*See also*: **Afforestation**: Species Choice. **Plantation Silviculture**: Multiple-use Silviculture in Temperate Plantation Forestry; Rotations; Sustainability of Forest Plantations. **Silviculture**: Coppice Silviculture Practiced in Temperate Regions; Natural Stand Regeneration; Unevenaged Silviculture. **Windbreaks and Shelterbelts**.

## Further Reading

Burns RM (1983) *Silviculture Systems for the Major Forest Types of the United States. Agriculture Handbook No. 445*. Washington, DC: US Department of Agriculture.

Dawkins HC and Philip MS (1998) *Tropical Moist Forest Silviculture and Management*. Wallingford, UK: CAB International.

Lamprecht H (1986) *Waldbau in den Tropen (Silviculture in the Tropics)*. Hamburg, Germany: Verlag Paul Parey.

Matthews JD (1989) *Silvicultural Systems*. Oxford: Clarendon Press.

Palmer J and Synnott TJ (1992) The management of natural forests. In: Sharma NP (ed.) *Managing the World's Forests: Looking for a Balance Between Conservation and Development*, pp. 337–373. Iowa, USA: Kendall/Hunt.

Parren MPE (1991) *Silviculture with Natural Regeneration: A Comparison Between Ghana, Cote d'Ivoire and Liberia*. AV. no. 90/50. Wageningen Agricultural University, The Netherlands: Department of Forestry.

Poore D (ed.) (1989) *No Timber Without Trees – Sustainability in the Tropical Forest*. London: Earthscan Publications.

Smith DM (1986) *The Practice of Silviculture*, 8th edn. New York: John Wiley.

Troup RS (1955) *Silvicultural Systems*. Oxford: Clarendon Press.

Whitmore TC (1990) *An Introduction to Tropical Rainforest*. Oxford: Clarendon Press.

# Bamboos and their Role in Ecosystem Rehabilitation

**I V Ramanuja Rao**, International Network for Bamboo and Rattan (INBAR), Beijing, China



## Introduction

Bamboos are a treelike, 'woody' plant of the grass family and botanically, one of the closest relatives to rice. It thus combines the best of both worlds – it grows speedily like a grass and in much the same way, while at the same time, it produces a considerable amount of high-strength and easily processed woody material with similar properties. It can grow in very poor soils, but also responds admirably to fertilization and irrigation, much like the modern rices, resulting in a doubling or more of size and annual biomass production.

Within the area of their natural distribution, bamboos are the plant equivalent of the domesticated animal like the cow, sheep, and goat. The high strength-to-weight ratio of the poles, and the absence of cross-fibers that lends bamboo to easy linear splitting, are characteristics that have made rural communities choose bamboo over other trees when it comes to structural as well as diverse subsistence uses. Over 1 billion people on earth live in houses that are reinforced with bamboo, even where wood is available nearby.

There are hundreds of traditional uses of bamboo, from food, construction material, housing, and bridges to household articles, and use in agriculture, fisheries, transportation, and in village industry. Bamboo also finds use today as a structural material, as a wood substitute, food, fuel, and a filtration medium.

## Diversity

Bamboos are the most diverse group in the grass family, and the most primitive subfamily. The taxonomy of bamboos remains poorly understood, though the general consensus seems to be that the subfamily Bambusoideae has between 60 and 90 genera with 1100 to 1500 species, with the vast majority being tropical. The main reason for this large variation in diversity estimates is that flowering bamboos are few and far between. Most bamboos flower once in several years (and die thereafter), with the vegetative period extending up to several decades, but commonly 30–60 years for the more useful species. Hence taxonomists have to contend with having to do species determination mainly on the basis of vegetative material, which results in open-ended results that need a flowering specimen for confirmation.

## Propagation

Bamboos are commonly propagated using vegetative (clonal) means and, when available, by seeds. The latter method is more common in tropical areas where the bamboos flower and set seed more frequently. Most bamboos produce copious quantities of seed (botanically termed caryopses that are technically fruits); these are called 'bamboo rice' and are even used as such. The rare exceptions are species such as *Melocanna baccifera* that produce large fruits, often the size of small mangoes. In some bamboos, infertility is rampant, with few viable seeds being produced.

