

# Biology, Distribution and Population Status of *Gymnocladus assamicus*

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## 1.1 Introduction

The eastern Himalayan region of northeast India is a global 'biodiversity hotspot', home to relict species found nowhere else in the world. However, the region's biodiversity has been threatened by anthropogenic activities such as over-harvesting, habitat degradation and agricultural extension, and thus requires an integrated approach for effective management at local and international levels (Dong *et al.*, 2017). Soap pod tree (*Gymnocladus assamicus* Kanj. ex. P.C. Kanjilal) is a tree species facing tremendous extinction pressure in its natural habitat due to several such activities. The species possesses enormous economic and ecological importance throughout its distribution range and an effective conservation initiative is urgently needed. *G. assamicus* is a medium-sized deciduous tree with horizontal ascending branching. Etymologically, *Gymnocladus* means 'naked twigs' (Greek), a name which is derived from the tree's branches, which remain leafless for a prolonged period and appear 'naked' after leaf fall. *G. assamicus* is locally known as *Menangmanba-shi* among the Monpa tribe and *Minkling* among the Lish Monpa tribe in Arunachal Pradesh, meaning 'soap tree'.

Ethnobotanical use of the *G. assamicus* pods is very popular among the local people, and is intimately associated with the culture and tradition of the region. However, the species has been listed recently as critically endangered in the International Union for the Conservation of Nature (IUCN) Red List due to natural and anthropogenic activities, and requires urgent protection measures (Saha *et al.*, 2015). Natural populations of actively reproducing *G. assamicus* trees were found to be extremely small (Menon *et al.*, 2010) and, as such, the species has been included on the priority list for the recovery programme in India (Ganeshaiah, 2005).

## 1.2 Taxonomy of *G. assamicus*

The taxonomic position of *Gymnocladus assamicus* as par Benthum and Hooker (1862–1883) is as follows:

- **Phylum:** *Angiospermae*
  - **Class:** *Dicotyledonae*
    - **Subclass:** *Polypetalae*
      - **Order:** *Rosales*
        - **Family:** *Leguminosae*
          - **Subfamily:** *Caesalpinioideae*
            - **Genus:** *Gymnocladus* Lamarck, 1785
              - **Species:** *G. assamicus* Kanjilal ex. PC Kanjilal

**Botanical name:** *Gymnocladus assamicus* Kanjilal ex. PC Kanjilal, 1934.

**Type:** India, Assam, Khasi Hills, Laitkshé, Marngor, 1800 m, UN Kanjilal 7624, holo: DD; iso: ASSAM, CSL, K.

### 1.2.1 Taxonomic description

This is a medium-sized tree with average height of 15 to 17 m (Fig. 1.1.); the trunk is horizontal with ascending branching. The bark is greyish-brown with an outer reticulate corky layer having parallel furrows (Fig. 1.2). Bi-pinnate compound leaves are alternate, 38–45 x 20–25 cm, obscurely glandulose with a swollen base, having 10–12 pairs of pinnae (Fig. 1.3). The pinnae are opposite or distantly sub-opposite, 10–22 x 6–8 cm with 15–20 leaflets. Leaflets are shortly petioled, subopposite to alternate, 2–2.3 x 0.64–0.67 cm, oblong to ovate oblong, minutely mucronate, nearly glabrous above with minutely brown pubescent beneath the midrib. The main lateral nerves are 5–8 in number on either side and are very obscure, slightly elevated above and depressed beneath. The base of the leaflets is rounded to slightly cuneate with short petiolules mounted with sparsely adpressed hair.

### 1.2.2 Floral sexuality

The inflorescence of *Gymnocladus assamicus* is of terminal racemose type, having fine pubescence throughout. Male inflorescence is larger, 13–16 x 5–6 cm, with nearly whorled lateral branches comprising 15–20 flowering nodes (Fig. 1.4). In comparison, hermaphrodite inflorescence is smaller and varies from 4–6 x 5–6 cm (Fig. 1.5). The average number of flowers per male inflorescence was observed to be 72.50 ( $\pm 4.01$ ,  $n=20$ ) and that of hermaphrodite flowers per inflorescence was observed to be 23.40 ( $\pm 4.01$ ,  $n=20$ ). Both male and bisexual flowers are small, tubular, violet-coloured and odourless.



**Fig. 1.1.** Habitat of a mature *G. assamica* tree (photo: Baharul I. Choudhury).



**Fig. 1.2.** *G. assamicus* bark: reticulate corky outer cover having parallel furrows (photo: Baharul I. Choudhury).



**Fig. 1.3.** Bi-pinnate compound leaves of *G. assamicus* (photo: Baharul I. Choudhury).

### 1.2.3 Hermaphrodite flower

Complete, pedicellate, actinomorphic, pentamerous, tubular, narrowed at the base and becoming gradually wider at the mouth. Corolla is with five united petals. Petals 10–15 mm long, hairy, shaggy throughout, corolla tube ca 3.43 mm wide. Calyx with five basally connate sepals, subequal, lanceolate to ovate, 4–6 mm long with shaggy brown hair. Corolla tube is 5–7 mm long and 3.43 mm wide at anthesis and is also shaggy brown hairy outside.

Calyx comprising five lobes, which are subequal and lanceolate to subulate, 4–6 mm long with shaggy brown hairy outside. Stamens 10, didynamous, alternate with 1.5–2.5 mm long filaments. Anthers are oblong, ovoid and dithacous.





**Fig. 1.4.** Male *G. assamica* inflorescence (photo: Prabhat C. Nath).



**Fig. 1.5.** Hermaphrodite *G. assamica* flowers (photo: Baharul I. Choudhury).

Pistil one, 9–10 mm long at anthesis, slightly arched, thick and compressed, well demarcated into stigma, style and ovary. Ovary superior, unilocular with 5–8 ovules in each locule, style straight, slightly thick and compressed with oblique stigma. Stigma surface is slightly slanted, papillate with wet sticky exudates.

#### 1.2.4 Male flower

Male flowers are shorter pedicellate as compared with hermaphrodite flowers. Each corolla tube is 4–6 mm long and ca 3 mm wide at anthesis and is also shaggy brown hairy on the outside. Vestigial carpel is visible at the base of the perianth tube.

#### 1.2.5 Fruit

The fruits of *G. assamica* are of typical pod type and range from 10–16 to 2.5–4 cm in dimension, and are compressed and turgid over the seeds. Pericarp is polished and fleshy; mesocarp is highly saponaceous (Fig. 1.6). Each pod contains 4–8 seeds. Seeds are 14–15 x 15–17 mm in dimension, ovoid or subglobose, have black horny testa, and are extremely hard. Radicle is comparatively small and erect.



**Fig. 1.6.** Highly saponaceous *G. assamicus* mature pods (photo: Baharul I. Choudhury).



**Fig. 1.7.** *G. assamicus* mature pods from previous fruiting season (photo: Baharul I. Choudhury).

Fully mature pods are fleshy, having a pungent smell which persists on the trees for a prolonged period of time (Fig. 1.7). Wood is moderately hard and yellowish white. Pith is soft, spongy and more prominent in young shoot (Fig. 1.8).

### 1.3 Ethnobotanical Uses of Fruits

Ethnobotanical information forms a rich knowledge system for the health and nutrition of indigenous people, particularly within resource-poor rural communities.



**Fig. 1.8.** Longitudinal section of *G. assamicus* wood (Photo: Baharul I. Choudhury).

Such invaluable information is often unwritten and inherited through generations via verbal communication. However, this knowledge system is being threatened by modern cultural practices and global economic changes. Therefore, documentation and preservation of ethnobotanical knowledge is crucial for sustainability of natural resources, preservation of tradition, resource management, conservation and community development.

Traditional societies in the eastern Himalayan region are integral to the local ecosystems, and play a significant role in the maintenance of their ecological surroundings. Non-timber forest products (NTFPs) have been collected and used for generations for subsistence and trade. *G. assamicus* pods are unique in multiple aspects. Pods become brown and fleshy during maturation and develop an alluring smell. Post-maturation, pods persist on trees for an extended period and are clearly visible (Fig. 1.7). This trait helps local people locate mature pods from a fair distance and harvest the pods for future use.

The local Monpa people are largely dependent on NTFPs for food, medicine, dye, firewood, resin and fibre (Saha and Sundriyal, 2012). *G. assamicus* is intimately associated with the daily life and rituals of the Monpas of Arunachal Pradesh due to its multiplicity of ethnobotanical uses (Choudhury *et al.*, 2007a). Local people are familiar with the locations of most of the mature trees in the neighbourhood, and harvest fully mature pods mainly from the tree directly, or from the ground. Large-scale harvesting, often of all mature pods, has been found to be common. Excess pods are stored for future use, sometimes for four to five years, as documented in the Monpa community. In some cases, pods are harvested by cutting down the branches, which severely damages the tree (Fig. 1.9). Monpa people consider mature *G. assamicus* pods sacred, and exchange them as gifts within the community. Additionally, Buddhist monks, locally known as *lama*, gratefully accept the pods as religiously significant gifts.

