population size was estimated as the product of estimated area of occupancy and mean density for each sampling site.

Before comparison of mean of population density, growth characters, and reproductive output among sampling sites, the data were tested for normality (Kolmogorov–Smirnov test) and homogeneity of variance (Levene test). The density was normalized when square root transformations did not improve normality, and homogeneity of variance in growth and reproductive characters; for these data nonparametric tests (Kruskal–Wallis and Mann–Whitney U-tests) were used for comparison of means across the sites. Similarly, morphological characters and reproductive output of individual plants occurring in juniper, other shrubs, and open areas were also compared by Kruskal–Wallis and Mann–Whitney U-tests.

Regression analyses were done to understand the relationship among environmental variables (elevation, RRI, soil OC, and soil N), abundance of *A. naviculare* (density and biomass), growth (plant height, petiole length, stem mass, and tuber mass), and reproductive characters (flowers/plant, seeds/follicle, and mass per 100 seeds). The data were checked for normality and were log transformed if necessary. As suggested by Sokal and Rohlf (1995), during log transformation, if the original values were <1, then each of these values was multiplied by 100 to avoid negative values after transformation. All statistical analyses were done by using the Statistical Package for Social Sciences (SPSS 2002, version 11.5).

**Results**

**Life history**

*A. naviculare* is a perennial alpine herb with biennial tuberous roots. *A. naviculare* growing in open areas were much more branched than the individuals growing with junipers and other shrubs. Aerial parts of the plant died at the end of every growing season but it perennated as a tuberous root with a fully developed apical bud buried in the soil at a depth of 2–3 cm (Figure 2B). Thus, *A. naviculare* is a cryptophyte, according to Raunkiaer’s classification of life forms. The mother plant produced a fusiform, tuberous white root with apical bud in the first year. After winter perennation, aerial parts developed from the apical bud early in the growing season after snow melt (May–June). The plant flowered from late September to early October. By the time fruit was mature, the development of the new tuber was completed and the old one dried up. Thus, the plant was perennial with biennial tuberous root and annual aerial parts. In general, a single unbranched tuber is produced by each individual plant. There is the presence of meristematic tissue joining tuber and stem; hence, these 2 parts can easily be detached from each other. When aerial parts were pulled during collection, the tuberous root remained in the soil.

A single plant produced 1–17 flowers (Table 2). With the development of fruits, the sepals dried up, becoming papery but remained persistent and covered the developing fruits until dehiscence. Seeds/follicle varied from 4 to 16 (mean, 11). A single plant produced an average of 165 seeds (3 × 5 × 11 = 165). Seeds were small (mass, 47
± 11 mg/100 seeds) and had no active mechanism of dispersal. At the time of seed dispersal, temperature and soil moisture were low, which prevented immediate germination. Germination occurred in the next growing season when the area became snow free in June.

Variation in growth and reproduction

Growth and reproductive characters differed significantly ($P < 0.001$) among the sampling sites (Figure 3). Most of the characters measured were lowest at Khangsar site. The greatest difference among the sites was observed in stem mass, for which the largest value (Manang hill) was 5 times larger than the smallest one (Khangsar and Yak Kharka). *A. naviculare* was generally found in association with thorny shrub species (Table 1). Quantitative measurement at Ledtar showed that life forms of associated species (such as junipers, other shrubs, and herbs between patches of shrubs) had a significant effect on the height of *A. naviculare*, petiole length, and flowers/plant, and a marginal effect on tuber mass/plant and seeds/follicle (Table 3). Average stem mass/plant was not affected by life forms of the associated species. Plant height and petiole length of *A. naviculare* were the highest within juniper patches, whereas tuber mass/plant, flowers/plant, and seeds/follicle were the highest in individuals growing in open areas.

Among the growth and reproductive characters, petiole length and seed mass increased linearly with plant height, but the tuber mass and flowers/plant showed nearly unimodal relations (Figure 4). The relationship was positive in 6 other pairs of characters (Figure 5); it was linear in 3 pairs but, in 3 other pairs, it deviated slightly from linear relationships.

Stem mass/plant decreased with an increase in elevation (linear regression, $P = 0.001$, $R^2 = 0.37$). Plant height, petiole length, tuber mass, flowers/plant, and seeds/follicle did not vary significantly with elevation. We were not able to find any significant relation between growth and reproductive characters of *A. naviculare*, and soil OC and N.