More commonly, vegetative propagation methods are used. The methods primarily use (1) rhizome cuttings (or with attached culms (stems)), (2) culm (main stem) cuttings, and (3) branch cuttings. It is observed that the success rate commonly considerably decreases from rhizome cuttings to branch cuttings, but this needs to be considered against the larger number of cuttings available from branches as against the few rhizome cuttings (often one to two from a plant), and the damage the parent plant suffers on removal of material for propagation, which is significantly greater with rhizome removal.

Tissue culture has also been used to propagate bamboos, and has been widely employed where facilities, and availability of seeds that easier starting materials for culture, are available. Fewer bamboos have been mass-propagated by tissue culture from mature adult plants.

## Production and Characteristics

The annual incremental biomass production on air-dry basis for a bamboo plantation can range from 10 to 40 tonnes $ha^{-1}$ depending on the species, planting density, soil, and climate, including slope and aspect of a hill. An increase in strength is reported to occur until about 3–4 years and thereafter it decreases. Therefore the maturity period of bamboo is commonly considered 3–4 years with respect to density and strength, although for other applications, younger bamboos from ages 1–2 are used.

The mechanical properties of bamboo differ with species, age, climatic factors, moisture content, and different heights of the culm. Because of its hollowness, the effectiveness of bamboo as a beam is 2.9 times better than a wood beam. Bamboo possesses excellent strength properties especially tensile strength. It is as strong as wood and some species even exceed the strength of timbers such as *Shorea robusta* and *Tectona grandis*.

The density of bamboo varies from 500 to 800 $kg\,m^{-3}$. The general mechanical properties of bamboo are:

- tensile strength = 1000–4000 $kg\,cm^{-2}$
- compression strength = 250–1000 $kg\,cm^{-2}$
- bending strength = 700–3000 $kg\,cm^{-2}$
- modulus of elasticity = 100 000–300 000 $kg\,cm^{-2}$.

## Ecological Requirements and Distribution

Bamboos are important ecologically because of the vast area over which they are distributed, the total quantum of the resource, and the diversity of species and the ecological habitats they occupy. According to an estimate, bamboo accounts for one-quarter of the biomass in tropical regions and one-fifth in subtropical regions. Bamboos occur in latitudes as far north as 46° N and as far south as 47° S, and at elevations from sea level to as high as 4000 m in the Himalayas. Most bamboo is found in the area between the Tropic of Cancer and the Tropic of Capricorn, and its principal distribution completely girdles the world like a belt around the equatorial region, with extensions both to the north and the south into the subtemperate areas.

Bamboos thrive in a semi-evergreen and moist deciduous forest, with the wet evergreen and dry deciduous types as its two extreme limits. The controlling factors for its abundance, distribution of species, growth, and development within these typical limits are mainly annual precipitation, relative humidity, and the nature of the soil. Bamboos can grow as an understory in almost all the forests excepting mangrove vegetation and form a rich belt of vegetation in well-drained parts of tropical and subtropical habitats.

Most clump-forming (or pachymorph) bamboos grow at temperatures ranging from 7°C (sometimes 2–3°C) to 40°C and can tolerate higher temperatures for short periods. Altitude affects the distribution of bamboo even in the tropical region. The clump-forming type is observed to predominate in low and medium altitudes, while the nonclump-forming running (or leptomorph) type occurs more abundantly at high elevations. Altitude and temperature are closely related and it is difficult to separate one from the other, for example, some species of *Phyllostachys* are cultivated at high elevations in India and Nepal but also occur at low elevations in countries of the temperate zone.

Bamboo commonly grows well in areas with an annual rainfall of 1000–6000 mm, but is also found in areas with lower (800 mm) and higher annual rainfall levels.

## Role in Ecosystems

Bamboos grow in a vast diversity of ecosystems, both natural and human-made. In general, bamboos are one of the first members to colonize a new site in a seed year and perhaps the last to leave it. Once established on a site, it is relatively difficult to eradicate, with the rhizomes being found throughout the forest area. Even if the bamboos are felled with the trees, the underground rhizomes remain alive and give out new shoots in the following growing season. In the absence of tree regeneration the site would become a pure bamboo forest; with tree regeneration the bamboo comes up as undergrowth.

Generally, one bamboo species will grow in a pure condition. It is rare to encounter a mixture of two or more species.