Pods are exploited for multiple purposes. They are primarily used during worship at monasteries, locally known as *gompa*. The Buddhist people of Arunachal Pradesh prepare a decorative, colourful and sacred structure known as a *torgen*, meaning 'flower' (Fig. 1.10), to perform rituals. The main ingredient of the *torgen* is *torma* which is a mixture of wheat flour, clarified butter (ghee) from yak milk, and wax. *Torma* is very sticky in nature, and clings to the hands during *torgen* preparation. Pre-soaked pods are rubbed between the hands to prevent such clinging during preparation, as a substitute for detergent (Fig. 1.11). The use of *G. assamicus*

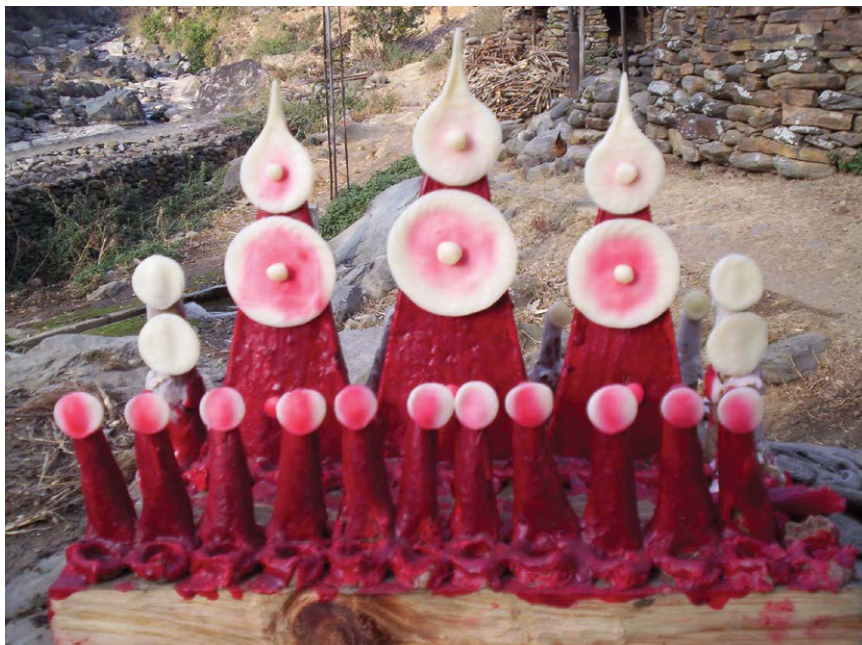


**Fig. 1.9.** Mature pods have been collected here by cutting down branches of the *G. assamicus* tree (photo: Baharul I. Choudhury).

pods is more effective than commercial soaps in eliminating the stickiness of the *torma*. More importantly, use of this natural soap substitute for such rituals is regarded as sacrosanct.

Cleanliness is a human necessity, and traditional ways of maintaining cleanliness using available means and methods have been practiced for centuries. Multiple plant species with rich saponin content and effective cleansing properties have been reported in India (Mehta and Bhatt, 2007) and other parts of the world (Osborn, 1996). The fruit of *Sapindus mukorossi*, popularly known as soapnut, is recognized in many cultures across Asia for its cleansing properties (Nakayama *et al.*, 1986; Suhagia *et al.*, 2011). The cleansing action of soapwort (*Saponaria officinalis*) has also been known for centuries (Osborn, 1996). However, due to a lack of documentation, *G. assamicus* pods are lesser known despite their strong cleansing properties. Pods are popularly used for domestic cleansing purposes such as washing clothes, hands and utensils. Older generations still prefer the pods for bathing, in lieu of soap. We documented a very efficient cleansing properties of the pods against a wide range of strong fats, oils and other complex stains from daily activities. Women use the pods for shampooing, and cite them as superior to commercial shampoos for the removal of dandruff. In one study, MeOH extracts from the fruits of *Gymnocladus* were found to exhibit anti-HIV activity (Konoshima *et al.*, 1995). In another study, Lee and Morris-Natschke (1999) found that *Gymnocladus* saponin isolated from fruits inhibited HIV replication with an  $EC_{50}$  value of  $27\mu\text{M}$ . Dried fruits of *G. chinensis* have long been known





**Fig. 1.10.** *Torgen* made of highly greasy materials assisted with the use of *G. assamicus* pod (photo: Baharul I. Choudhury).



**Fig. 1.11.** Demonstration of *G. assamicus* pod use during *torgen* preparation in Dirang monastery (photo: Baharul I. Choudhury).

in oriental medicine as saponin drugs, and used as diuretics and expectorants (Konoshima *et al.*, 1995). A recent study reported the synthesis of gold (Au) nanoparticles by using *Gymnocladus assamicus* pod extract in an aqueous medium (Tamuly *et al.*, 2013). However, chemical properties of the saponin are not fully

known or characterized chemically as yet, and this may provide a better understanding of the active compounds in the mature pods.

Forest dwellers in Tawang and West Kameng districts of Arunachal Pradesh use the decoction of pods on the bodies of their domestic animals to prevent leech and other insect bites. Pods are soaked overnight in water and applied to the animals externally before they are let out to graze in forest land. Black-coloured seeds are round and extremely hard. Local people occasionally munch roasted *G. assamicus* seeds, or prepare beverages by boiling the powdered seeds.

The North American *G. dioica* is commonly known as the Kentucky coffee tree (USDA, 2017), a name which stems from the resemblance of its seeds to coffee beans. The early immigrants to Kentucky are said to have roasted and ground the coffee-tree beans, and used them as an inferior substitute for coffee. There are some reports that indigenous North Americans used the seeds for food. However, the seeds are unpleasantly bitter, and contain the alkaloid cystosine, which causes gastrointestinal disorders and may lead to irregular pulse and coma (Bowles, 2004). Overconsumption of *G. assamicus* seeds causes dizziness, nausea and vomiting. Cattle fatalities have also been reported after ingesting the mature seeds.

The dark, round, shiny seeds also have some aesthetic appeal and are used as beads in rustic jewellery. *G. dioica* seeds are known as ‘hully-gullies’ and are sometimes carried by children as good luck charms. The wood of the tree is coarse-grained, heavy and strong. In the USA, it is sometimes used for railway ties, fence-posts and construction but is of little commercial importance due to its lack of abundance. *G. dioica* is also grown extensively as an ornamental tree (Bowles, 2004).

