Bioremediation, Biodiversity and Bioavailability ©2010 Global Science Books

Conservation and Management of Endangered Plant Species: A Case Study from Northeast India

Baharul Choudhury[1,2*] • M. Latif Khan[2]

[1] Department of Biology, Concordia University, 7141, Sherbrooke Street West, Montreal, Quebec, H4B 1R6, Canada
[2] Department of Forestry, North Eastern Regional Institute of Science and Technology (Deemed University), Nirjuli -791 109, Arunachal Pradesh, India

Corresponding author: * **baharulchoudhury@gmail.com**

ABSTRACT

Extinction and species introduction are two major biodiversity crises of the current millennium. A species may become endangered and eventually extinct when death rate exceeds birth for a prolonged duration. The reasons may be natural or anthropogenic. Anthropogenic activities are now-a-days prominent and causing extinction of many plant species of ecological and economic significance. Many species are facing tremendous pressure and are on the verge of extinction in Northeast India, one of the global biodiversity hotspots in the world. In the present communication, we present the population status and conservation requirement of three rare/endangered and endemic plant species of the region *viz. Aquilaria malaccensis*, *Gleditsia assamica* and *Gymnocladus assamicus*. Natural populations of *A. malaccensis* have been depleted due to over-harvesting of mature trees for its precious 'agarwood'. However, plantations have been established in home-gardens of upper Assam and serving as a means of *ex-situ* of conservation of the species. The *G. assamica* and *G. assamicus* populations are also very poor in nature which culminates with poor natural regeneration. Therefore, a similar way of *ex-situ* conservation in plantations as practiced in *A. malaccensis* is suggested for effective conservation of the species.

Keywords: *Aquilaria malaccensis*, conservation, *Gleditsia assamica*, *Gymnocladus assamicus*, home-garden, population
Abbreviations: CITES, Convention on International Trade in Endangered Species of Wild Fauna and Flora; **IUCN**, International Union of Conservation of Nature; **IVI**, importance value index

INTRODUCTION

The current millennium is experiencing a fast rate of extinction and species introduction posing a major threat to the biodiversity. Five mass extinctions that occurred in the past 500 million years caused over 50% species extinction (Myers 1997; Erwin 1998); however, we are into the opening phase of a sixth mass extinction (Myers 1993) which is predicted to be human impacted (Eldredge 2008). On the other hand, unprecedented human impact affected the speciation process as well, creating a major threat to future biodiversity and is being severely pressured through the removal of contiguous related biotic habitats (Erwin 1991). Plants are extremely important for conservation of biodiversity both from ecological and human economics view point. However, plant diversity is facing tremendous threat mainly because of unsustainable harvesting for their multifarious utilization and habitat degradation. According to the World Conservation and Monitoring Centre (WCMC) it is estimated that more than 8000 tree species are endangered worldwide (www.unep-wcmc.org), however, another estimate predicts this between 22 and 47 percent of the world's plants (Graham 2002). The rate of extinction is also approximated to be very fast and it is estimated that around 1800 populations are being destroyed per hour (16 million annually) in tropical forests alone (Hughes *et al*. 1997).

Northeast India is one of the biodiversity hotspot regions in the world (Mittermeier *et al.* 2005). The region harbors a great diversity of plant resources and is considered to be the '*cradle of flowering plants*' (Takhtajan 1969). All the Northeastern states of India *viz*., Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, form about 8% of the geographical area of the country having around 25% of the country's total forest area. Nearly 64% of the total geographical area of the region is under forest cover and about 30% of the total growing forest stock of the country is supported by the region (Gupta 2007). The Northeastern region is also endowed with several plant and animal species of immense ecological and economic importance. However, such vast resources are under tremendous pressure and facing threats towards extinction.

Aquilaria malaccensis (Thymelaeaceae) is an economically important tree species known for its precious resin-impregnated 'agarwood'. Evergreen trees are 6 to 20 m tall with straight bole, up to *ca*. 2-4 m in circumference (**Fig. 1A**). Trees bear bisexual white flowers (**Fig. 1B**) and capsular fruits with one or two seeds per fruit. Mature capsules split open longitudinally and seeds remain hanging by the funicular cord (**Fig. 1C**). Variously known as '*eaglewood*', '*aloeswood*' or '*gaharu*', *Aquilaria* is a rich and sacred source of oleoresin since ancient period of time (Anonymous 1994). It has been utilized in Egypt, Arabia and throughout the Far East from time immemorial in incense, perfume, medicinal, writing material and ceremonial uses (Chakrabarty *et al.* 1994 and references there in). Agarwood has been widely utilized for religious and medicinal purposes in Chinese societies for over thousand years (Anonymous 2007). Assam region of Northeast India is believed to be the origin of agarwood and spread throughout Southeast Asia in to its current range (Burkill 1966). Natural distribution of the genus *Aquilaria* ranges throughout South and Southeast Asia from India in the West to Indonesia in the East and China in the North (Hou 1960; Whitmore 1972). In India, it is distributed throughout the foothills of Eastern Himalayas extending up to West Bengal. Specific distribution of the species in Northeast India has been recorded from East Kameng, East Siang and Tirap Districts of Arunachal Pradesh, Garo Hills of Meghalaya (Haridasan and Rao 1987) Kailasahar in Tripura (Deb 1981) and Dibru-

Received: 29 May, 2009. Accepted: 29 January, 2010.