Their unique biological properties have enabled the bamboos to adapt to diverse situations. Their role in ecosystem rehabilitation is best understood in terms of (1) their role in various natural and human-made ecosystems, and (2) the unique combination of characteristics and properties of this plant that increase the comparative advantage of the plant, and have enabled it to survive and spread around the globe. Principal amongst these are its treelike stature, the aggressive spreading underground rhizome, the strong adventitious root system, the rapid shooting of the pointed and leafless new culms, the production of leaves and branches from the tip downwards, the considerable tensile strength of the culms, the often several decades-long lifespan, and the gregarious flowering of bamboo, all of which together enable the remarkable adaptability of bamboo to diverse ecological conditions.

## Treelike Stature and Dense Canopy

Bamboos commonly grow to 15 m; some species are diminutive, some are climbers, while others reach a height of up to 40 m. Bamboos have a dense canopy. A bamboo produces considerable biomass, and a significant part of this is in the form of foliage. For example, in *Gigantochloa scortechnii*, the amount of biomass is 50–100 tonnes $ha^{-1}$, divided into 60–70% for culms, 10–15% for branches, and 15–20% for the leaves.

Bamboos are not purely evergreen plants. Most of the clump-forming types in the tropical regions shed their leaves in winter when it is dry and renew the leaves simultaneously in a short time. The amount of leaf fall from *Melocanna baccifera*, *Oxytenanthera nigrociliata*, *Bambusa tulda*, and *Dendrocalamus giganteus* is 6.0, 5.6, 5.8, and 7.0 tonnes $ha^{-1}$, respectively. Bamboos contribute approximately 20 kg $tonne^{-1}$ of organic matter to the soil, which is largely similar to that of other broadleaved species. The abundant leaf fall and rhizome growth in the topsoil layer serves to ameliorate soils.

The spreading foliage takes the impact of the fierce tropical rains and softens their impact on the ground. Leaves that fall up to 10 cm thickness per year also help absorb the impact of rain. A project in China conclusively proved that the canopy and leaf litter of temperate bamboo stands can intercept rainfalls much higher than those for conifers and pines.

## Strong Adventitious Root System

The strong and solid underground rhizome of bamboos produce copious roots. Eighty-three percent of the roots of a well-grown clump of *Bambusa tulda* were reported to be present in the upper 33 cm of the soil; 12% between 33 and 66 cm, 4% between 66 and 100 cm, and only 1% between 100 and 135 cm below the surface. Bamboos are thus a superficial grower and feeder, and this characteristic gives them the ability to bind soils and prevent erosion. A study estimated that a single bamboo plant could bind up to 6 $m^3$ of soil. The weight of the soil bound is considerably more than the weight of the over-ground light tubular, cross-reinforced plant – the considerable dead-weight prevents it from being easily uprooted.

## Underground Rhizome

The complex branched and robust underground rhizome system and infrequent flowering also distinguish the bamboo from common trees. The rhizome system spreads horizontally and produces culms from new rhizome growth. Even if a bamboo species is 30 m or more in height, the rhizome seldom grows more than 75 cm deep within the soil, mostly occurring within the top 20–50 cm.

There are two principal categories of bamboos – the clumping type (pachymorph bamboos) and the running type (leptomorph bamboos). The extent of spread of the former is dependent on the length of the rhizome neck, while in the latter, the running rhizome produces buds that grow up into culms. Bamboos can well be called the 'walking tree.' A bamboo can thus quickly expand and consolidate its 'territory' compared to most trees. In more dense wet tropical forests, climbing bamboos are not uncommon.

The underground rhizome network is a function of the type of bamboo. Clumping or pachymorph bamboos would have a clustered set of rhizomes under the clumps with limited spread outwards. Pachymorph bamboos like *Melocanna baccifera* but having an open and diffuse type of rhizome system with long rhizome necks of 1–2 m, form a complete underground network over the entire area that gridlocks the soil and do not give way even under considerable pressure from liquefied soils under strong monsoonal rains. Running or leptomorph bamboos have rhizomes that criss-cross the ground. This kind of rhizome system is stronger than the clumping bamboos but not as strong as that of the diffuse pachymorph type.