## 1.4 Distribution

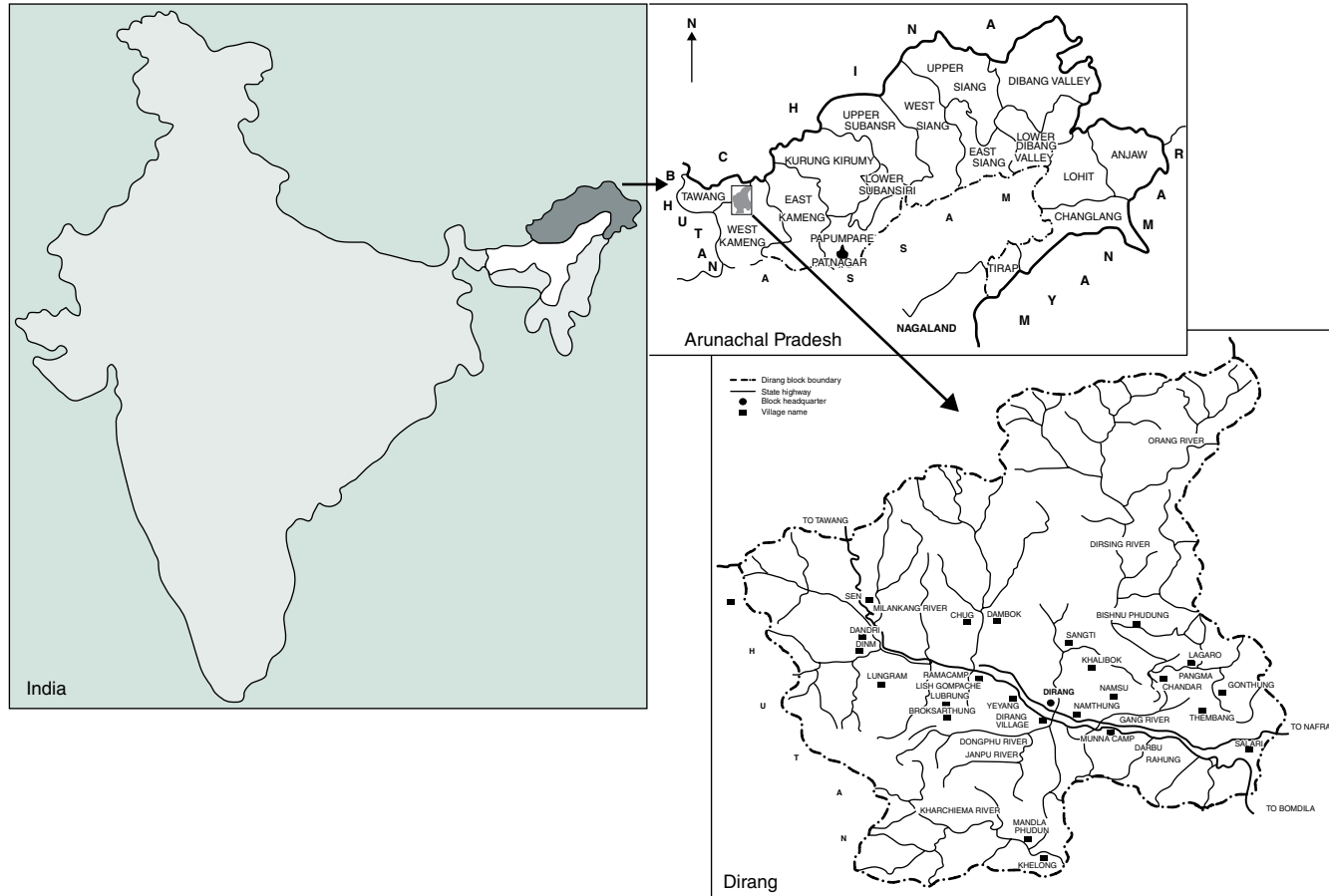
The edapho-climatic conditions of northeastern India favour luxuriant growth of vegetation attaining the stage of climax formation which is represented by the scattered oak forests of the region. Arunachal Pradesh is located in the extreme northeastern part of India with a geographical area of 8.37 million ha and is the largest state in the region. It consists of 16 districts and is home to extraordinarily high levels of biodiversity (Dong *et al.*, 2017). The state has a wide range of elevations, ranging from 100 m in adjacent areas of the Assam plains, to 7000 m in the Shiwalik hill ranges of the greater Himalayas. The species richness of the state is very high, with 4,000–5,000 species of vascular plants per 10,000 sq. km, and it is thus considered the second most biodiverse region on the globe (Valdiya, 2002). It is endowed with six major forest types within four major climatic categories (Kaul and Haridasan, 1987) and is home to 4,117 species of flowering plants belonging to 1,295 genera and 192 families (Chowdhery and Pal, 1997). Major groups include 600 species of orchids, 89 species of bamboos, 18 species of canes, 400 species of ferns, 24 species of gymnosperms and innumerable species of algae, fungi, lichens, bryophytes and microorganisms (Hegde, 2002). New taxa are routinely added from the area (Rappole *et al.*, 2005; Bawri *et al.*, 2016) which

harbours great potential for continued discovery through field exploration and the use of geographic information system (GIS) technologies.

*G. assamicus* is rarely documented due to its extremely small natural population. After its first report from the Khasi Hills of Meghalaya (undivided Assam) in 1934 (Kanjilal *et al.*, 1938), the species remained undocumented for several decades except two sporadic records from Arunachal Pradesh (Hajra *et al.*, 1996) and Nagaland (Sanjappa, 2000) of northeast India. It has been re-documented recently from the West Khasi Hills district of Meghalaya (Venugopal and Pamidimarri, 2015). We performed an extensive field survey throughout Arunachal Pradesh to document the distribution of *G. assamicus*, and recorded individual trees from each site from 2004 to 2007.

Locating populations of such rare, endangered and poorly understood species is an important consideration in biodiversity conservation for assessing species' conservation status and for developing effective strategies for in situ and ex situ conservation. Poor records of *G. assamicus* populations may be associated with challenging field surveys constrained by rugged terrain, political unrest, poorly understood distributional ecology and/or low population sizes with widely dispersed individuals. To overcome these challenges, we applied an ecological niche modelling (ENM) technique which provides a powerful predictive framework for targeting areas for field surveys to locate additional populations. ENM combines known occurrence records with relevant environmental layers to estimate species' ecological requirements and potential geographic distributions (Guisan and Zimmermann, 2000; Soberón and Peterson, 2005). The technique assists in narrowing down the most plausible occurrence sites for targeted field surveys, which otherwise may constitute a formidable time and labour sink with low probability of success. The ENM approach has been successfully used in locating new populations of poorly understood species (Raxworthy *et al.*, 2003; Bourg *et al.*, 2005; Menon *et al.*, 2012; Jathar *et al.*, 2015).

We focused on Tawang and West Kameng districts in Arunachal Pradesh for this study (26° 54' to 28° 01' N, 91° 16' to 92° 40' E). The region is bordered by Tibet to the north, Bhutan to the southwest and the state of Assam to the south. Detailed field inventories were carried out between 2004 and 2007 in the Dirang forest area located in West Kameng, Arunachal Pradesh, northeastern India (Fig. 1.12). The forest is variously classified as eastern Himalayan wet temperate forest (Champion and Seth, 1968) or subtropical deciduous forest (Kaul and Haridasan, 1987). The area is mostly mountainous, covering 892 km<sup>2</sup>, and is surrounded by higher elevation terrain (2,800–3,400 m) in Bomdila and Tawang districts. The Dirang Forest Range was declared an 'unclassed state forest' by the state forest department as most of the area is under the jurisdiction of local communities. The forest areas are exposed to diverse forms of anthropogenic and natural influences, including logging, agricultural extension, human settlement, road construction and landslides. Detailed field inventories of natural populations of *G. assamicus* were collected from local inhabitants and direct field visits to nine locations. The type locality for *G. assamicus* is located approximately 200 km southwest of the present location in Latikesh, Marngor, Assam, Khasi Hills, now



**Fig. 1.12.** Location map of Dirang showing distribution of *G. assamicus* populations (starred numbers).

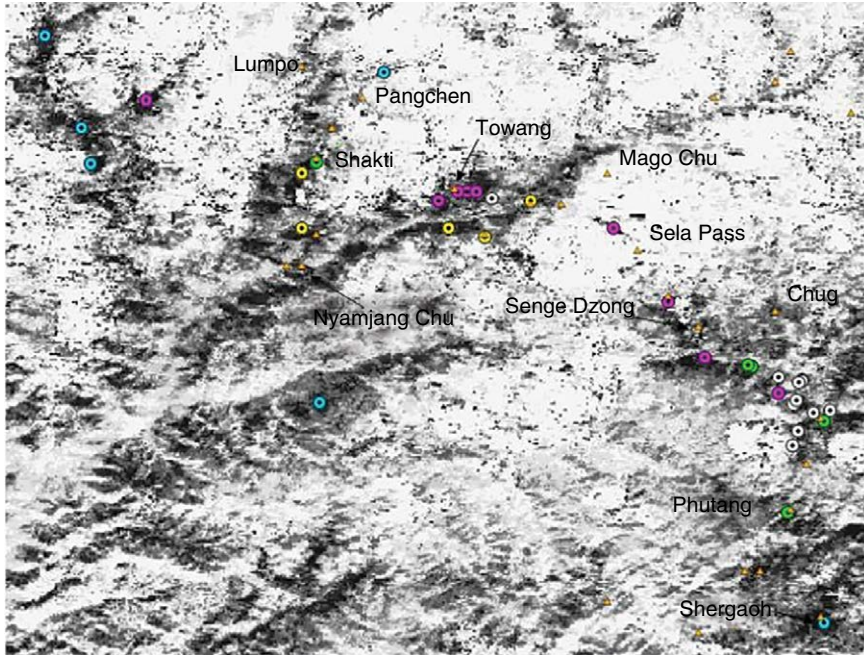


in Meghalaya. However, it may be extirpated from the site since no collection has been made since 1920. All occurrence locations were georeferenced using geographic/global positioning system (GPS) units accurate to 10–100 m. Finally, we recorded 14 discrete populations of one to seven trees each and the occurrence points were used as input data to train the niche model. We then applied two ENM techniques (GARP and Maxent), along with a jackknife validation approach, to develop ENMs based on the few known occurrences.

Eleven remotely-sensed layers from the NASA-MODIS/Terra data set (spatial resolution 500 x 500 m – Justice *et al.*, 1998) were used to characterize environments across the region. Six of the layers were 16-day composite images of the enhanced vegetation index (EVI) from every second month in 2005, and five summarized the difference between each consecutive pair of the six EVI layers. Two evolutionary-computing approaches were used to develop ENM and associated geographic predictions: the genetic algorithm for rule-set prediction (GARP) (Stockwell, 1999) and Maxent (Phillips *et al.*, 2006). Both algorithms relate known occurrence points to sets of digital raster GIS data layers that describe relevant environmental parameters (in this case, the EVI data sets) to derive a model in the form of decision rules differentiating areas of suitable conditions from areas presenting unsuitable conditions. GARP uses a genetic algorithm to optimize the predictive ability of models regarding independent suites of occurrence information, whereas Maxent uses the principle of maximum entropy to achieve the same end. In this application, we used default parameterization of both algorithms (except that a soft omission threshold of 20% was used in GARP, and a 50% random test percentage was used in Maxent). Both algorithms are well described in the literature and have been used to predict species occurrences with maximum success in locating the species of interest (Stockwell, 1999; Peterson *et al.*, 2007; Batalden *et al.*, 2014; Raghavan *et al.*, 2016). The ENM approach was designed, developed and implemented in collaboration with Dr Shaily Menon from Grand Valley State University (USA) and A. Townsend Peterson from the University of Kansas (USA). Detailed ENM methodology is described in Menon *et al.* (2010).