Original Research Paper

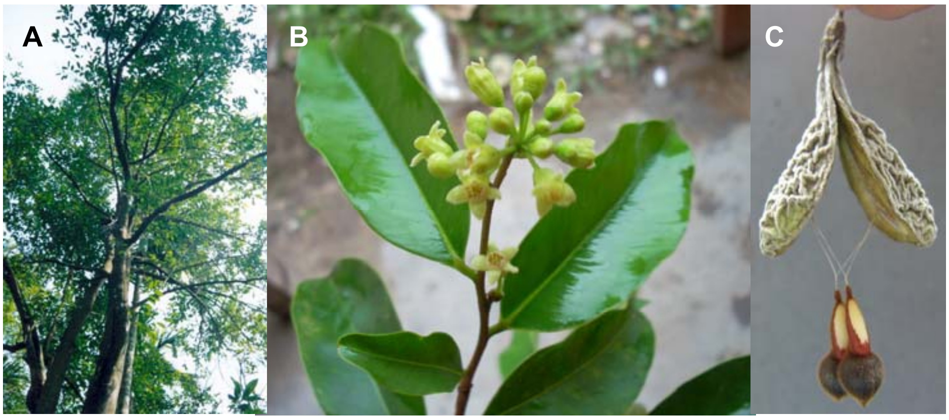

Fig. 1 ***Aquilaria malaccensis*****.** (**A**) Mature tree, (**B**) flowering twig, (**C**) mature fruit.

Fig. 2 ***Gleditsia assamica*****.** (**A**) Mature tree, (**B**) green pods.

garh, Golaghat, Karbi Anglong, Nagaon, North Cachar Hills, North Lakhimpur, Sibsagar, Kokrajhar, Darrang and Sonitpur districts of Assam (Ahmed and Gogoi 2000). Because of its multifarious uses and high market demand, mature agarwood trees have been harvested indiscriminately from wild resulting in rapid decline of the species in natural habitat (Beniwal 1989). This created concern all over the world and *Aquilaria* has been included in Appendix II of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1994 (CITES 1994). It is also listed as 'Vulnerable' in the International Union of Conservation of Nature (IUCN) red list of threatened species (IUCN 2009).

Gleditsia assamica and *Gymnocladus assamicus* (Caesalpinioideae) are two endemic tree species of northeast India. Both the sister genera have typical distribution pattern and a few species are available in North and South America, Egypt and Vietnam (Sanjappa 2002). Schnabel *et al*. (2003) revealed their centre of origin to be Eastern Asia which migrated afterwards across the Bering Land Bridge in their current range. *G. assamica* grows in primary and secondary forests of Northeast India at an elevation range of 100-250 m altitude. It is a medium to large sized tree (15-20 m) with a conical crown and thick canopy (**Fig. 2A**). Bright green glossy leaves are alternate, pinnately or bipinnately compound, typically with many small leaflets. Small flowers bloom during March-May. Pods are 20-50 × 1 cm in dimension, flattened and straight (**Fig. 2B**) and mature during September-October. Spines are numerous during seedling stage while these are prominent only on trunk in mature trees. Pods have ethnobotanical use and Garo tribes of Nokrek Biosphere Reserve use the paste to heal stomachache. Clear felling along with habitat degradation severely affected the natural population of *G. assamica* and the species is also listed as 'Vulnerable' in the IUCN red list of threatened species (IUCN 2009).

G. assamicus, locally known as '*Menangmanba-shi*' by the Monpa tribe (Choudhury *et al*. 2007a) is a medium sized (15-17 m in height) deciduous tree (**Fig. 3A**). Inflorescence is of terminal racemose type with fine pubescence (**Fig. 3B**) having male and bisexual flowers on separate trees (**Fig. 3C**). Highly saponaceous mature pods (**Fig. 3D**) are popularly used in cleansing as well as religious activities (Choudhury *et al*. 2007a). Natural population of *G. assamicus* is extremely small having very few reproducing individuals (Choudhury *et al*. 2007b). Though the species is