Seed germination

Germination after 10 and 15 weeks of seed collection was 49% ($\pm 35$ SD, $n = 35$) and 43% ($\pm 38$ SD, $n = 35$), respectively. Most of the seeds germinated between 8 and 11 weeks.
16 days after sowing, and germination of new seeds continued until 24 days (Figure 6A). Seed germination varied across the sampling sites from 17 to 97% after 10 weeks and 6 to 99% after 15 weeks of collection (Figure 6B). After 20 weeks, average seed germination declined to 7% with no germination (Khangsar site) to 24% (Yak Kharka). Germination was epigeal (sensu Baskin and Baskin 1998).

Population status and conservation
The total area of occupancy of A. naviculare at sampling sites in Manang Valley was estimated to be 40 ha (Table 4). Because the present sampling sites represented nearly three fourths of the total area of occupancy of this plant in Manang Valley, the estimated total area of occupancy could be about 50 ha. In Manang hill, Khangsar, and Phedi, it was found in small and fragmented patches, whereas at the Ice Lake area, it was found only in a single patch. In Ledtar, A. naviculare was found in a large area where the population density, estimated population size, and above-ground biomass were also the highest. The density of A. naviculare was the highest at the Ice Lake area and the lowest at Manang hill, the latter being at the nearest distance from the densely populated Manang village (Table 4). Average density increased with increasing RRI (Figure 7A). No relationship was detected between population density and

![Figure 3](http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00003.1)
any of the soil variables measured. Above-ground biomass of *A. naviculare* declined with elevation (Figure 7B).

**Discussion**

**Variation in growth and reproductive characters across the sites**

Growth and reproductive characters varied significantly across the sites, which could be attributed to large microhabitat differences in alpine regions (Bliss 1956). The lowest value of most of the characters measured (Figure 3), together with the lowest seed mass (Figure 6B) and the smallest population size (Table 4) at Khangsar, could be an indication of harsh environmental conditions, including low temperature (because of upper elevation limit of *A. naviculare* in Manang) and high anthropogenic pressure (grazing and collection). Plant height and petiole length were determined mainly by height and canopy structure of associated species. Lower height and petiole length at Khangsar, Ice Lake area, and Yak Kharka were caused by the dominance of dwarf shrub species, such as *C. microphyllus* and *C. gerardiana* as associated species (Table 1). Highest flowers/plant at Ledtar (Figure 3) were caused by dominance of individuals in open areas in the population of *A. naviculare* because individuals growing in open areas produced more flowers/plant than individuals growing within patches of shrubs (Table 3).

Seeds/follicle was the highest at Manang hill (Figure 3) where density of *A. naviculare* was the lowest (Table 4). Bosch and Waser (1999) reported a positive correlation between density and seed set in *A. columbianum* and *Delphinium nuttallianum*, and the decline in seed set in sparse populations was attributed to receipt of inbreed pollens or harsh environmental conditions. But at Manang hill, despite low population density, growth vigor was high as evident from high biomass (Figure 3, Table 4). This indicates favorable physical environmental conditions, and the low density could be attributed to high anthropogenic pressure. Thus, it appears that seed set was determined by growth vigor of individual plants, and population density was not low enough to prevent effective pollination, fertilization, and seed set at Manang hill.

**Variation in growth and reproductive output with life forms of associated species**

Variation in growth characters and reproductive outputs among the individuals of *A. naviculare* growing in juniper, other shrubs, and open areas (Table 3) represent growth responses to resource availability and can be considered as phenotypic plasticity. The variation in plant height and petiole length was an adaptive response to light. Plasticity of shoot helps to place the leaves in areas of high light (de Kroon and Hutchings 1995). Herbaceous dicot plants...
growing in open habitats often respond to shading by elongating internodes and petiole length (Huber 1996), and improved access to light (Falster and Westoby 2003). Because of the long stem and petiole of *A. naviculare* growing with shrubs, the leaf lamina were exposed to full sunlight and flowers to pollinators. This variation allowed *A. naviculare* to grow and reproduce in open areas as well as with dense shrubs.