Altogether, 26 discrete areas were predicted by the ENM as having the highest probability of occurrence (i.e. most highly suitable) for *G. assamicus*. Maps were generated to guide the field survey demarcating the centre and search radius for each of the 26 areas. The search radii ranged from 0.5–2.0 km, corresponding to the extent of the high probability prediction at each site. A rapid field survey was conducted over a 10-day period with the help of the maps and a GPS. Of the 26 predicted areas, 14 were relatively accessible. The field survey team directly visited each of these 14 sites and searched for *G. assamicus* individuals within the radius predicted by the niche model. The remaining 12 areas could not be visited due to inaccessibility. Instead, the field survey team interviewed residents from nearby villages to gather indirect evidence.

The ENM prediction from GARP and Maxent identified small patches of suitable areas across the region (Fig. 1.13) and the average of the two niche modelling approaches was used to predict the potential distribution of *G. assamicus*. The



**Fig. 1.13.** ENM map showing *G. assamicus* populations in the mapped area. Darker patches represent regions with higher probability of the species' occurrence. White circles represent input data (14 previously known occurrence points) used to create the models; green circles represent direct evidence of the species' presence; yellow circles represent indirect evidence of the species' presence; purple circles represent the species' absence; and blue circles represent areas not yet surveyed.

predictions also identified similar areas across the study area. The jackknife tests of model validations confirmed that both predictions were predicting the species' occurrence significantly better than random expectations ( $p < 0.05$ ). Averaging the two predictions produced a predictive map that identified relatively restricted portions of the study areas as presenting the highest suitability for the species (Fig. 1.13). The field surveys encountered five new occurrences of *G. assamicus* at 14 of the 26 suitable sites that could be directly surveyed.

Populations comprising four mature trees each were encountered in Sapper Camps 1 and 2 at the Chug predicted site. Both populations were on slopes on the bank of a small river. Although the trees were mature, flowering and fruiting were not observed during the field survey. Two fruiting trees were found growing between small hillocks in the Dirang Dzong (Phadam) predicted site. One mature tree was discovered at each of the Shakti and Phudung (Wangkethanka) sites in valleys near small streams. Interviews of villagers from nearby villages indicated the likely presence of additional trees at five sites that were not accessible for field visits.

This study illustrates the potential of ENM in enabling and improving endangered species research, permitting identification of additional populations of rare and poorly understood species via rapid field surveys, targeted and guided by niche model predictions. Our study demonstrates that models generated with small numbers of known occurrence points can be effective in predicting high probability areas of species occurrence. This validation approach has demonstrated the considerable predictive power of models generated with scarce locality records with respect to their potential for the discovery of new species and populations (Peterson *et al.*, 2007). More detailed field surveys, including areas where only indirect evidence of the species' presence was recorded, will likely uncover additional populations and individuals of this species. Despite our discoveries, the numbers and population size of *G. assamicus* remain extremely small.

## 1.5 Population Status of Soap Pod Tree and its Associated Vegetation

The population dynamics of plant species can be described by demographic variables such as the recruitment, mortality and growth rates of individuals (Watkinson, 1997). Patterns of birth and death determine population size and vary drastically within species (Roff, 1993). Balance among these variables has been found to regulate the dynamics and structure of a population (Kohyama and Hara, 1989). The structure of plant communities in any forest ecosystem is largely determined by intensity, magnitude and frequency of disturbances that take place in a forest (Armesto and Pickett, 1985; Miller *et al.*, 2011). Disturbance often causes different effects on vegetation including canopy opening and creating treefall gaps that provide opportunities for the quick appearance of pioneer tree species in areas where direct sunlight reaches the ground (Brokaw, 1982; Whitmore, 1984; Holeksa *et al.*, 2017). On the other hand, intense disturbance events may destroy a larger section of the forest, leading to more widespread regeneration (Wright and Heinselman, 1973). Quantitative studies have shown that pioneer species have fast growth rates, short life spans, low wood density and efficient seed dispersal (Swaine and Hall, 1983; Whitmore, 1984). Different types of disturbances differentially affect vegetation (Segura *et al.*, 2003). For example, disturbance may increase biodiversity within a community (Thom and Seidl, 2016), thus enacting positive change. In contrast, disturbance may also disrupt the climax species, thereby destabilizing the community (Clements, 1936) and decreasing the density and basal area of tree species (Nath *et al.*, 2005), thus enacting negative change.

A few plant species are restricted to very small areas due to specific microclimatic conditions (Wulff *et al.*, 2013) or climatic regression after the last Ice Age (Cox and Moore, 1993; Garcia *et al.*, 2000). Due to climate change and human disturbance, distribution of many species has reduced considerably or has become limited to small isolated patches with fewer number of individuals or migration of species towards suitable habitats (Franco, 1986; Garcia *et al.*, 2000; Corlett and Westcott, 2013). Species of such limited distribution often face acute regeneration

failure, leading to extinction. Many authors have studied the regeneration status of tree species in various parts of the world and have predicted regeneration status based on the age and size structure of a population (Khan *et al.*, 1987; Bhuyan *et al.*, 2003; Götmark and Kiffer, 2014). Successful natural regeneration is dependent upon several intrinsic and extrinsic factors such as the production and germination of seeds, sufficient seedling production, and establishment of seedlings and saplings (Good and Good, 1972; Rao, 1988). Biotic and abiotic environmental factors also greatly influence natural regeneration (Khan and Tripathi, 1986; Hirayama and Sakimoto, 2003; Tingstad *et al.*, 2015). However, very few studies have been conducted on population structure and regeneration status of rare/endangered northeast Indian species. The present study was undertaken to understand the population structure and regeneration status of *G. assamicus* in three different sites: Changfu Moon, Dambla village and Moishing village of the West Kameng district, Arunachal Pradesh.

Vegetation associated with *G. assamicus* was studied from 2004 to 2006 to understand the community structure by quadrat method. Multiple study plots were selected after preliminary field surveys based on the availability of *G. assamicus* population and geographic accessibility. Nine different plots were earmarked where *G. assamicus* is present, out of which three representative sites, that is, Changfu Moon, Dambla village and Moishing village, were selected for vegetation and microclimate analysis. Dambla village and Moishing village sites are located near to small streams and have gentle slopes (25°–30°), whereas Changfu Moon is located on a hilltop with a steep slope (50°–60°). Physical conditions of the hill slopes are drier compared to the stream sites. Geography, altitude and aspects of each of the study sites are given in Table 1.1. Distance between and among the sites ranges from 3 km (between Changfu Moon and Dambla village) to 8 km (between Moishing village and Dambla village).

To record the tree species, 20 quadrats of 10 m x 10 m size (covering 0.2 ha area) were randomly laid in the three selected sites. Similarly, 20 quadrats of 5 m x 5 m for shrubs and 20 quadrats of 1 m x 1 m for herbs were laid randomly within the same above-mentioned 10 m x 10 m quadrats in each of the three sites.

Girth at breast height (gbh) for trees and collar diameter (cd) for saplings (10≥20 cm cd at base and >30 cm height) and seedlings (≤10 cm cd at base and <30 cm height) were recorded. Seedling population and survival in relation to distance from the mother tree were ascertained by counting the number of seedlings and saplings with respect to increase in radial diameter following Khan and

**Table 1.1.** Geographic location and microclimate of the three study sites.

Study site	Latitude (N)	Longitude (E)	Mean altitude (m)	Aspect	PAR (mmol s <sup>-1</sup> m <sup>-2</sup> )
Changfu Moon	27°20'91"	92°14'16"	1922	Northwest	242–250
Dambla Village	27°20'51"	92°16'57"	1715	Southeast	1123–1130
Moishing	27°18'16"	92°14'11"	2052	Northwest	38–45



Tripathi (1986). Periodic determination of densities of seedlings was studied in one-year intervals between 2005 and 2007 in 20 randomly laid permanent quadrats of 1 m x 1 m size. All the seedlings and saplings that were recorded in each permanent quadrat were labelled with permanent aluminium tags. Survival, mortality and new recruits were estimated from such data, and demography of the species was drawn accordingly.