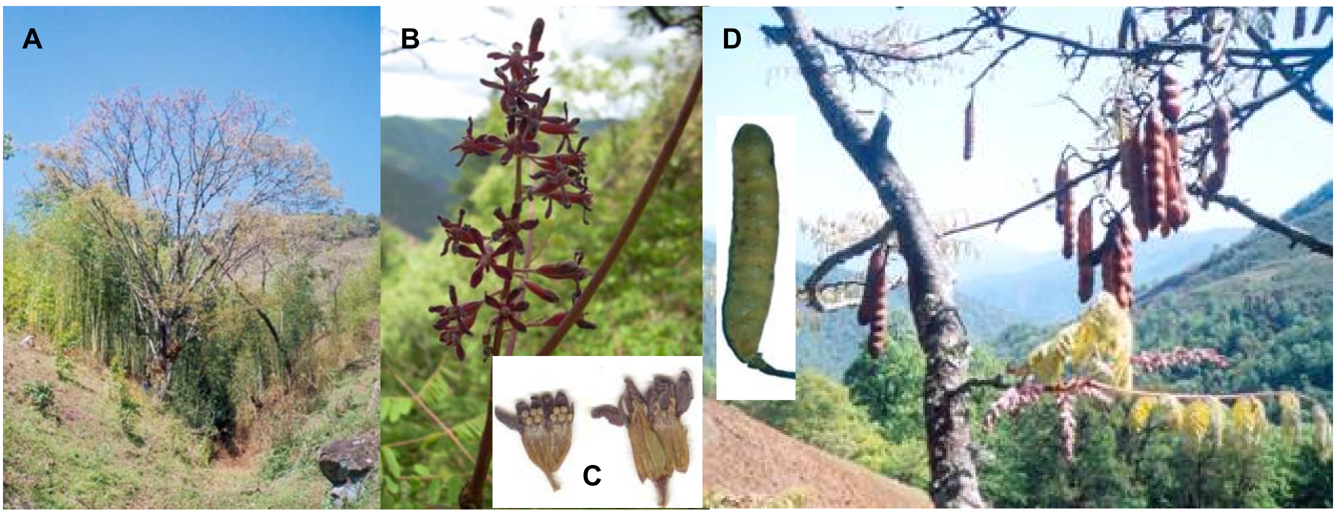

Fig. 3 ***Gymnocladus assamicus*****.** (**A**) Mature tree, (**B**) inflorescence, (**C**) male and hermaphrodite flowers, (**D**) ripe pods rich in saponin.

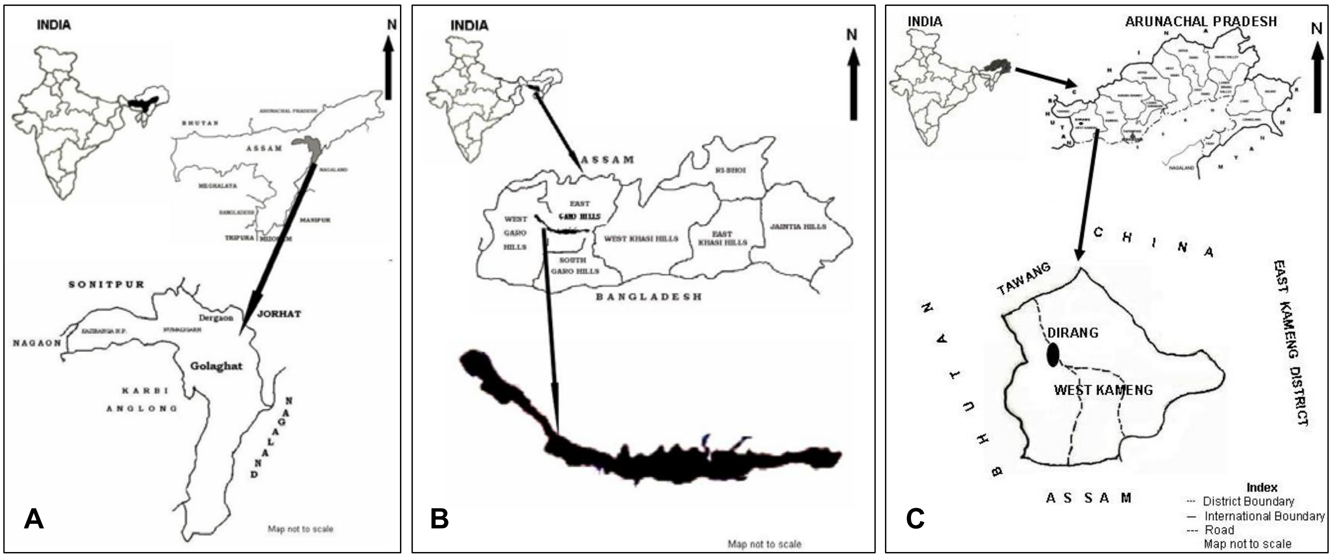

Fig. 4 Maps showing different study sites. (**A**) Golaghat District of Assam, (**B**) Nokrek Biosphere reserve, Garo Hills, Meghalaya, (**C**) Dirang Valley, West Kameng District, Arunachal Pradesh.

not included in the IUCN red list of threatened species, it has been designated as critically endangered regionally (CAMP report 2003) and also included in the priority list for national recovery program in India (Ganeshaiah 2005).

In the present communication, we have demonstrated the population structure and regeneration status of *A. malaccensis*, *G. assamica* and *G. assamicus* on the basis of field observation as well as published data (for *G. assamicus*) from different regions of Northeast India. This also suggests a few conservation initiatives which may be adopted to save the species from extinction risk.

MATERIALS AND METHODS

Study sites

Different study sites were selected for *A. malaccensis*, *G. assamica* and *G. assamicus* on the basis of preliminary field survey and species availability. Natural populations of *A. malaccensis* could not be located after rigorous field survey throughout various forest areas of Arunachal Pradesh and neighboring states. However, it is planted in home-gardens of Golaghat, Jorhat, Sivsagar and Nagaon districts of Assam. Randomly selected home-gardens nearby Golaghat town (25°50'-26°47' N latitude and 93°16'-94°10' E longitude) (**Fig. 4A**) were sampled for studying population structure of *A. malaccensis* and other associated plant species. A sacred grove (*Lungarsah Majar*) of around 0.5 ha area in Golaghat town was also studied to compare the population structure in a comparatively undisturbed habitat. Climate of Golaghat district is tropical with a hot and humid summer and cold winter. Average annual rainfall is 1300 mm (maximum precipitation occurs in June and July) having mean annual temperature range between 10°C (December) to 38°C (June).

