Chapter 3

Brief Description of the Main Types of Forest Vegetation

Sub-Alpine Coniferous Forests

The sub-Alpine coniferous forests dominated by various coniferous species, such as fir (*Abies*), spruce (*Picea*), larch (*Larix*), and Sabina (*Juniperus*) are distributed throughout the sub-Alpine belt of the Himalayan-Hengduan Mountains from 3,000 (2,800) to 4,000 (4,300m). Sub-Alpine forests account for over 50 per cent of the land area and over 60 per cent of the growing stock and are the most important forest resources in the region.

Fir (Abies) Forests

The Himalayan-Hengduan Mountains constitute a distribution centre for the genus *Abies*. Out of 50 species of *Abies* found in the northern hemisphere, 22 species are native to China. In the Himalayan-Hengduan Mountain Region, 18 species of *Abies* have been identified. However, only a few of them are the dominant species in the forests.

According to natural distribution, *Abies* species can be divided into two groups. One group is found in the cool temperate sub-Alpine belt. It includes *Abies squamata, A. georgii, A. delavayi, A. spectabilis, A. forrestii, A. faxomiana, A. recurva*, and *A. nukiangensis*. Another group is distributed throughout the

temperate forest belt at lower altitudes, between 2,000 to 3,000m. The representatives of the second group include *Abies ernestii* and its subspecies *ernestii* var *salouensis*.

As for horizontal distribution, *Abies georgii* var *smithii* and *A. spectabilis* are the main species in the Himalayas; *Abies fabrii, A. forgesii, A. georgei, A. squamata, and A. forrestii* dominate the northern part of the Hengduan Mountains; in the southern part of the Hengduan Mountains, *A. georgei* and *A. delavayi* are the dominant species. The vertical distribution of *Abies* is given in Figure 5.

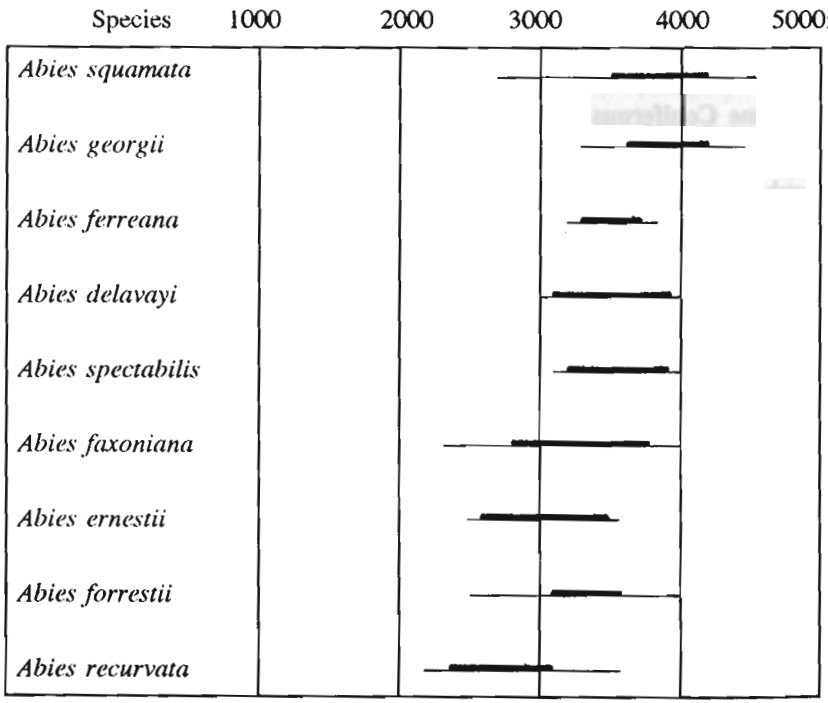


Fig. 5: Vertical Distribution of Species of *Abies*

Alpine fir forests are adapted to cool temperate climates. According to observations, the temperature indicators for the distribution of sub-Alpine *Abies* forests in this region are as follows:

- mean annual temperature 2-8°C,
- accumulated temperature ≥ 10°C 490-1900°C,
- warmth index 13-48°C,
- mean temperature of coldest month -8-0°C,
- mean temperature of warmest month 10-15°C,
- absolute minimum temperature -27--18°C, and
- frost-free period 85-160 days.

The distribution of fir forests is closely related to moisture conditions. The annual precipitation usually exceeds 700mm, with a distribution that ensures adequate moisture during the growing season and an average annual relative humidity exceeding 70 per cent.