Stem mass of *A. naviculare* did not vary significantly among the 3 habitats (Table 3). There appeared to be a trade-off between height and thickness of stem. In shaded conditions, the stems are thinner and longer than in full sunlight (Huber 1996). The lowest tuber biomass of this plant growing within juniper scrubs could be the result of the “inevitable effect of resource limits” (*sensu* Sultan 2003) rather than adaptive response. To position the leaves and flower in the upper layer of canopy, relative allocation of biomass to stem increased in shade conditions (Huber 1996), which could have reduced tuber biomass of *A. naviculare* growing in juniper scrubs. Relatively low stem and tuber biomass of *A. naviculare* growing in juniper scrub was also indicative of a stressful environment, which was expressed as the lowest flowers/plant of *A. naviculare* growing in juniper scrub (Table 3).

**Adaptation to the alpine environment**

*A. naviculare* showed a number of adaptive features to alpine environments with strong wind. The flower did not open completely and was globular, with a small opening on the lateral side. A globular shape has been suggested as...
an adaptation to minimize mechanical damage by strong wind in alpine environments (Garg and Husain 2003). The temperature inside the blue flower is higher than in flowers of other colors (Bliss 1962). This could, to some extent, compensate the problem of the short time span with favorable air temperature, enabling late flowering plants to develop seeds and fruits completely (Molau 1993). Persistent sepals could help to maintain relatively high temperature inside for rapid development of fruits and protect developing fruits from the desiccating effects of strong wind and solar radiation. Burial of perennating bud and meristem below the soil surface may prevent damage from low temperature (Körner 2003). A. naviculare also used food reserves from the previous year for early growth during the growing season. All these characters have been considered important adaptive features of plants to alpine environments (Bliss 1962; Körner 2003).

**Seed size and germination**

Seed size of *A. naviculare* (mean, 47 mg/100 seeds = 470 µg/seed) was very close to mean seed size (467 µg/seed) of alpine forbs from various latitudes compiled by Körner (2003). There was wide variation in germination of seed across the sampling sites. However, we could not detect any consistent pattern in the relationship between population size and seed germinability of *A. naviculare*. Some earlier studies also failed to detect the effect of population size on germination (e.g., Oostermeijer et al. 1994; Morgan 1999).

Seeds collected from Khangsar had the smallest size and lost germination after 20 weeks of storage (Figure 6B), which could be an indication of harsh environmental conditions at that site. Low seed germination at the Khangsar site, at the upper elevation limit, could be attributed to low temperature. In late flowering alpine plants like *A. naviculare*, low temperature may result in underdeveloped seeds with low seed mass, poor germination, and short viability (Molau 1993). Relatively high temperature at the Ice Lake area because of the highest RRI among the sampling sites (Table 1) allowed complete seed and fruit development in a short period before the plant died. The habitat of *A. naviculare* at Yak Kharka represented the lower elevation limit (4090–4270 m) of distribution in upper Manang valley.

**Table 4**

| Sites       | Area of occupancy (ha) | Population density (pl/m²) | Estimated population size | Above-ground biomass (g/m²) |
|-------------|------------------------|---------------------------|---------------------------|----------------------------|
| Ice lake    | 2.0                    | 8.67 ± 3.37              | 173,200                   | 2.67 ± 0.24                |
| Manang Hill | 5.5                    | 4.08 ± 2.45              | 223,850                   | 5.02 ± 1.32                |
| Khangsar    | 1.3                    | 6.43² ± 6.35             | 80,250                    | 3.06 ± 1.4                 |
| Yak Kharka  | 7.3                    | na                       | na                        | na                         |
| Ledtar      | 21.0                   | 8.35² ± 4.47             | 1,751,400                 | 5.73 ± 2.71                |
| Phedi       | 3.0                    | na                       | na                        | na                         |
| **Total*/mean** | **40.1**               | **7.35 ± 4.75**           | **2,228,700**             | **4.99 ± 2.58**            |

* na, data not available.

² Values were square root transformed before performing ANOVA; values with same letter in superscript are not significantly different at *P* < 0.05.
which could be relatively warm. Seed development could be complete there too, leading to the highest seed germination (approximately 98%) (Figure 6B).