G. assamica population was studied in Nokrek Biosphere Reserve situated in the Garo Hills district of Meghalaya (25°9'-26°1' N latitude and 89°49'-91°2' E longitude and 250 to 1500 m altitude above mean sea level) (**Fig. 4B**). Total area of the reserve is 820 km^2 having around 48 km^2 core zone (Rodgers and Panwar 1988). Three plots (plot 1-3) having *G. assamica* population was selected along the buffer zone of the reserve. *Garo* tribes predominate the area and are largely dependant on forest resources for their livelihood. Slash-and-burn agriculture (*jhum*) is mainly practiced in and around the reserve boundaries which has tremendous pressure on flora and fauna of the reserve. Climate of the region is tropical with high rainfall, humidity and temperature (temperature ranges from 12°C in winter to 30°C in summer months) (Singh and Mudgal 2000).

Study on population structure and regeneration status of *G. assamicus* was carried out in the Dirang Forest Range (27°18'-27°34' N latitude and 91°13'-92°15' E longitude; elevation 1500-2100 m asl) located in West Kameng district of Arunachal Pradesh, Northeast India (**Fig. 4C**). Three extent populations *viz*. *Changfumoon*, *Dambla* village and *Moishing* village were only available for a detailed study. Climate of the study area is subtropical with wet warm summer (34°C) during May-July and dry chilly winter (0°C) during December-February. Mean annual rainfall during the study period (2004-2006) was 2024 mm of which maximum (80%) precipitation received during April to September (rainy season). The area (*ca*. 892 km^2) is mostly mountainous and a greater part of it consists of mass tangled peak and valleys surrounded by higher mountain range (2800 to 3400 m) of Bomdila and Tawang.

Distribution and population structure

Distribution of each of the study species was recorded through extensive field survey during 2004-2007 and each location were geographically marked with Global Positioning System (Garmin, eTrex). Population structure and vegetation associated with each species was studied by quadrat method. Twenty quadrats of 10 m × 10 m size (covering 0.2 ha area) were laid randomly in and around the study species. Randomly selected home-gardens of different size (0.01 to 0.20 ha) were sampled to study the *A. malaccensis* population by following the same method as mentioned before. The objective of studying vegetation associated with the study species is to assess their association with other species. Partial data for population structure of *G. assamicus* is used from our earlier publication (Choudhury *et al.* 2007c). Plant specimen were collected and identified following different floras (Kanjilal *et al.* 1938; Hajra *et al.* 1996; Polunin and Stainton 2006; Stainton 2007) as well as consulting different herbaria (Botanical Survey of India, Itanagar and Shillong; State Forest Research Institute, Itanagar) and experts of the region.

Regeneration study

Regeneration of the selected plant species was studied by periodic sampling of seedlings and saplings at one year interval in 20 permanent quadrats of 1 m × 1 m size. Measurements were recorded on 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). All the seedlings and saplings recorded in each quadrat were labeled with permanent aluminum tag. Survival, mortality and new recruits were estimated from such data and demography of each species was drawn accordingly.

Quantitative analysis

Quantitative analysis of vegetation for frequency, density and relative density was performed following Misra (1968). The impor-

Table 1 Overall population structure of the three studied species in different locations.

Species	Area of study	Relative frequency	Density ha^{-1}	Number of associated species
Aquilaria malaccensis	Homegardens in Golaghat	19.03	692.73	57
Gleditsia assamica	Nokrek biosphere reserve	11.25	2.75	31
Gymnocladus assamicus	Dirang	6.42	2.08	60

tance value index (IVI) was computed by summing up relative frequency, relative density and relative basal area.

Sorensen similarity index was calculated using the formula given by Sorensen (1948). Sorensen similarity index =

$$\frac{2c}{a+b}\times 100$$

where 'a' is the total number of species in site A, and 'b' is the total number of species in site B and 'c' is the number of species shared by the two sites.

RESULTS

Distribution and population structure

A. malaccensis was found the most common tree in the home-gardens around Golaghat town area of Assam along with 57 woody plant species belonging to 32 families and 54 genera. Majority of the home-garden plants have different utilities such as cash crop, fruits, timber and fuelwood. Whereas bamboos are almost common, tea plantations are also found in many homegardens of the area. Relative frequency and density of *A. malaccensis* was found to be the highest (19.03 and 692.73 ha^{-1}, respectively) followed by *Areca catechu* (relative frequency =13.39; density =300.21 ha^{-1}) (**Table 1**). Similarly, *A. malaccensis* was found the most dominant species in *Lungarshah Majar* having 80.95 and 895.24 relative frequency and density ha^{-1}, respectively. Altogether 30 associated woody species belonging to 22 families and 29 genera were also recorded from the same site. Sorensen similarity index showed 29.89% similarity among woody species in home-gardens and the sacred grove.

Population of *G. assamica* is found diminishing and only 11 mature individuals were located from four different locations of the Nokrek Biosphere Reserve. Diversity analysis revealed the occurrence of 31 associated plant species belonging to 27 genera and 17 families. The most dominant tree species was *Schima wallichii* (3 individuals ha^{-1}) followed by *Castanopsis* sp., *Ficus gibbosa* and *Lithocarpus elegans*. Relative frequency and density of *G. assamica* were 11.25 and 2.75 ha^{-1}, respectively. Major regenerating individuals were located from secondary forests mainly in shifting agricultural fallow land. Plots 2 and 3 were the most similar (Sorensen similarity index =92.86%) while plots 1 and 2 were the most dissimilar (Sorensen similarity index = 64.86%) in woody species composition. The overall population structure is represented in **Table 1**.