Plant specimens were collected and identified by consulting different herbaria (Botanical Survey of India, Itanagar and Shillong; State Forest Research Institute, Itanagar), following different floras (Kanjilal *et al.*, 1938; Hajra *et al.*, 1996; Polunin and Stainton, 2006; Stainton, 2007) and by consulting experts of the region. Nomenclature of plant species followed Benthum and Hooker (1862–1883). Quantitative analysis of vegetation for frequency, density and relative density was done following Misra (1968). Importance value index (IVI) was computed by summing up relative frequency, relative density and relative basal area for the woody species, while the same was calculated by summing up relative frequency and relative density values for herbaceous species.

The Sorenson similarity index was calculated using the formula given by Sorenson (1948).

The Sorenson similarity index =  $\frac{2C}{A+B} \times 100$  – where C is the number of species common to two relevés, A is the total number of species in relevé A, and B is the total number of species in relevé B.

In the present study, altogether 28 mature *G. assamicus* trees were documented from nine sites located in Dirang circle of West Kameng District, Arunachal Pradesh. The sites were scattered among 10 km<sup>2</sup> (altitude 1500–2000 m asl) of landscape, fragmented by heterogeneous geographical barriers such as rivers, small mountains, roads, human settlements and shifting agricultural land. Each of the sites is located at a different distance from human settlements, and as a result experiences different degrees of human interference. Moishing is the furthest location from human settlements (about 5 km) and thus experiences the least anthropogenic pressure. Other sites are located in the vicinity of small villages and thus harvesting pressure is comparatively high. The species is mostly distributed on the hill slopes and along the banks of streams. Number of mature trees per site ranged from one to seven, and only two sites (Moishing and Dambla) had seedlings and saplings. The distribution, sexuality and current population status of *G. assamicus* in and around Dirang of Arunachal Pradesh is presented in Table 1.2.

A total of 60 plant species (16 tree species, 16 shrubs and 28 herbs) belonging to 37 families and 60 genera were found to be associated with *G. assamicus* in the three study sites. *Quercus griffithii* and *Rhus wallichii* were the most common trees growing with *G. assamicus* in the three studied sites. Other associated woody species were *Alnus nepalensis*, *Illicium griffithii*, *Juglans regia*, *Rhododendron arboreum* and so forth (Table 1.3). The most common herbaceous species among the three sites were *Crassocephalum crepidioides* and *Smilacina purpurea*, whereas *Artemisia indica*, *Globba clarkei*, *Hydrocotyle asiatica*, *Polygonum plebeium* and *Spilanthes paniculata* were also common among two of the three studied sites (Table 1.3).

**Table 1.2.** Population status of *Gymnocladus assamicus* in and around Dirang of Arunachal Pradesh.

Site	Locality	Date of survey	Altitude (m)	Latitude (N)	Longitude (E)	No. of individuals	
						M	H
1	Changfu Moon	21.09.2005	1960	27°21'	92°14'	4	–
2	Dambla Basti	02.06.2005	1723	27°23'	92°14'	2	5
3	Dirang Basti	21.09.2005	1715	27°20'	92°15'	–	1
4	Jyotinagar	8.01.2005	1724	27°22'	92°14'	1	–
5	Lishpa Village I	26.04.2007	1870	27°23'	92°13'	5?	–
6	Lishpa Village II	27.04.2007	1900	27°23'	92°13'	5?	–
7	Moishing	19.11.2004	2052	27°18'	92°14'	1	1
8	Runkung Village	04.12.2006	1669	27°22'	92°15'	–	1
9	Yewang Village	19.11.2004	1688	27°21'	92°14'	1	1

M = male; H = hermaphrodite.

**Table 1.3.** Density (plants ha<sup>-1</sup>) and IVIs of tree species and relative importance of shrub and herb species occurring in the three selected sites.

Species	Family	Habit	Changfu Moon		Dambla village		Moishing village	
			Density ha <sup>-1</sup>	IVI	Density ha <sup>-1</sup>	IVI	Density ha <sup>-1</sup>	IVI
<i>Alnus nepalensis</i> D. Don.	Betulaceae	T	1	11.21	1	12.30	—	—
<i>Alstonia neriifolia</i> D. Don	Apocyanaceae	T	1	6.87	0.25	2.70	4.25	26.52
<i>Erythrina stricta</i> Roxb.	Leguminosae	T	—	—	10.25	94.55	—	—
<b><i>Gymnocladus assamica</i></b> <b>Kanj. ex PC Kanj.</b>	<b>Leguminosae</b>	<b>T</b>	<b>1</b>	<b>17.31</b>	<b>1</b>	<b>9.05</b>	<b>0.5</b>	<b>7.70</b>
<i>Ilex fragilis</i> Hook. f.	Aquifoliaceae	T	1.75	11.92	1.25	11.02	—	—
<i>Illicium griffithii</i> Hook. f. & Thomson	Illiciaceae	T	2.75	11.81	—	—	1	10.28
<i>Juglans regia</i> L.	Juglandaceae	T	3.5	32.02	4.75	45.11	—	—
<i>Phyllostachys mannii</i> Gamble	Poaceae	T	—	—	2.5	10.14	17.5	63.15
<i>Pinus roxburghii</i> Sargent.	Pinaceae	T	4.5	38.11	—	—	—	—
<i>Pyrus phasia</i> Buch. Ham. ex D. Don	Rosaceae	T	1.25	8.77	0.75	8.14	—	—
<i>Quercus griffithii</i> Hook. f. & Thomson ex Miq.	Fagaceae	T	4.25	36.70	2.75	34.20	12.75	182.45
<i>Rhododendron arboreum</i> Smith.	Ericaceae	T	3.75	29.98	—	—	0.25	4.57
<i>Rhus wallichii</i> Hook. f.	Anacardiaceae	T	3.25	26.72	1	9.09	0.25	5.33
<i>Rinorea bengalensis</i> Wallich	Violaceae	T	1.25	7.67	0.5	5.47	—	—
<i>Schima khasiana</i> Dyer.	Theaceae	T	5.25	60.90	4.5	58.22	—	—
<i>Achyranthes aspera</i> Hook. F.	Amaranthaceae	H	3,950	21.7	—	—	243	11.9

Continued

Table 1.3. Continued.

Species	Family	Habit	Changfu Moon		Dambila village		Moishing village	
			Density ha <sup>-1</sup>	IVI	Density ha <sup>-1</sup>	IVI	Density ha <sup>-1</sup>	IVI
<i>Alstonia neriifolia</i> D. Don	Apocyanaceae	S	600	5.9	—	—	—	—
<i>Anaphalis busua</i> DC.	Asteraceae	H	1,100	7.4	—	—	—	—
<i>Arisaema consanguineum</i> Schott.	Araceae	H	1,500	10.7	—	—	—	—
<i>Artemisia indica</i> Willd	Asteraceae	H	—	—	2,350	8.6	105	7.4
<i>Betula elnoides</i> Buch.-Ham. ex D. Don	Betulaceae	S	—	—	—	—	160	7.5
<i>Bidens pilosa</i> L.	Asteraceae	H	4,000	17.9	—	—	—	—
<i>Boehmeria platyphylla</i> D. Don	Urticaceae	S	—	—	8,300	21.5	—	—
<i>Cirsium verutum</i> (D. Don) Sprengel	Asteraceae	H	—	—	1,100	5.9	—	—
<i>Clematis acuminata</i> Bruehl	Ranunculaceae	H	—	—	500	4.3	—	—
<i>Commelina paludosa</i> Blume	Commelinaceae	H	—	—	—	—	458	18.9
<i>Crassocephalum crepidioides</i> S. Moore	Asteraceae	H	750	5.7	2,550	8.9	93	7.1
<i>Cynotis voga</i> (Lour) Schultes & Schultes	Commelinaceae	H	—	—	4,500	13.9	—	—
<i>Desmodium oblongum</i> Wallich ex Benth.	Leguminosae	S	—	—	1,150	4.8	—	—
<i>Elaeagnus caudata</i> Schlecht	Elaeagnaceae	S	—	—	—	—	53	4.9
<i>Elsholtzia blanda</i> Benth.	Nyctaginaceae	S	1,300	8.7	—	—	—	—
<i>Fagopyrum esculantum</i> Monech	Polygonaceae	H	450	4.7	—	—	180	11.6