**Population status, harvesting pattern, and conservation prospects**

Population density of *Aconitum* spp found in the Himalaya was relatively low (<1 to 8 pl/m²) (Ghimire et al 1999; Kala 2000, 2005; Nautiyal et al 2002). The mean density (7.3 pl/m²) of *A. naviculare* in the present study area was comparable with the mean density (6.7 pl/m²) of *A. violaceum* in the Garhwal Himalaya, India (Nautiyal et al 2002). Among 3 *Aconitum* spp (*Aconitum balfourii, Aconitum heterophyllum, and Aconitum violaceum*) found in Garhwal Himalaya, the highest density was recorded for *A. violaceum*, which was attributed to habitat inaccessibility and less exploitation by humans (Nautiyal et al 2002). The smaller size of *Aconitum* spp found in the alpine zone could also have contributed to their higher density than other *Aconitum* spp found at lower elevation. The mean density of *A. naviculare* in Manang was relatively high in comparison to reported values for other *Aconitum* spp. However, the present data represented the maximum density of this species because the sampling plots were selected subjectively. By using a similar sampling strategy, Kala (2000) reported density up to 7.7 pl/m² for *A. violaceum*. *A. naviculare* was found only in small areas in 3 of the 6 sampling sites (Table 4), and the population was either much fragmented (Yak Kharka) or confined to a single patch (Ice Lake area).

Population density of *A. naviculare* increased with increasing RRI (Figure 7A); it was highest at Ice Lake area (Table 4) where RRI was the highest (Table 1). The highest density might also be because of the high seed germination at Ice Lake area (Figure 6B). Population density was the lowest in Manang hill (Table 4), which is close to the densely populated villages of Manang and Tanki Manang. The lowest density at Manang hill could be attributed to the high pressure of human collection and animal grazing. At Ledtar, *A. naviculare* was more commonly found in open areas than within patches of shrubs, which may indicate low animal damage. This was the least disturbed site because of its location far from traditional settlements. The great abundance (high density, above-ground biomass, and the largest population) of *A. naviculare* at Ledtar might be attributed to the lowest pressure of human collection and animal damage.

The destructive effect of cattle grazing, and collection of aerial parts by local people before seed set, appeared to be responsible for declining abundance of *A. naviculare* and the very low density at some sites. The natural habitats of *A. naviculare* are near to human settlements, with high pressure of livestock grazing (Shrestha and Jha 2009). Large animals with wide mouths often avoid thorny shrub species (Chandrashekar et al 2007), which are the most common associates of *A. naviculare* (Table 1). The population density of this species was the highest at Ice Lake area (Table 4), but it was only found in a single patch among a thorny shrub *C. gerardiana*, which could protect *A. naviculare* from damage by livestock and collection by humans. The protective role of shrubs is often important for the persistence of rare species (Facelli and Temby 2002). Because *A. naviculare* was found only within alpine shrubs at the localities with high grazing pressure (Ice Lake area, Manang hill, Khangsar, Yak Kharka, and Phedi), the importance of protective roles, as hypothesized by Bertness and Callaway (1994), was high at these localities. The protective role of associated shrubs against animal damage and human collection is a kind of facilitation, as proposed by Callaway (2007), and it is important for the persistence of this species in the study area.

For sustainable management of alpine medicinal plants in their natural habitats, the harvesting pattern and life history characters should be considered together (Ghimire et al 2005). The entire plant is used in the case of alpine species of *Aconitum* (eg *A. violaceum, A. naviculare, Aconitum gammiei*) (Baral and Kurmi 2006). Although whole plant of *A. naviculare* is medicinally important, people in the study area have been collecting only aerial parts at the flowering stage (Shrestha et al 2007b). This method is less destructive in terms of parts removed, but collection of the plant at flowering stage did not allow regeneration by
seeds. This might have a negative impact on increasing or maintaining population size, as has been also reported by Ghimire et al. (1999). The negative impact could be more critical for areas with a small populations and/or low density, such as Ice Lake area, Manang hill, and Khangsar.