Importantly, the underground rhizomes enable bamboo to survive forest fires, including fires set for clearing land for slash-and-burn agriculture. Thus they are fairly tenacious, and difficult to kill or eradicate. In burnt lands that previously had growth of bamboo, it is often the first plant to regenerate.

Once established, the early formation of rhizome protects seedlings from grazing. Even if the tops get eaten, new shoots are produced from the rhizome.

### Rapid Shooting of New Culms

The new shoots grow to full height within 2–4 months which is the total time taken from when the newly forming bamboo culm (pole) starts to break ground as a new bamboo shoot to the attaining of full height. This period is the same for a short-stature bamboo and one whose culms reach up to 40 m with a diameter of up to 30 cm. During this period the bamboo shoots can grow 1.2 m in 24 h. The pointed, leafless culms reach full height before branches and leaves are produced on the naked culm from the apex downward. The culms can therefore fully occupy even small open spaces in the forest before spreading their branches.

### Annual Production of Culms

Bamboo produces several new full length culms each year. Thus a clump ordinarily produces several kilometers of culms during its lifetime. Since culms are produced each year, annual harvests are possible and recommended. Bamboo therefore combines characteristics of an annual and a perennial, and hence can span agriculture and forestry. Given that there is no secondary growth in bamboo (it being a grass), but that several tonnes of new woody biomass are produced *de novo* each year as new culms, bamboo offers the opportunity to sequester considerable carbon throughout its lifetime. *Guadua* in Costa Rica has been calculated to sequester 17 tonnes $ha^{-1}$ of carbon each year throughout its lifetime.

### Considerable Tensile Strength of the Culms

Bamboos poles have a remarkably high tensile strength – weight for weight, this is greater than that of steel. It therefore can withstand very high winds and typhoons.

Bamboo poles mostly attain full strength by the third year, while trees take a considerably longer time to mature. Yet another very important characteristic is that the total quantum of bamboo wood is produced in the very first year of growth, although its composition undergoes a change from year to year.

### Gregarious Flowering of Bamboo

Depending on the periodicity of flowering, bamboos fall into three groups: (1) annual flowering (or nearly so), (2) irregular flowering, and (3) gregarious and periodical flowering. Many species that flower gregariously also flower sporadically. Gregariously flowering clumping species generally have vegetative periods of around 25–35 years within a larger range of 15–60 years, while many running bamboos flower after 60–120 years. There are also bamboos such as *Bambusa vulgaris* that have not been known to flower, or do so rarely without seed set and concomitant death, but never gregariously. Gregariously flowering species from the same cohort will flower at the same time even if separated geographically across the globe.

More recently, bamboo hybridization has become possible through an ingenious nutrition control means that seeks to physically bring together naturally flowering bamboos and maintain them in a flowering state. Interspecific and intergeneric hybrids have been produced. The flowering of bamboos *in vitro* has also been demonstrated. Once *in vitro* flowering is established, the bamboo can be alternated between the flowering and vegetative states.

Most species of bamboo die after gregarious flowering at the end of a long vegetative period of growth, often three decades and more, depending on the species. This event with catastrophic economic and social effects (because of the suddenness and scale) has a major impact on the local ecosystem, and affects the vegetation with which it is associated. There is also the possibility of increased soil erosion, effects on wildlife, and also significant social and food security effects. The latter is mostly due to its nutritious seeds and fruits that form food for field rats (commonly called bamboo rats) which increases the number of litters and the live pups per litter. When the bamboo seeds/fruits are exhausted, the ferocious rats turn to household grain stocks. In Mizoram, which is a state in the northeastern part of India, a revolution was spawned as a result. In Thailand, the flowering of *Dendrocalamus asper* brought a flourishing edible shoots export industry to its knees. In Zambia, whole communities were uprooted when the bamboo that was the mainstay of their life and livelihood flowered and died.

The natural regeneration of bamboos occurs profusely after each gregarious flowering. Masses of seedlings form and there is intense competition with consequent natural thinning. By around 6 years, the area again has fairly uniformly spaced clumps, unless there is human intervention, intense grazing or fire. The first year or two are critical since there is little protection, except for refuges in the dead clumps.

Much learning is rapidly taking place in this area, with the result that where prior data of flowering is known, advance steps can be taken to reduce its impact. Mapping of flowered areas on to the geographical information system (GIS) with dates and species/cohorts have started in some areas.