Altogether 28 mature *G. assamicus* trees were recorded from nine sites located in Dirang circle of West Kameng District, Arunachal Pradesh (Choudhury *et al.* 2007b). Number of mature trees per site ranged from one to seven and only two sites (Moishing and Dambla) had seedlings and saplings. Population study in three sites showed that density of *G. assamicus* ranges from 0.50 (Moishing village) to 1.00 (Changfu Moon and Dambla) individual ha^{-1}. In the Changfu Moon site, only mature individuals were recorded while in Moishing and Dambla sites, regenerating populations were also observed. Overall species richness varied site wise and highest number of associated plant species (34) was recorded from Dambla site and lowest (24) from the Moishing site. While Changfu Moon and Dambla sites were found the most similar in tree species composition (Sorensen similarity index = 80%), Dambla and Moishing sites were the least similar sites (Sorensen similarity index = 55.56%; **Table 2**). The overall phytosociological data of *G. assamicus* is given in **Table 1**.

Table 2 Similarity (Sorenson) among the tree (T), shrub/herb (S/H) species occurring in the three study sites of *Gymnocladus assamicus*.

Sites/Habit		Changfu Moon		Dambla 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 3 Regeneration status of the three studied species.

	Aquilaria malaccensis	*Gleditsia assamica*	*Gymnocladus assamicus*
% mature tree	14.56	23.40	12.50
% saplings	29.38	19.15	11.36
% seedlings	56.06	57.45	76.14

Regeneration status

Natural regeneration of *A. malaccensis* was found quite fare and seedling and sapling population was significantly higher than mature tree population in home-garden as well as in the sacred grove. A few large home-garden owners have pure *A. malaccensis* stand and very good regeneration was recorded. Overall data of home-gardens and sacred grove showed 56.06% seedling, 29.38% sapling and 14.56% mature trees (**Table 3**). Regeneration through coppicing was also observed from the harvested cut stumps and average number of coppice per cut stump was recorded 2.83 (±0.24) indicating good regeneration through coppicing. Home-garden owners also prefer to grow *A. malaccensis* seedlings for their economic importance and, therefore, they survive better than other species.

Regeneration of *G. assamica* was found diminishing and only 11 mature trees were traced from Nokrek Biosphere Reserve. The density of the species was 2.75 ha^{-1} but is restricted only to very small areas of the reserve. Seedling and sapling population was also scanty and contributed 57.45 and 19.15%, respectively in the studied sites (**Table 3**). More interestingly, a few seedlings and saplings populations were recorded from secondary '*jhum*' fallows of the park periphery and it is predicted that secondary forest is a preferred habitat for regeneration of *G. assamica*.

Regeneration of *G. assamicus* was found poor having 100% mature trees in Changfu Moon site, following 87.50 and 1.16% in Dambla and Moishing site, respectively. Seedling population was recorded only in Moishing site and contributed 92.49% of the total *G. assamicus* population while sapling population at Dambla and Moishing site was 12.50 and 6.36%, respectively (Choudhury *et al.* 2007c). Our present observation revealed that the percentage of mature tree population is higher than that of sapling/seedling population in two sites except Moishing (**Fig. 5**). Over all sites, the average percentage of tree, sapling and seedling were 12.50, 11.36 and 76.14%, respectively (**Table 3**). Sapling population and survival were recorded only at 8 to 12 m radial distance from the base of the mother plant indicating very poor seed dispersal and there was no seedling or sapling population beyond 12 m radius.

DISCUSSION

Study on population of *A. malaccensis*, *G. assamica* and *G. assamicus* revealed that the natural population is decreasing and facing severe regeneration constraints. *A. malaccensis* is almost extinct in the wild; however, its density is very high (692.73 ha^{-1}) in the home-gardens of Golaghat district

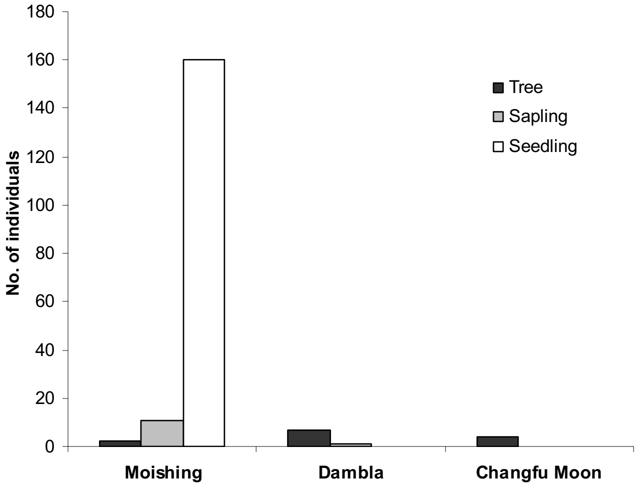

Fig. 5 Number of trees, saplings and seedlings of *G. assamicus* in three study sites.