Conclusions

The growth characters and reproductive outputs of *A. navicularis* varied significantly across the sites; most of them were lowest at Khangsar, a site at the highest elevation, which indicates harsh environmental conditions for this plant at Manang. Variation in plant height, petiole length, and flowers/plant were largely governed by life forms of associated species. Reproductive outputs were determined by growth vigor of individual plants and associated species. Seed germination varied across the sites. Temperature and anthropozoogenic pressure appeared to be the most important environmental factors that determine distribution and abundance of *A. navicularis*. The presence of tuberous root with well-developed winter perennating bud, shoot, and leaf meristem buried inside soil, globular blue flower, and persistent sepals, and rapid germination of seed after moistening are likely adaptive features of this plant in alpine environments. Variation in plant height and petiole length enabled this plant to grow from open areas to dense juniper scrubs. Alpine scrub seems to have protected this plant from livestock damage and human collection.

ACKNOWLEDGMENTS

Financial support from the Volkswagen Foundation (Germany) is gratefully acknowledged. We are thankful to Annapurna Conservation Area Project for permission to work in the protected area. We acknowledge the help of Prof RP Chaudhary and RK Sharma of the Central Department of Botany, Tribhuvan University, during the field study. K. Gurung, P. Sherpa, A. Pariyar, C. Gurung, and M. Gurung of Manang helped at various times during field sampling. We thank P. S. Chapagain of the Central Department of Geography, Tribhuvan University, for preparing the map of the study area.

REFERENCES

Baral SR, Kurmi PP. 2006. A Compendium of Medicinal Plants in Nepal. Kathmandu, Nepal: R. Sharma.

Baskin CC, Baskin JM. 1998. Seeds. San Diego, CA: Academic Press.

Bertness MD, Callaway RM. 1994. Positive interactions in communities. Trends in Ecology and Evolution 9:191–193.

Bhattarai S, Chaudhary RP, Taylor RSL. 2006. Ethnomedicinal plants used by the people of Manang district, central Nepal. Journal of Ethnobiology and Ethnomedicine 2:41. http://dx.doi:10.1186/1746-4269-2:41.

Bliss LC. 1956. A comparison of plant development in microenvironment of arctic and alpine tundras. Ecological Monograph 26:303–337.

Bliss LC. 1958. Seed germination in arctic and alpine species. Arctic 11:180–188.

Bliss LC. 1962. Adaptation of arctic and alpine plants to environmental conditions. Arctic 15:117–144.

Bosch M, Waser NM. 1999. Effect of local density on pollination and reproduction in Delphinium nuttallianum and Aconitum columbianum (Ranunculaceae). American Journal of Botany 86:871–879

Callaway RM. 2007. Positive Interactions and Interdependence in Plant Communities. Dordrecht, The Netherlands: Springer.

CAMP. 1998. Selected Medicinal Plants of Northern, Northeastern and Central India: Conservation Assessment and Management Plans (CAMP). Lucknow, India: Forest Department of Uttar Pradesh.

Chandrashrhekar K, Rao KS, Malikur TK, Saxena KG. 2007. Ecological implications of traditional livestock husbandry and associated land use practices: A case study from the trans-Himalaya, India. Journal of Arid Environments 69:299–314.

de Koon H, Hutchings MJ. 1995. Morphological plasticity in clonal plants: The foraging concept reconsidered. Journal of Ecology 83:143–152.

Dhar U, Rawal RS, Upreti J. 2000. Setting priorities for conservation of medicinal plants: A case study in the Indian Himalaya. Biological Conservation 95:57–65.

Facelli JM, Temby AM. 2002. Multiple effects of shrubs on annual plant communities in arid lands of South Australia. Austral Ecology 27:422–432.

Felsther DS, Westoby M. 2003. Plant height and evolutionary game. Trends in Ecology and Evolution 18:337–343.

Garg A, Husain T. 2003. Strategies adopted by the alpine genus Pedicularis L. (Scrophulariaceae) to overcome environmental stress. Current Science 85:1413–1414.

Ghimire SK, McKee D, Aumeeruddy-Thomas Y. 2005. Conservation of Himalayan medicinal plants: Harvesting patterns and ecology of two threatened species, *Nardostachys grandiflora* DC. and *Neoporicniza scrophulariiflora* (Penniset) Hong. Biological Conservation 124:463–475.

Ghimire SK, Sah JP, Shrestha KK, Bajracharya D. 1999. Ecological study of some high altitude medicinal and aromatic plants in the Gyasungdo valley, Manang, Nepal. Ecoprint 6:17–25.