<i>Ficus altissima</i> Blume.	Moraceae	S	—	—	900	3.2	—	—
<i>Fragaria nubicola</i> Lindley ex. Lacaita	Rosaceae	H	—	—	—	—	305	14.0
<i>Globba clarkei</i> Baker	Zingiberaceae	H	3,350	19.1	2,150	7.1	—	—
<i>Glycine max</i> L.	Papilionaceae	H	1,700	12.6	—	—	—	—
<i>Goldfussia nutans</i> Nees	Acanthaceae	H	—	—	1,200	4.3	—	—
<i>Hemiphragma heterophyllum</i> Wallich	Scrophulariaceae	H	—	—	1,100	4.7	—	—
<i>Hydrocotyle asiatica</i> L.	Apiaceae	H	3,550	18.4	4,450	13.3	—	—
<i>Ilex fragilis</i> Hook. f.	Aquifoliaceae	T	—	—	—	—	383	15.3
<i>Ligustrum indicum</i> (Lour.) Merr.	Oleaceae	S	—	—	—	—	263	13.6
<i>Litsea cubeba</i> (Lour.) Pers.	Ericaceae	S	—	—	1,400	4.7	—	—
<i>Lygodium japonicum</i> (Thunb. ex Murr.) Sw.	Lygodiaceae	H	1,450	8.5	—	—	—	—
<i>Lyonia ovalifolia</i> C.B. Clarke) Ridley	Ericaceae	T	—	—	—	—	50	2.4
<i>Melastoma normale</i> D. Don	Melastomaceae	S	—	—	500	3.7	—	—
<i>Morus macroura</i> Miq.	Moraceae	T	—	—	—	—	283	13.5
<i>Nepeta longibracteata</i> Benth	Lamiaceae	H	1,000	7.8	—	—	—	—
<i>Oenanthë javanica</i> (Blume) DC	Apiaceae	H	—	—	—	—	95	6.5
<i>Panicum insicum</i> L.	Poaceae	H	—	—	4,100	11.5	—	—
<i>Phaseolus vulgaris</i> L.	Papilionaceae	S	1,200	7.7	—	—	—	—
<i>Pilea umbrosa</i> Blume.	Urticaceae	S	1,650	11.8	—	—	—	—
<i>Polygonum plebeium</i> R. Br.	Polygonaceae	H	—	—	1,950	6.2	113	7.6
<i>Pouzolzia fuscescens</i> Kuntze	Utriculaceae	H	—	—	—	—	295	13.8

Continued

**Table 1.3.** Continued.

Species	Family	Habit	Changfu Moon		Dambla village		Moishing village	
			Density ha <sup>-1</sup>	IVI	Density ha <sup>-1</sup>	IVI	Density ha <sup>-1</sup>	IVI
<i>Pyrus phasia</i> Buch. Ham. ex D. Don	Rosaceae	S	900	9.5	650	2.8	—	—
<i>Rubia manjith</i> Roxb. Ex Flem.	Rubiaceae	H	—	—	6,450	21.8	—	—
<i>Schima khasiana</i> Dyer.	Theaceae	T	—	—	2,550	7.8	—	—
<i>Senecio wallichii</i> DC.	Asteraceae	H	1,900	12.6	—	—	—	—
<i>Smilacina purpurea</i> Wallich.	Liliaceae	H	1,450	9.2	2,350	9.1	418	16.8
<i>Solanum torvum</i> Swartz	Solanaceae	S	—	—	2,500	8.8	—	—
<i>Spilanthes paniculata</i> Wall. ex DC	Asteraceae	H	—	—	750	3.0	430	17.7
<i>Spiraea micrantha</i> Hook	Rosaceae	S	—	—	—	—	193	9.5
<i>Thalictrum alpinum</i> L.	Ranunculaceae	H	—	—	1,850	6.6	—	—
<i>Viburnum erubescens</i> Wallich ex DC	Sambucace	S	—	—	2,900	10.1	—	—

IVI: importance value index; T = tree; H= herb; S= shrub; '—' = absence.

The overall species richness varied among sites, and the highest number of associated plant species (34) was recorded from the Dambla site, and the lowest (24) from the Moishing site. Out of the total 60 plant species, 18 were woody species and 42 were shrubby/herbaceous species. Thirteen woody and 16 herbaceous species were documented in the Changfu Moon site. Twelve woody species were found in the Dambla site, while seven woody species were found in the Moishing site. The number of herb/shrub species found was 25 and 17 in the Dambla and Moishing sites, respectively (Table 1.3). The highest number of woody species were found in the Changfu Moon site (12), while the highest number of herbaceous species were found in the Dambla site (25).

The highest stand density of woody species (36.5 stems ha<sup>-1</sup>) was recorded in the Moishing site and the lowest (30.5 stems ha<sup>-1</sup>) in the Dambla site. The highest basal area of woody species was recorded in the Changfu Moon site (938.19 m<sup>2</sup> ha<sup>-1</sup>) followed by the Dambla (808.98 m<sup>2</sup> ha<sup>-1</sup>) and Moishing (332.42 m<sup>2</sup> ha<sup>-1</sup>) sites (Table 1.3). The density of shrub layer and ground vegetation was highest in the Dambla site (59,000 m<sup>2</sup> ha<sup>-1</sup>) followed by Changfu Moon (31,800 m<sup>2</sup> ha<sup>-1</sup>) and Moishing (4,115 m<sup>2</sup> ha<sup>-1</sup>). The dominance of the tree species was determined using calculated IVI values for each species. In the Changfu Moon site, *Pinus roxburghii*, *Quercus griffithii*, *Juglans regia* and *Rhododendron arboreum* were the dominant tree species, while *Erythrina stricta*, *Schima khasiana* and *Juglans regia* were dominant in the Dambla site. The Moishing site was dominated by *Quercus griffithii* and the bamboo species *Phyllostachys mannii*. Data for density and IVI for each of the associated species is presented in Table 1.3.

The Sorenson similarity index value among the three study sites varied greatly (Table 1.4). The highest similarity index of tree species (80%) was found between the Changfu Moon site and the Dambla site. The similarity index value between these two sites in terms of shrubs/herbs was 23.26% (Table 1.4). The Dambla and Moishing sites were the most dissimilar in tree species content (55.56%) while the herb/shrub richness among the three sites was similar in all the three (Table 1.4).

The density of *G. assamicus* was very low in all sites and ranged between 0.5 (Moishing) to 1 (Changfu Moon and Dambla) individuals per ha (Table 1.5). The IVI of the tree was higher in the Changfu Moon site than in the other two sites (Table 1.5). Seedlings, saplings and tree population varied greatly within the three

**Table 1.4.** Similarity (Sorenson) among the tree, shrub/herb species occurring in the two study sites.

Site		Changfu Moon		Dambala Village	
		T	S/H	T	S/H
Moishing	T	63.16	–	55.56	–
	S/H	–	22.22	–	23.26
Changfu Moon	T	–	–	80.00	–
	S/H	–	–	–	23.26

**Table 1.5.** Population status of *G. assamicus* trees in the three study sites.

Site	Density ha <sup>-1</sup>	IVI
Changfu Moon	1	17.31
Dambla village	1	9.05
Moishing village	0.5	7.70

IVI = Importance Value Index.

**Table 1.6.** Population status of three *G. assamicus* populations determined from all individuals located during the study.

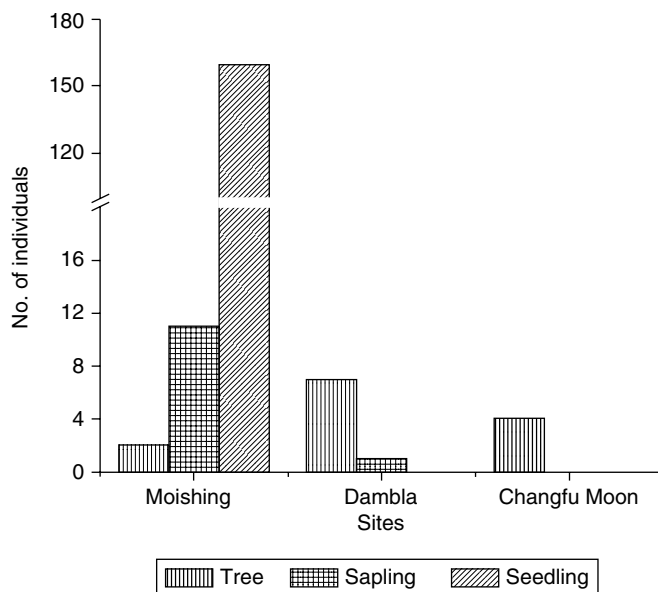
Parameter	Changfu Moon	Dambla village	Moishing village
Number of individuals	4	8	173
% mature tree	100	87.50	1.16
% saplings	—	12.50	6.36
(10≥20 cm cd at base and >30 cm height			
% seedlings	—	—	92.49
(≤10 cm cd at base and <30 cm height)			
Seedling survival (%)	—	—	80–83
New recruitment (%)	—	—	11–14

cd = collar diameter.

sites. In the Changfu Moon site, 100% *G. assamicus* were mature trees while only 1.16% of trees were mature in the Moishing site (Table 1.6). The proportion of saplings at the Dambla and Moishing sites was found to be 12.50% and 6.36%. However, seedling population was recorded only in the Moishing site and constituted 92.49% of the total *G. assamicus* population. Results of the demographic survey of three *G. assamicus* populations are summarized in Tables 1.5 and 1.6.