of Assam. This shows a rich population structure, indicating an effective and alternative way of conserving rare/endangered tree species in *ex-situ* condition. On the other hand, rich species diversity in the home-gardens of Golaghat district was observed having 57 woody species of multifarious use. Though species diversity is less than that of Kerala home-gardens of India (Kumar *et al.* 1994), high density of *A. malaccensis* signifies an important aspect of home-gardens in conserving rare/endangered plant species. Population of *G. assamica* is found very poor in Nokrek Biosphere Reserve. Though seedling and sapling population was observed in the three studied plots nearby mature trees, their contribution in natural regeneration is not sufficient. This is predicted because of absence of adult trees in all the studied plots. The presence of a regenerating population in secondary '*jhumland*' indicates its better survival in secondary forest and thereby, *G. assamica* may be recognized as a light demanding species (Everham *et al.* 1996). Population of *G. assamicus* is found to be small having very few individuals in all sites (**Table 3**). Though mature trees were present in all the sites, regenerating individuals were very scanty, or none at all (as in Changfu Moon and Dambla village). Rogers (1996) also reported similar results in case of the threatened tree *Olearia hectorii* in New Zealand. Subash Chandran *et al.* (2008) found very small and relic populations of two critically endangered tree species *Madhuca bourdillonii* (Gamble) Lam. and *Syzygium travancoricum* Gamble, in Western Ghats, India. Mature tree density is very low in all the sites ranging between 0.5 to 1 individuals ha^{-1} which is less than another rare species (*Dipteryx panamensis*) in Costa Rica (Clark and Clark 1984). Regeneration status of a plant species can be predicted by counting the population size of seedlings and saplings (Khan *et al.* 1987; Uma Shankar 2001; Bhuyan *et al.* 2003). A species may be designated as having good regeneration 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 occur only in adult form, it is considered as not regenerating (Devi 2004). Age structure of *A. malaccensis* showed very good regeneration status in home-gardens. Though *G. assamica* showed fair regeneration in different plots, their contribution in maintaining a stable population is dubious. This is predicted because of absence of adult trees from the studied areas of Nokrek Biosphere Reserve. The age structure of *G. assamicus* indicates that it has very poor regeneration in Changfu Moon and Dambla site except Moishing site. 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), *Grewa pandaica* in Western Ghats, India (Parthasarathy and Karthikeyan 1997) and *Acer opalus* subsp. *granatense* in Iberian Peninsula (Gomez-Aparicio *et al.* 2005). Only Moishing site has fair regenerating population which may be due to less disturbance and anthropogenic activity. Seedlings of *G. assamica* and *G. assamicus* are surviving better away from their mother plant which may be due to lesser competition among seedling for growth and escape from the parent tree. This follows Janzen and Connell's '*escape hypothesis*' which says that tree seedling survive the best at greater distance from the parent plant (Janzen 1970; Connell 1971). Seedling population of *G. assamica* in secondary '*jhum*' lands away from mother tree also reflects the same hypothesis. Preference of growing *A. malaccensis* in home-gardens may be the probable reason for better regeneration of the species in their *ex-situ* condition. However, seedling mortality was found prominent during dry season which may be due to prolonged dry condition during the winter period (November to March).

CONCLUSION

Overall, the study showed that the population status of all three species has been threatened and faces extinction pressure in the wild. *G. assamicus* has been the most diminishing tree species having enormous economic and ecological significance following *G. assamica*. Though the genus *Gymnocladus* has worldwide distribution, *G. assamicus* is endemic to Northeast India and is mainly distributed in specific pockets of high altitude areas in Arunachal Pradesh. It was found that 80-83% *G. assamicus* seedlings survived in the Moishing site and another 11-14% new seedlings were recorded during each studied year. Winter drought due to lack of rainfall coupled with chill weather during November-March may be a reason for seedling mortality (Hodar *et al.* 1998; Castro *et al.* 2004). Harvesting of mature pods for traditional use (Choudhury *et al.* 2007a) may be considered a significant factor contributing to poor regeneration. *A. malaccensis* is one of the most precious plant species having enormous economic importance. As a result of large scale extraction from natural sources (Chakrabarty 1994) the species is endangered in the wild and there is hardly any regenerating individual left for maintaining natural population stock. However, the species is now-a-days considered as a plantation crop and large scale plantations are established in home-gardens as well as in plantation plots. Practice of home-garden plantation thus proved to be a very efficient conservation strategy for rare/endangered species. In the present study, it was also found that individual trees of *G. assamicus* bear either male or hermaphrodite flowers. This phenomenon is regarded as exceedingly rare and is called as androdioecy (Pannell 2002), however, thorough research is needed to prove the mechanism. *G. assamicus* pods are preferred by many tribal people for its effective cleansing properties and its plantation in home-gardens may be an alternative and effective option to recover the species from danger of extinction. *G. assamica* is also having tremendous ecological significance for its interesting distribution, primitive origin (Schnabel *et al.* 2003) and diminishing population. In the present study, the species was reported only from Nokrek Biosphere Reserve of Meghalaya and natural regeneration was found very poor mainly due to destruction of forest areas. Therefore, *ex-situ* conservation measure is to be initiated for effective recovery of the species.

Plantation initiatives have been taken for many economically and ecologically important tree species. Nursery routines of these planting stocks for artificial regeneration are very important. Ecological studies of such species provide guidance for refining management interventions to improve establishment and growth. Conservation of the species in natural habitat and artificial regeneration would be the best option to recover the species from near extinction. Though there is no such community interest in *G. assamica* (other than its minor ethnobotanical use) awareness among local people for conservation of existing populations and facilitating new recruitments would be highly recommended. Reintroduction of rare and endangered species in to their natural habitat is one of the effective ways of supplementary regeneration (Maunder 1992). Such population restoration initiative by introducing nursery grown seedlings could be an adaptive strategy to compensate for the lack of natural regeneration.