Gnisenko AJC, Long D. 1984. Flora of Bhutan. Vol 1. Part 2. Edinburgh, United Kingdom: Royal Botanical Garden.

Gupta PK. 2000. Methods in Environmental Analysis: Water, Soil and Air. New Delhi, India: Agrobios.

Huber H. 1996. Plasticity of intemodes and petioles in erect and prostrate Potentilla species. Functional Ecology 10:401–409.

Kala CP. 2001. Status and conservation of rare and endangered medicinal plants in the Indian trans-Himalaya. Biological Conservation 93:371–379.

Kala CP. 2005. Indigenous uses, population density and conservation of threatened medicinal plants in protected areas of Indian Himalayas. Conservation Biology 19:368–378.

Körner C. 2003. Alpine Plant Life. 2nd edition. Berlin, Germany: Springer-Verlag.

Kunwar R, Bussmann RW. 2008. Ethnobotany in the Nepal Himalayas. Journal of Ethnobiology and Ethnomedicine 4:24. http://dx.doi:10.1186/1746-4269-4:24.

Lama YC, Ghimire SK, Aumeeruddy-Thomas Y. 2001. Medicinal Plants of Dolpo: Amchis’ Knowledge and Conservation. Kathmandu, Nepal: WWF [World Wide Fund for Nature] Nepal Program.

Liangqian L, Kodata Y. 2001. Aconitum L. In: Zhengyi W, Raven PH, Deyuan H, editors. Flora of China. Vol 6. Caryophyllaceae through Lardizabalaceae. Beijing, China: Science Press, pp 149–222.

Miehe G, Winiger M, Böhner J, Zhang Y. 2001. The climate diagram map of High Asia. Purpose and concepts. Erdkunde 55:94–95.

Molau U. 1993. Relationship between flowering phenology and life history strategies in tundra plants. Arctic and Alpine Research 25:391–402.

Morgan JW. 1999. Effects of population size on seed production and germinability in an endangered, fragmented grassland plant. Conservation Biology 13:266–273.

Murray BR, Thrall PH, Gill AM, Nicotra AB. 2002. How plant life history and ecological traits relate to species rarity and commonness at varying spatial scales. Austral Ecology 27:291–310.

Nautilly BP, Prakash V, Bahuguna R, Maitiun U, Bisht H, Nautilly MC. 2002. Population study for monitoring the status of rarity of three aconite species in Garhwal Himalaya. Tropical Ecology 43:297–303.

Ohba H, Iokawa Y, Sharma LR, editors. 2008. Flora of Mustang, Nepal. Tokyo, Japan: Kodansha Scientific Ltd.

Öke TR. 1987. Boundary Layer Climates. New York, NY: Methuen and Co.

Olsen CS, Larsen HO. 2003. Alpine medicinal plant trade and Himalayan mountain livelihood strategies. The Geographical Journal 169:243–254.

Oostermeijer JGB, van Eljke MW, den Nijs JCM. 1994. Offspring fitness in relation to population size and genetic variation in the rare perennial plant species Gentiana pneumonanthe (Gentianaceae). Oecologia 97:289–296.
Shrestha BB, Ghimire BK, Lekhak HD, Jha PK. 2007a. Regeneration of treeline birch (Betula utilis D.Don) forest in a trans-Himalayan dry valley in central Nepal. Mountain Research and Development 27:259–267.

Shrestha BB, Jha PK. 2009. Habitat range of two alpine medicinal plants in a trans-Himalayan dry valley, central Nepal. Journal of Mountain Science 6:66–77.

Shrestha BB, Jha PK, Gewali MB. 2007b. Ethnomedicinal use and distribution of Aconitum navicular (Brühl) Stapf, in upper Manang, Nepal. In: Chaudhary RP, Aase TH, Vetaas OR, Subedi BP, editors. Local Effects of Global Changes in the Himalayas: Manang, Nepal. Kathmandu, Nepal: Tribhuvan University, pp 171–181.

Sokal RR, Rohlf FJ. 1995. Biometry. New York, NY: WH Freeman.

Stainton A. 1997. Flowers of the Himalayas: A supplement. New Delhi, India: Oxford University Press.

Sultan SE. 2003. Phenotypic plasticity in plants: A case study in ecological development. Evolution and Development 5:25–33.