## Preventing Soil Erosion in Uplands and Lowlands

The extensive underground root-and-rhizome system makes bamboo a good instrument for arresting the ravages of water erosion in areas prone to it (such as slopes and lowlands). Researchers in Puerto Rico, who experimented with several plant species, found bamboo to be one of the most effective in controlling landslides. It is reported that the *Guadua* bamboo in Colombia has effectively prevented millions of tonnes of mountain soil from being washed down into the ocean. In China it has been observed that the mixed bamboo stands that adorn the southwest mountainous area are instrumental in ensuring that the quantity of soil that reaches Yangtze River through sheet erosion is just half that of the quantity washed out into the Huang River (Yellow River). The plant is so effective in binding soil on steep slopes that Malaysia has planted bamboos on hillsides to block mud and stones sliding on to roads.

## Watersheds

Bamboo is commonly used in watersheds for increasing rain interception, reducing impact on the ground of heavy rain, reducing soil erosion, increasing water recharge, and for increasing postmonsoonal flow. In Ecuador, it is common for farmers to plant *Guadua* on the slope above farms since it increases water availability.

## Riverbanks, Dam Sites, Lakes, and Ponds

As a plant that, unlike trees, spreads horizontally because of its rapidly growing rhizome and its pronounced ability to bind soil, bamboo is excellent for protecting riverbanks, dam sites, lakes, and ponds. It is also able to tolerate intermittent flooding which helps in this function. For this reason, bamboo cultivation in Japan has been recommended since the sixteenth century.

Bamboo's efficacy as a soil binder has been successfully used in Puerto Rico, Costa Rica, Nepal, the Philippines, and China. Bamboo planted at certain strategic points along the course of a river, especially at points where the river curves, have solved the problem of damage to the riverbank and also flooding. Not only is this due to the soil-binding capacity, but also the clumping bamboos often tend to 'mound,' leading to an increase in the height of banks as well. In Dayingjiang River in Yunnan Province and Jiulongjang River in Fujian Province in China, bamboo succeeded in protecting riverbanks after soil-rock engineering efforts and the planting of other trees had failed to yield results. It was shown that each clump can protect up to $12\,m^3$ of river embankment.

## Windbreaks

Bamboos, particularly the clumping type, are an effective shield against the onslaught of wind. The flexibility of the culms (for green culms the modulus of elasticity is about $9000–10\,000\,N\,mm^{-2}$ and the modulus of rupture $84–120\,N\,mm^2$) helps them to bend but not break even in relatively strong winds. Bamboo can bend even until it touches the ground in very strong winds, cyclones, and typhoons without getting uprooted like trees. Because of this bamboo is commonly used as a wind barrier along boundaries of farms, and to protect agricultural land from wind erosion during fallow periods.

Bamboo is also now being planted as an inner line plantation behind coastal mangrove and casuarinas to shield the interior from the effects of strong winds and cyclones.

## Inundated Areas and Saline Environments

Bamboo does not grow naturally under saline coastal inundation. However, in Bangladesh, it is common practice for people in coastal areas to cultivate bamboo in homesteads and farmlands. The most successful species is *Bambusa vulgaris*. Another such bamboo is *B. atra* (*B. lineata*) which is found in the tidal swamp forest of the Andaman Islands (India).

Species such as *Ochlandra scriptoria*, *O. stridula*, and *O. travancorica* that are indigenous to the states of Kerala and Tamilnadu in India are mostly found in marshy areas and riverbanks that get flooded in the monsoons. *Phyllostachys purpurata* (*P. heteroclada*) and *P. atrovaginata* are monopodial species that can grow in wet soils and waterlogged areas. Interestingly, the rhizomes of these monopodial species have air canals.

Most bamboos can tolerate a period of inundation. With longer periods of inundation there is death of a considerable number of culms, especially if this occurs during the growing season (up to 60% death of new culms), but the plant usually recovers in the subsequent growing season.

## Fish and Shrimp Farming in Water Bodies

Bamboos growing on the banks of water bodies contribute to an increase in aquatic life, including algae, fish, and shrimps. In Puerto Rico, despite the fact that bamboo litter is different from riparian inputs of the indigenous forest species bamboo displaces, the leaves decompose at similarly fast rates. There is also significant increases of filter-feeders (*Atya* spp.) and predators (*Macrobrachium* spp.) in bamboo pools. Data from experiments suggest a structural consideration in shrimp preference for bamboo substrata, in addition to the relative qualities of the leaves as food.