ACKNOWLEDGEMENTS

Financial support from DST (File No. SR/SO/PS-16/2002) is highly acknowledged. Cooperation received from State Forest Department, Arunachal Pradesh and Meghalaya by issuing work permit in forest areas, research support incurred from BSI, Itanagar and Shillong and SFRI Itanagar are worth mentioning. Logistic support received from village headmen and villagers of Dirang, and Nokrek Biosphere Reserve and members of *Lungar-shah Majar* committee is gratefully acknowledged. Support received from Mr. Pijush Dutta, (WWF-India) and Swapna Prabhu (BNHS-Bombay) is praise worthy.

REFERENCES

Ahmed GU, Gogoi P (2000) Germination behavior and storage of seed and seedling vigour of *A. agallocha* Roxb. In: Ahmed GU, Gogoi P (Eds) *Scope and Dimension of Agar (Aquilaria spp.) Plantation in NE India*, Proceedings of Seminar, All Assam Agar Traders and Agar Oil Manufacturers' Association, Hojai, Assam, India Nagaon, Assam, India, pp 28-33

Anonymous (1994) Fragrant black gold of Siberut Island. *Rainforest Alliance Newsletter* **Fall**, 5-7

Anonymous (2007) Agarwood. Available online: http://www.jdcorp.com/chome.html (in Chinese)

Beniwal BS (1989) Silvicultural characteristics of *Aquillaria agallocha* Roxb. *Indian Forester* **115 (1)**, 17-21

Bhuyan P, Khan ML, Tripathi RS (2003) Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. *Biodiversity and Conservation* **12**, 1753-1773

Brokaw NVL (1987) Gap phase regeneration of three pioneer tree species in a tropical forest. *Journal of Ecology* **75**, 9-19

Burkill I (1966) *A Dictionary of Economic Products of the Malay Peninsula-I*, Government of Malaysia and Singapore. The Ministry of Agricultural and Cooperatives, Kuala Lumpur

CAMP Report (2003) *Conservation Assessment and Management Prioritisation Workshop for Medicinal Plants of Arunachal Pradesh, Meghalaya and Sikkim,* Foundation for Revitalisation of Local Health Traditions (FRLHT)," Bangalore, India, February-March 2003

Castro J, Zamora R, Hodar JA, Gomez JM (2004) Seedling establishment of a boreal tree species (*Pinus sylvestris*) at its southernmost distribution limit: consequences of being in a marginal Mediterranean habitat. *Journal of Ecology* **92**, 266-277

Chakrabarty K, Kumar A, Menon V (1994) *Trade in Agarwood*. WWF-India/ TRAFFIC-India, New Delhi

Choudhury BI, Khan ML, Arunachalam A, Arunachalam K (2007a) *Gymnocladus assamicus* Kanjilal ex P.C. Kanjilal fruit – A soap substitute. *Natural Product Radiance* **6**, 427-429

Choudhury BI, Khan ML, Arunachalam A, Das AK (2007b) Population status of *Gymnocladus assamicus*; a critically endangered tree species in Arunachal Pradesh. *Current Science* **93 (11)**, 1489-1491

Choudhury BI, Khan ML, Arunachalam A, Das AK (2007c) Ecology and conservation of the critically endangered tree species *Gymnocladus assamicus* in Arunachal Pradesh, India. *Research Letters in Ecology* **2007**, Article ID 59282

CITES (1994) Resolutions of the conference of the Parties, Ninth meeting of the conference of the parties, Fort Lauderdale, USA, 7-18 November

Clark DA, Clark DB (1984) Spacing dynamics of a tropical rain forest tree evaluation of the Jenzen-Connel model. *American Naturalist* **124 (6)**, 769-788

Connell JH (1971) On the role of natural enemies in preventing competitive exclusion in some marine animals and in rain forest trees. In: Den Boer PJ, Gradwell G (Eds) *Dynamics of Populations*, PUDOC, Wageningen, The Netherlands, pp 298-310

Deb BD (1981) *The flora of Tripura State* (**Vol. I**) Today and Tomorrow's Printers and Publishers, New Delhi

Devi KA (2004) Studies on plant diversity and regeneration of a few tree species in the sacred groves of Manipur. PhD thesis, North-Eastern Hill University, Shillong, India, 252 pp

Eldredge N 2008 The Sixth Extinction Available online: http://www.actionbioscience.org/newfrontiers/eldredge2.html#primer

Erwin DH (1998) The end and beginning: recoveries from mass extinctions, *Trends in Ecology and Evolution* **13**, 344-349

Erwin TL (1991) An evolutionary basis for conservation strategies. *Science* **253**, 750-752

Everham III EM, Myster RW, van de Genachte E (1996) Effects of light, moisture, temperature, and litter on the regeneration of five tree species in the tropical montane wet forest of Puerto Rico. *American Journal of Botany* **83**, 1063-1068

Ganeshaiah KN (2005) Recovery of endangered and threatened species: Developing a national priority list of plants and insects. *Current Science* **89 (4)**, 599-600

Gomez-Aparicio L, Zamora R, Gomez JM (2005) The regeneration status of the endangered *Acer opalus* subsp. *granatense* throughout its geographical distribution in the Iberian Peninsula. *Biological Conservation* **121**, 195-206

Graham S (2002) *Global Estimate of Endangered Plant Species Triples*. Available online: www.sciam.com/article.cfm

Gupta AK (2007) Biodiversity and wildlife research in northeast India: new initiatives by the wildlife institute of India, Available online: http://www.wii.gov.in/envis/rain_forest/chapter18