Present observation revealed that the percentage of mature tree populations was higher than that of sapling/seedling populations in the Dambla and Changfu Moon sites. The largest seedling (160) and sapling (11) populations were recorded in the Moishing site while only one sapling was found in the Dambla site (Fig. 1.14). In the Moishing site, 55% of seedlings occurred within 4 to 8 m radial distance from the mother plant. The density and survival of saplings was recorded only at 8 to 12 m radial distance from the base of the mother plant. There was no seedling or sapling population beyond 12 m radius, suggesting that seed dispersal of *G. assamicus* is very limited.

Our study revealed very few *G. assamicus* individuals in all the studied sites. Though mature trees were present in all sites, regenerating individuals were much less common, and sometimes absent (as in the Changfu Moon and Dambla villages). Rogers (1996) reported similar results in the case of the threatened tree *Olearia hectorii* in New Zealand. Subash Chandran *et al.* (2008) found small and relic populations of two critically endangered tree species *Madhuca bourdillonii* (Gamble) Lam.

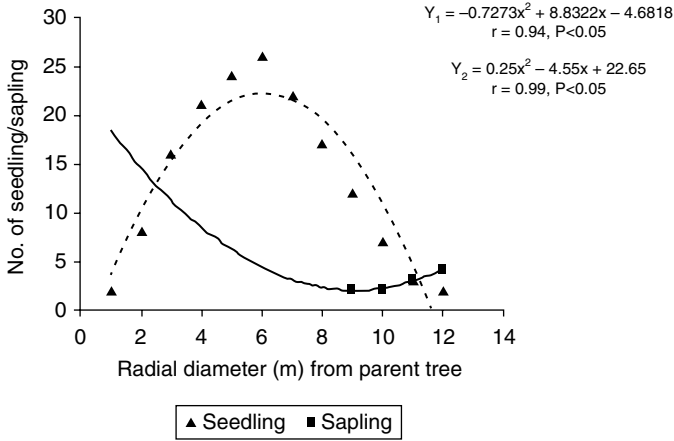


**Fig. 1.14.** Total number of trees, saplings and seedlings of *G. assamicus* that were recorded in the Moishing, Dambla and Changfu Moon sites.

and *Syzygium travancoricum* Gamble, in Western Ghats, India. The regeneration status of a plant species can be predicted by determining the population size of seedlings and saplings (Khan *et al.*, 1987; Bhuyan *et al.*, 2003). A species may be designated as ‘regenerating good’ if seedlings > saplings > adults; or fair regenerating if seedlings > or ≤ saplings ≤ adults; and poor regenerating if the species survives only in sapling stage, but no seedlings (saplings may be <, > or = adults – Khan *et al.*, 1987). If a species is present only in adult form, it is considered as ‘not regenerating’ (Devi, 2004). The age structure of *G. assamicus* indicates that it has very poor regeneration in the Changfu Moon and Dambla sites. The largest seedling and sapling population was recorded in the Moishing site (160 and 11 respectively) and thus regeneration was found to be ‘good’. Similar discontinuous population structure has also been reported for a number of tree species such as *Endospermum medullosum* in Solomon Island (Whitmore, 1984), *Trema micrantha* in Barro Colorado Island, Panama (Brokaw, 1987), and *Acer opalus* subsp. *granatense* in the Iberian Peninsula (Gomez-Aparicio *et al.*, 2005).

Though 55% of recorded seedlings were found within a 4–8 m radial distance, density and survival of saplings was recorded only at 8–12 m radial distance and is located away from the crown of the mother tree. Seedling population was found to be significantly ( $p < 0.05$ ) higher at 4–8 m radius under the parent tree canopy, whereas sapling population was significantly higher ( $p < 0.05$ ) at 8–12 m radial distance (Fig. 1.15). This follows Janzen and Connell’s ‘escape hypothesis’ which states that tree seedlings survive better at greater distances from the parent plant (Janzen,





**Fig. 1.15.** Relationship between radial increase and seedling ( $Y_1$ )/sapling ( $Y_2$ ) survival.

1970; Connell, 1971). Survival at a greater distance may be due to lesser competition among seedlings for growth, and escape from the parent tree. Spatial differences in micro-environment could also be the determining factors behind these differences.

Sapling population size was recorded only from the Dambla and Moishing sites while no sapling was found in the Changfu Moon site. A total of 11 saplings were recorded in the Moishing site while only a single sapling was recorded in the Dambla site. The Changfu Moon site may experience less regeneration due to a lack of fruiting as the site had no hermaphroditic trees, and there is no fruit production in male trees (Table 1.2).

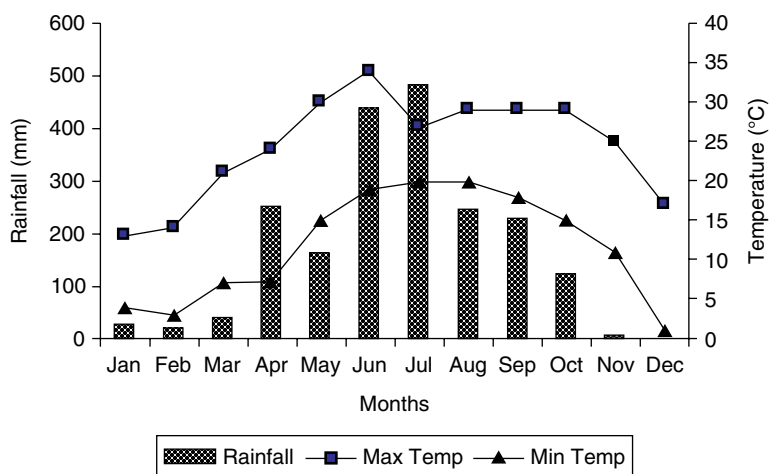
Although there are reports that the survival of tree seedlings is greater in the disturbed forest compared to protected forest (Tripathi and Khan, 1992), present observations revealed that the survival of tree seedlings of *G. assamicus* is greater in less human-impacted forest. This may be due to its remote location, favourable microclimatic conditions and/or its nutrient rich soil. The harvesting of mature fruit, which is a major anthropogenic threat, is also comparatively less in the Moishing site. On the other hand, very poor regeneration in the Dambla site may be due to anthropogenic activities (over-harvesting of mature pods, forest clearance and grazing) due to its proximity to human settlements. However, human disturbances are less prominent at Moishing primarily due to its remote location (Choudhury *et al.*, 2007b).

The survival of seedlings and saplings is greatly impacted by the microclimate, edaphic and biotic factors (Castro *et al.*, 2004). While low temperature is a major abiotic constraint to seedling establishment (James *et al.*, 2004), invertebrate herbivory and pathogenic activity are major biotic constraints (Burdon *et al.*, 1994; Seager *et al.*, 2013). Solar irradiance also impacts seedling establishment (Fisher and Gardner, 1995). Additionally, nutrients play a significant role in seedling growth and survival (Kelly, 2002). Interaction between such biotic and abiotic factors exerts a powerful impact on the spatial pattern of recruitment, concentrating regeneration in some

microhabitats and preventing seedling establishment in others (Zackrisson *et al.*, 1997). Moreover, high soil moisture content, higher soil organic C and total Kjeldahl N in the Moishing site may have favoured better regeneration of *G. assamicus*.

During the three years of observation, it was found that 80–83% of seedlings survived in the Moishing site. Additionally, new recruitment of seedlings (11–14%) in the Moishing site was recorded during each study year (Table 1.6). Winter drought due to lack of rainfall coupled with chilly weather between November and March (Fig. 1.16) may be a reason for seedling mortality (Castro *et al.*, 2004). Because of the slow growth rate of *G. assamicus*, no seedling could have been found to attain sapling stage during the three-year study period. Herbivory is an important biotic influence on seedlings because of their size and meal availability to animals (Swaine, 1996). Herbivory was observed as common in all *G. assamicus* sites and may be contributing to survival and growth of the seedling in all studied sites.

The present investigation showed that the *G. assamicus* population is extremely small, and the total number of reproducing individuals is even smaller. Therefore, the species may be designated as ‘critically endangered’ (Frankel *et al.*, 1995). Very few seedlings, saplings and mature *G. assamicus* trees at the study sites indicates that *G. assamicus* has very poor natural regeneration and survival potential. Other such relict and isolated populations have also experienced decline in recent centuries due to human activity (Blanca *et al.*, 1998; Goettsch *et al.*, 2015). Moreover, no seedling or sapling population has been recorded beyond a 12 m radius from the parent tree, which suggests that seed dispersal of *G. assamicus* is very limited. As dispersal by scatter-hoarding rodents and birds has important implications for the natural regeneration of many tree species (Jansen and Forget, 2001; Niederhauser and Matlack, 2017), the lack of dispersal observed in *G. assamicus* may act as a potential regeneration constraint.



**Fig. 1.16.** Ombrothermic diagram of the study area. Mean monthly rainfall (mm) and maximum and minimum temperature (°C) for 2004–2006.