Sub-Alpine fir forests have developed on different varieties of dark brown and podzol soils. The soil is characterised by acid reaction and relatively poor, available nutrient content.

In spite of the great number of dominant species, the general morphology of the different forests is quite similar. In general, more than one species from the genera *Abies* and *Picea* can be found in the tree layer on an individual plot. In the natural *Abies* forests, the growing stock varies from 350 to 700 cubic metres per hectare. The canopy density is relatively high (0.6 to 1.0). The average height of the stands varies between 30 to 40m, and the diameter from 35 to 50m. In valleys with favourable natural conditions in the Himalayas, undistributed *Abies* forests can grow over 40m in height and 60cm in diameter, with a total growing stock of 800 to 1,200 cubic metres per hectare. However, the overmature forests on the tree line (4,600m) can reach an average DBH of 30cm and an average height of 13m, with a growing stock of 125 cubic metres per hectare.

Sub-Alpine *Abies* forests can be grouped into four different types. From low elevations to high elevations, one can distinguish *Abies sinarundinaria*, *Abies* herb-shrub, *Abies* moss type, and *Abies* rhododendron.

As a rule, under the canopy of densely-populated natural forests, there is a relatively large number of small seedlings of less than one to two years old. However, few of them are able to survive until the next phase. After clear felling, the forests are replaced by secondary vegetation, consisting of different species of herbs and shrubs and broad-leaved species such as birch and poplar. The regeneration of spruce and fir can occur only after the canopy of these secondary forests, consisting of broad-leaved species, closes.

Sub-Alpine *Abies* forests exist in the fragile environment around the upper reaches of many big rivers of regional and international importance. They play an important role in regulating soil/water runoff and in conservation. The rich biodiversity of such forests has important scientific and (potential) economic significance. *Abies* forests constitute the major forest resource in the southwestern, high mountainous region of China. Most of the fir (*Abies*) forests are mature and overmature and have been seriously damaged by decay.

Due to the high elevation of the sub-Alpine fir forests, the damage caused by insects is limited. However, the damage caused by decay fungi is widespread and leads to substantial economic losses. In particular, *Fomes annosus, F. connatus, Polyporus schweitzii, P. dradeus, and Phellinus pini,* are the most common fungi species that damage timber. It has been observed that the degree of damage is closely correlated to the age and altitudinal distribution of the forests.

In contrast to the sub-Alpine fir forests, the warm temperate fir forests (*Abies ernestii,* var *salouensis*) are distributed at lower elevations between 2,100 to 2,000 masl. According to our estimates, the climatic conditions for the distribution of this species are mean annual temperature - 10°C; accumulated temperature - >10°C to 2,800°C; warmth index - 72; mean temperature of the coldest month - 17°C; and frost-free period - about six months. The annual precipitation in the distribution area normally exceeds 700mm with a mean relative humidity of over 65 per cent. The forests are usually distributed throughout wide valleys with gentle slopes in medium humus, brown soil.

As a rule, the forests dominanted by *Abies ernestii* are always associated with a number of broad-leaved species such as *Toona sinensis*, *Ulmus* spp, *Cyclobalanopsis oxyodon*, and *Picea brachytyla*.

Abies ernestii is a valuable and rare species and is included in the list of national protected species. Occasionally, gigantic trees can be found in the forests. For example, in Zhayu County in the southwestern Himalayas, an old forest community with the following inventory indicators was found: average DBH - 1.08cm with maximum DBH - 2.6cm; average height - 52m with maximum height - 60m; and growing stock of over 1,000 cubic metres. Figure 6 shows the results of the stem analysis of *Abies ernestii* var *salouensis*.

In order to manage sub-Alpine coniferous forests on a sustainable basis, it is necessary to divide the *Abies* forests into two different categories, i.e., protective and exploitive.

Forests which are located around the upper streams of watersheds, as well as forests in the ecotone between forest vegetation and scrub meadows, should be strictly protected. For other mature and overmature forests, an appropriate felling system should be developed so that timely regeneration can take place.