In India, villagers increasingly plant bamboo on water body margins. Even in new ponds established in degraded agricultural land from which the topsoil has been dug out for brickmaking, bamboo planted on the pond banks results in an increase in the fish population because of the leaf fall into the pond (which also reduces the amount of additional feed required). In Bangladesh, bottom mud from the ponds is dug out and used as a fertilizer for the bamboo clumps.

## Wastelands

Bamboo is especially useful in converting wastelands, previously used only for grazing based on natural grass growth, to productive agriculture. Such lands after planting with bamboo have been successfully intercropped with soybean, groundnut, and maize, and the results have prompted several farmers to adopt this approach.

Because of the ability of bamboo to grow in poor soils, it has been used in dense plantations at close intervals to build up considerable woody and leafy biomass over ground, considerable leaf litter, and an extensive rhizome system. Together these contribute to a substantial build-up of organic carbon in the soil, an increase in soil microflora, increase in water holding capacity, and amelioration of soil pH from acidic towards neutrality. Bamboo soil is a commodity in some countries because of its fertility.

## Agroforestry Systems

A variety of agroforestry systems exists for bamboo. It is common to see bamboo interplanted in fruit orchards in Thailand, and in tea estates in Bangladesh. Agricultural crops are mostly interplanted in the first 4 years of establishment of a bamboo plantation before canopy closure takes place. A diversity of crops are grown depending on the local agroclimatic condition, such as watermelon, soybean, sweet potato, sugar cane, and vegetables in the initial years. Within adult bamboo stands, the raising of pineapple, ginger, turmeric, and shade-tolerant varieties of sweet potato, etc. is undertaken in places where land is scarce. Continued agriculture is possible in situations where bamboo is the interplant.

A large number of mushrooms are also raised in China in bamboo stands which satisfy the fungi's need for humidity, shade, and a fertile bed. Key amongst these are *Dictyophonra tomentose*, *Plenrotus ostreatus*, and *Auricularia auricular-judoe*.

Medicinal plants are also interplanted with bamboo.

## Interplanting with Trees

Bamboo is interplanted with conifers and broadleaf timber trees; in the latter case this is especially successful with trees with deciduous light crowns rather than heavy canopies. Interplanting of bamboo plantations and even dense bamboo plantations with casuarinas (and with eucalyptus) has been done successfully over the past two decades in western India.

## Degraded Lands

Bamboo has proved to be ideal for making productive land degraded by removal of the clayey topsoil down to 3 m for producing bricks, down to the sandy layer. The bamboo that is grown interspersed and also on boundaries of farms acts as a shelterbelt. It prevents further soil erosion due to wind action, improves the microclimate at the crop level, improves moisture retention, and contributes to soil rebuilding by increasing organic carbon content from leaf fall, including an increase in water holding capacity. Increases in groundwater levels have been recorded using this method.

The method is increasingly being used following the initial successes, and has significant implications for the over 3 million ha of land that are degraded in India, and similar lands elsewhere.

## Ecological Role of Bamboos in Forests

Bamboos grow naturally as a component of forests, often as the understory. Their role in deciduous forests in areas with a pronounced dry season appears to be more significant in that the understory bamboo results in a reduction in soil erosion. The association of teak with bamboo is a common one, with significant benefits in controlling soil erosion.

The gregarious flowering of bamboo has been said to be the reason for development of bamboo brakes and pure bamboo stands; it probably occurs when there is complete death of all tree saplings growing in the understory of the closed bamboo canopy.

Bamboo also appears to play a role in the protection and regeneration of forests. Detailed studies in Asiatic old-growth forests with a bamboo understory have also noted the influence of the life cycle of the bamboos on the age structure of tree populations, and the tendency of synchronization of tree regeneration following bamboo dieback following flowering.