## 1.6 Microclimatic Conditions

The survival and growth of a species largely depends on various ecological conditions and is largely influenced by microenvironmental variables and microsite heterogeneity. Climate dominantly exerts control over the distribution of major vegetation types (Woodward, 1987). Each and every stage of the plant life cycle, such as leaf flushing, flowering, pollination and fertilization, fruit set and maturation, seed dispersal, germination and survival of seedlings, is influenced by the climate. Alteration of climatic conditions between years affects seed production significantly (Owens, 1995). Aussenac (2000) studied the interactions between forest stands and microclimate, and found marked influence on forest trees. For example, the survival and growth of seedlings of a few tree species was found to be higher in gaps as compared with the understory, and the prevailing micro-environmental conditions may have favoured the growth and establishment of the seedlings (Khumbongmayum *et al.*, 2005).

To understand the various microclimatic conditions, we measured photosynthetic active radiation (PAR) in the study sites using plant canopy analyser (LI-COR, Model LI-250, US made) between March and April (2005) at 08.00, 12.00 and 16.00 h for seven days. The mean quantum of light recorded at the ground level varied significantly ( $F=108399.635$ ;  $p<0.001$ ) within the study sites with maximum values in the Moishing site and minimum in the Changfu Moon site. PAR ranged between 242–250, 1,123–1,130 and 38–45  $\mu\text{mol s}^{-1}\text{m}^{-2}$  in Changfu Moon, Dambila village and Moishing village respectively (Table 1.1).

Soil properties of a land under pasture with a 17-year-old naturally regenerated secondary forest were studied by Alfaro (2000), who found that soil under forest area had better conductivity. Variation in community structure in a plantation has been attributed to a soil fertility gradient, defined by increasing pH and available soil nutrients, that is, available N in  $\text{NO}_3$  (Sharma, 1993). Daws *et al.* (2002) in Barro Colorado Island found that large variations in soil water regime over small spatial scales may play a role in maintaining high species richness by opening up ecological niches.

Physico-chemical properties of soil such as colour, texture, bulk density, water-holding capacity, soil moisture content, pH, organic carbon and total Kjeldahl nitrogen (TKN) were analysed. Triplicate soil samples were collected in April 2005 from each site using a steel corer (5.5 cm inner diameter and 30 cm height) from two soil depths (0–15 and 15–30 cm) after removing the litter layer. The replicated samples of each site and depth were thoroughly mixed to obtain a composite sample. The samples were brought to the laboratory and select sub-samples were analysed for soil moisture and pH in fresh conditions. Remaining soil samples were air dried, passed through a 2 mm mesh sieve to remove stone particles and gravels and then again sieved through 0.5 mm mesh screen for determination of chemical parameters. Separate soil samples were collected from each site for determination of soil bulk density.

Soil colour was determined with the help of the Munsell soil colour chart. Soil texture was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962) and bulk density was determined by the soil core method (Blake and Hartge, 1986).

Water-holding capacity (WHC) was determined following the Keen's box method (Piper, 1944), while soil moisture content was measured gravimetrically by incubating 10 g of field-moist soil sample in a hot air oven at 105°C for 24 h. Soil organic carbon (SOC) was determined by dichromate oxidation and titration with ferrous ammonium sulphate (Walkey, 1947). TKN was determined following semi-micro Kjeldahl procedure by acid digestion, distillation and titration (Anderson and Ingram, 1993). The pH of soil samples was determined through the soil–water suspension method (1:2.5 w/v) using a digital pH meter (Systronics MK VI).

All the data were statistically analysed following Zar (1974), using multiway ANOVA to elucidate the effects of site characteristics on distribution, growth and other phytosociological parameters of *G. assamicus*.

All the sites are located within an elevation range of 1,700 and 2,100 m asl and have either a northwest or southeast aspect. The mean PAR varied between 38.34  $\mu\text{mol s}^{-1} \text{m}^{-2}$  in the Moishing site to 1123.65  $\mu\text{mol s}^{-1} \text{m}^{-2}$  in the Dambla site. Lesser quantum of light in the Moishing site may be due to partially closed canopy cover and less disturbance, while more quantum in the Dambla site may be due to fully open canopy cover. Similar variation has also been reported by Chen *et al.* (1999).

The soil in all study sites was classified as sandy loam, having 67.67–70.33% sand with a small proportion of clay (Table 1.7). Soil colour varied among the sites. In the Dambla site, soil colour was brown and dark brown, whereas in the Changfu Moon and Moishing sites, it was dark grey to very dark grey (Table 1.7). Soil moisture content ranged from 17.10–30.71% with a maximum value in the Moishing site, and a minimum value in the Dambla site. Variation in soil moisture content was significant between sites ( $F = 3571.710$ ;  $p < 0.001$ ), and insignificant between the two soil depths. WHC ranged between 46.07–67.32%; the

**Table 1.7.** Soil physical properties of the three study sites.

Site	Changfu Moon		Dambala village		Moishing	
Soil depth (cm)	0–15	15–30	0–15	15–30	0–15	15–30
Texture						
Sand (%)	67.67	70.33	67.67	69.00	67.00	70.33
	$\pm 1.76$	$\pm 1.76$	$\pm 1.76$	$\pm 2.00$	$\pm 1.15$	$\pm 1.76$
Silt (%)	24.00	23.33	26.00	25.67	23.67	23.00
	$\pm 2.08$	$\pm 2.03$	$\pm 1.73$	$\pm 2.33$	$\pm 1.45$	$\pm 1.73$
Clay (%)	8.33	6.33	6.33	5.33	9.33	6.67
	$\pm 0.33$	$\pm 0.33$	$\pm 0.33$	$\pm 0.33$	$\pm 0.33$	$\pm 0.33$
Textural class	SL	SL	SL	SL	SL	SL
WHC (%)	67.32	65.37	48.43	46.07	61.37	60.61
	$\pm 0.07$	$\pm 0.13$	$\pm 0.32$	$\pm 0.47$	$\pm 0.16$	$\pm 0.11$
BD ( $\text{g cm}^{-3}$ )	0.83	0.87	0.98	1.01	0.67	0.72
	$\pm 0.003$	$\pm 0.002$	$\pm 0.007$	$\pm 0.005$	$\pm 0.006$	$\pm 0.003$
SMC (%)	22.45	23.51	17.38	17.10	31.67	30.71
	$\pm 0.19$	$\pm 0.11$	$\pm 0.21$	$\pm 0.05$	$\pm 0.24$	$\pm 0.12$

$\pm$  SE (n=3); WHC: water-holding capacity; BD: bulk density; SMC: soil moisture content; SL = sandy loam.

highest value was recorded in the the Changfu Moon site (67.32%) and the lowest (46.07%) in the Dambla site (Table 1.7). Variation in moisture and WHC of soil is due to the change in soil texture within different sites.

Soil was medium acidic to strongly acidic (pH 5.97–4.71) in all the three sites, with maximum acidity (pH=4.71) being recorded in the Moishing site. The pH value varied significantly between sites ( $F=230.311$ ,  $p<0.001$ ), whereas the difference was insignificant between soil depths. Soil pH was generally lower in the surface soil layer than in the subsurface layer. Low soil pH in the Moishing site as compared with the Changfu Moon and Dambla sites could be due to a lower rate of soil leaching, leading to greater accumulation of partially decomposed organic matter. An increase in pH in the other sites was due to low organic matter accumulation. The SOC varied significantly among the sites, as well as between the two soil depths ( $F=246.112$ ,  $186.483$ ;  $p<0.001$ ). Similarly, total Kjeldahl nitrogen varied significantly between the two soil depths and sites ( $F=627.706$ ,  $1409.086$ ;  $p<0.001$ ). The highest concentration of TKN was recorded in the surface soil layer of the Moishing site, while the lowest concentration was recorded in the subsurface soil layer of the Dambla site (Table 3.3). Higher soil organic C and total Kjeldahl N in the Moishing site may be due to lesser disturbance as compared with the Changfu Moon and Dambla sites.

Disturbance in forest areas often changes the amount and quality of litter and hence reduces organic matter input and nutrient content of the soil (Dinesh *et al.*, 2003). Soil texture is also greatly affected by the openness of the canopy due to the erosion of topsoil during extreme rainfall events, and increases the proportion of sand in the disturbed stands due to loss of finer soil particles (Eyre, 1968). Loss of canopy trees and extreme rainfall events might have increased the erosion of topsoil layer and hence increased the proportion of sand particles in the Dambla and Changfu Moon sites. The Moishing site was found to have the highest clay and moisture content compared to the other sites, which may be due to lesser disturbance, low solar insolation and the presence of a seasonal stream. Highest moisture content in the surface soil layer may be due to greater organic content in this layer. WHC in all the sites was greater in the surface soil layer, which may be due to relatively higher clay content and the accumulation of organic matter in the topsoil layer. Higher bulk density in the Dambla site may be due to loss of organic matter, as the site experiences significantly higher levels of disturbance as compared with the other sites.

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