Hajra PK, Verma DM, Giri GS (Eds) (1996) *Materials for the Flora of Arunachal Pradesh* (Vol 1), Botanical Survey of India, Calcutta, 693 pp

Haridasan K, Rao RR (1987) Forest flora of Meghalaya (Vol II), Bishen Singh Mahendra Pal Singh, Dehradun, India, pp 453-937

Hodar JA, Castro J, Gomez JM, Garcia D, Zamora R (1998) Effects of herbivory on growth and survival of seedlings and saplings of *Pinus sylvestris nevadensis* in SE Spain. In: Papanastasis VP, Peter D (Eds) *Ecological Basis of Livestock Grazing in Mediterranean Ecosystems*, Office of the Official Publications of the European Communities, Luxembourg, pp 264-267

Hou D (1960) *Thymelaeceae.* In: Van Steenis CGGJ (Ed) *Flora of Malesiana. Series I, Vol 6*, Wolters-Noordhoff, Groningen, The Netherlands, pp 1-15

Hughes JB, Daily GC, Ehrlich PR (1997) Population diversity: Its extent and extinction. *Science* **278**, 689-692

IUCN (2009) Asian Regional Workshop (Conservation and Sustainable Management of Trees, Viet Nam) 1998. *Aquilaria malaccensis*. In: IUCN 2009. IUCN Red List of Threatened Species. Version 2009.2. Available online: www.iucnredlist.org

Janzen DH (1970) Herbivores and the number of tree species in tropical rain forests. *American Naturalist* **104**, 501-528

Kanjilal UN, Kanjilal PC, Das A (1938) *Flora of Assam* (Vols I-V), Shillong, Vol I: 386 pp, Vol II: 409 pp, Vol III: 578 pp, Vol IV: 377 pp and Vol V: 480 pp

Khan ML, Rai JPN, Tripathi RS (1987) Population structure of some tree species in disturbed and protected subtropical forests of northeast India. *Acta Oecologica* **8 (3)**, 247-255

Kumar BM, George SJ, Chinnamani S (1994) Diversity, structure and standing stock of wood in the homegardens of Kerala in Peninsular India. *Agroforestry System* **25**, 243-262

Maunder M (1992) Plant reintroduction: an overview. *Biodiversity and Conservation* **1 (1)**, 51-61

Misra R (1968) *Ecology Work Book*, Oxford and IBH Publishing Co., New Delhi, 244 pp

Mittermeier RA, Gil RP, Hoffmann M, Pilgrim J, Brooks T, Mittermeier CG, Lamoreux J, da Fonseca GAB (2005) *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecosystems*, Cemex, Mexico, 392 pp

Myers N (1993) Questions of mass extinction. *Biodiversity and Conservation* **2**, 2-17

Myers N (1997) Mass extinction and evolution. *Science* **278**, 597-598

Pannell JR (2002) What is functional androdioecy? *Functional Ecology* **16**, 858-869

Parthasarathy N, Karthikeyan R (1997) Population structure of *Grewa pandacia*, a rare and endemic tree species in South Western Ghats, India. *Biodiversity and Conservation* **8**, 1365-1381

Polunin O, Stainton A (2006) *Flowers of the Himalaya* (8^{th} Impression), Oxford University Press, 580 pp

Rodgers WA, Panwar HS (1988) *Planning a Protected Area Network in India* (Vols I and II), Wildlife Institute of India, Dehra Dun, India, 608 pp

Rogers GM (1996) Aspects of the ecology and conservation of the threatened tree *Olearia hectorii* in New Zealand. *New Zealand Journal of Botany* **34**, 227-240

Sanjappa M (2002) *Gleditsia* and *Gymnocladus* Lam. (Leguminosae-Caesalpiniodeae) in India. In: Rao RR (Ed) *Advances in Legume Research in India*, Bishen Singh Mahendra Pal Singh, Dehradun, India, pp 27-34

Schnabel A, McDonel PE, Wendel JF (2003) Phylogenetic relationships in *Gleditsia* (Leguminosae) based on ITS sequences. *American Journal of Botany* **90**, 310-320

Singh JN, Mudgal V (2000) Assessment of mineral content of tree leaf litter of Nokrek biosphere reserve and its impact on soil properties. *Tropical Ecology* **41 (2)**, 225-232

Sorensen T (1948) A method of establishing groups of equal amplitude on similarity of species content. *Biologiske Skrifter K. Danske Videnskbernes Selskab* **5 (4)**, 1-34

Stainton A (2007) *Flowers of the Himalaya. A Supplement* (1^{st} Impression), Oxford University Press, 86 pp

Subash Chandran MD, Mesta DK, Rao GR, Ali S, Gururaja KV, Ramachandra TV (2008) Discovery of two critically endangered tree species and issues related to relic forests of the Western Ghats. *The Open Conservation Biology Journal* **2**, 1-8

Takhtajan AL (1969) *Flowering Plants: Origin and Dispersal*, Smithsonian Institution Press, Washington, DC, 310 pp

Uma Shankar (2001) A case study of higher tree diversity in a sal (*Shorea robusta*) dominated lowland forest of Eastern Himalaya: floristic composition, regeneration and conservation. *Current Science* **81 (7)**, 776-781

Whitmore TC (1972) *Tree Flora of Malaya: A Manual for Foresters* (Vol 2), Longman, Kuala Lumpur, 471 pp

Whitmore TC (1984) *Tropical Forest of the Far East*, Oxford Claredon Press, 444 pp