In Costa Rica, oak (*Quercus*) forest regeneration is pulsed as a consequence of the synchronous life cycle of the *Chusquea* bamboos due to gregarious flowering. The *Chusquea* bamboo normally grows as the understory in the oak forests. In the steady state, the understory *Chusquea* clumps are small because of limited light conditions. If there are fires or gap creation through tree fall, the *Chusquea* rapidly responds to the increased availability of light, and grows up to become the local dominant species with a closed canopy under which saplings of trees now grow in a suppressed state because of the low light conditions under the bamboo canopy. When the *Chusquea* flowers gregariously and dies, the forest floor is more illuminated, and the already established suppressed saplings shoot up. The new generation of bamboo then grows under the newly formed tree canopy.

## Bamboos in Fire-Disturbed Lands

Bamboos are one community that colonizes disturbed lands in the tropics especially after fire, because of its well-developed underground rhizome system. The widespread distribution of *Melocanna baccifera* throughout eastern India, Bangladesh, northern Myanmar, and Thailand and of species of *Thyrsostachys* in Thailand and *Schizostachyum* in Vietnam mainly occurs as secondary vegetation due to the destruction of tropical rainforest by fire, shifting cultivation, and logging.

As a result of shifting agriculture, huge expanses of bamboo forests have been established in Asia. In northeast India, bamboos constitute the major vegetation after slash-and-burn agriculture, and due to their adaptability and nutrient conservational role, they play a special role in succession. Shortening of the cycle when the bamboos are still the dominant species largely results in the reduction and often elimination of tree species, such that the fire-tolerant bamboos that survive through the underground rhizomes become the permanent dominant species. Repeated firing over short cycles results in almost pure stands of bamboo over vast areas in the hills. While shrubs and trees tend to grow more slowly, the competitive bamboos have rapid rates of dry matter production, continuous stem extension and leaf production during the growing period, and rapid phenotypic adjustments in leaf area and shoot morphology in response to shade. The competitive bamboos also store more nitrogen, phosphorus, and potassium than stress-tolerant shrubs and trees while the reverse is true for calcium and magnesium. Overall it is seen that bamboos follow a strategy of faster uptake and storage of essential elements and a quicker turnover to supplement the soil fluxes, thus efficiently dominating the stress-tolerant shrubs and tree species for a long duration. Overall, bamboos promote stability in the ecosystem through regulation of its functions like other competitive early successional species.

*See also*: **Tropical Ecosystems**: Bamboos, Palms and Rattans. **Tropical Forests**: Tropical Dry Forests; Tropical Moist Forests; Tropical Montane Forests.

## Further Reading

Banik RL (2000) *Silviculture and Field Guide to Priority Bamboos of Bangladesh and South Asia*. Chittagong, Bangladesh: Bangladesh Forest Research Institute.

Farelly D (2003) *The Book of Bamboo: A Comprehensive Guide to this Remarkable Plant, its Uses and its History.* San Francisco, CA: Sierra Club Books.

Kumar A, Rao Ramanuja IV, and Sastry CB (eds) (2002) *Bamboo for Sustainable Development*, Proceedings of the 5th International Bamboo Congress and the 6th International Bamboo Workshop, Bali, Indonesia. Utrecht, The Netherlands: VSP.

Rao Ramanuja IV, Gnanaharan R, and Sastry CB (eds) (1990) *Bamboos*: *Current Research*, Proceedings of the International Bamboo Workshop, Cochin, India. Peechi, India: Kerala Forest Research Institute.

Rao Ramanuja IV, Rao IU, and Roohi FN (1992) Bamboo propagation through conventional and *in vitro* technologies. In: Baker FWG (ed.) *Rapid Propagation of Fast-Growing Woody Species*, pp. 41–56. Wallingford, UK: CAB International.

Rao Ramanuja IV and Sastry CB (eds) (1996) *Bamboo, People and Environment*, Proceedings of the 5th International Bamboo Workshop and the 4th International Bamboo Congress, Bali, Indonesia. New Delhi, India: International Network for Bamboo and Rattan.

# Natural Stand Regeneration

**J Huss**, University of Freiburg, Freiburg, Germany



## Introduction

There are two possible methods of forest stand establishment, namely natural and artificial regeneration. The process of natural regeneration involves the renewal of forests by means of self-sown seeds, root suckers, or coppicing. In natural forests, conifers rely almost entirely on regeneration through seed. Most of the broadleaves, however, are able to regenerate by means of the emergence of shoots from stumps (coppice) and broken stems. This type of forest reestablishment has obviously been important