Spruce (Picea) Forests

About 40 species of spruce (*Picea*) have been recorded in the northern hemisphere; 23 of them were found in China and 12 among them are distributed throughout the Himalayan-Hengduan Mountains. Among these species *Picea balfouriana, P. likiangensis, P. asperata, P. purpurea, P. spectabilis, P. smithiana*, and *Picea brachytyla* var *complanata* are most widely distributed. As a whole, spruce forests grow from 2,800 to 3,800 masl and are located below the forests dominated by *Abies*. The exception to this is *Picea balfouriana* which can grow as high as from 4,300 to 4,500m and is one of the spruce forest types growing near the treeline. Other species such as *Picea brachytyla, P. brachytyla* var *complanata*, and *P. smithiana* have a much lower distribution (between 1,900 to 3,000m) and frequently grow among other species. Dominant species vary according to location. Horizontal distribution of sub-Alpine spruce forests also varies from place to place. The vertical distributions of *Picea* and *Larix* are shown in Figure 7, (page 55). Altitudinal and horizontal distributions of dominant species are also given in Table 9.

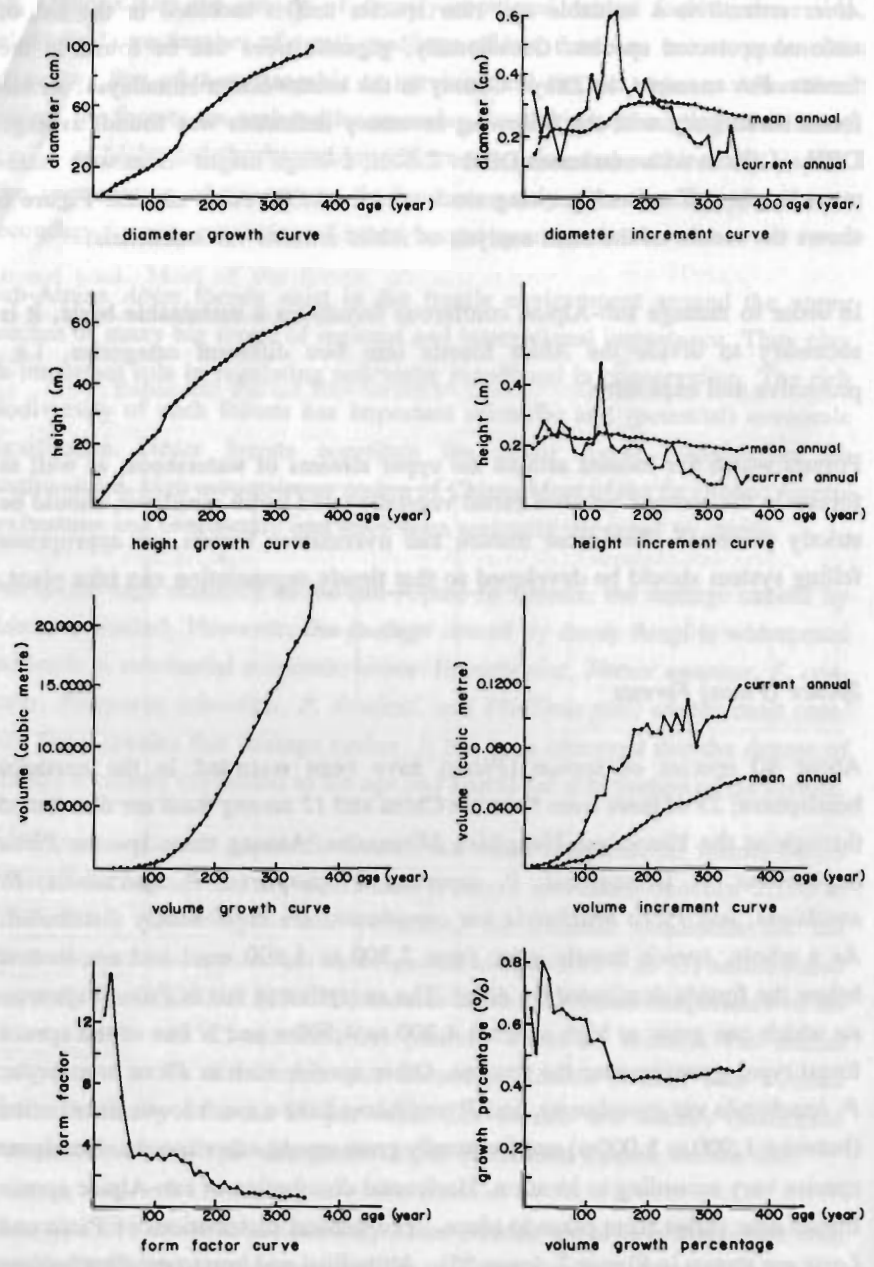


Fig. 6: Stem analysis of *Abies ernestii* var. *Salouensis*

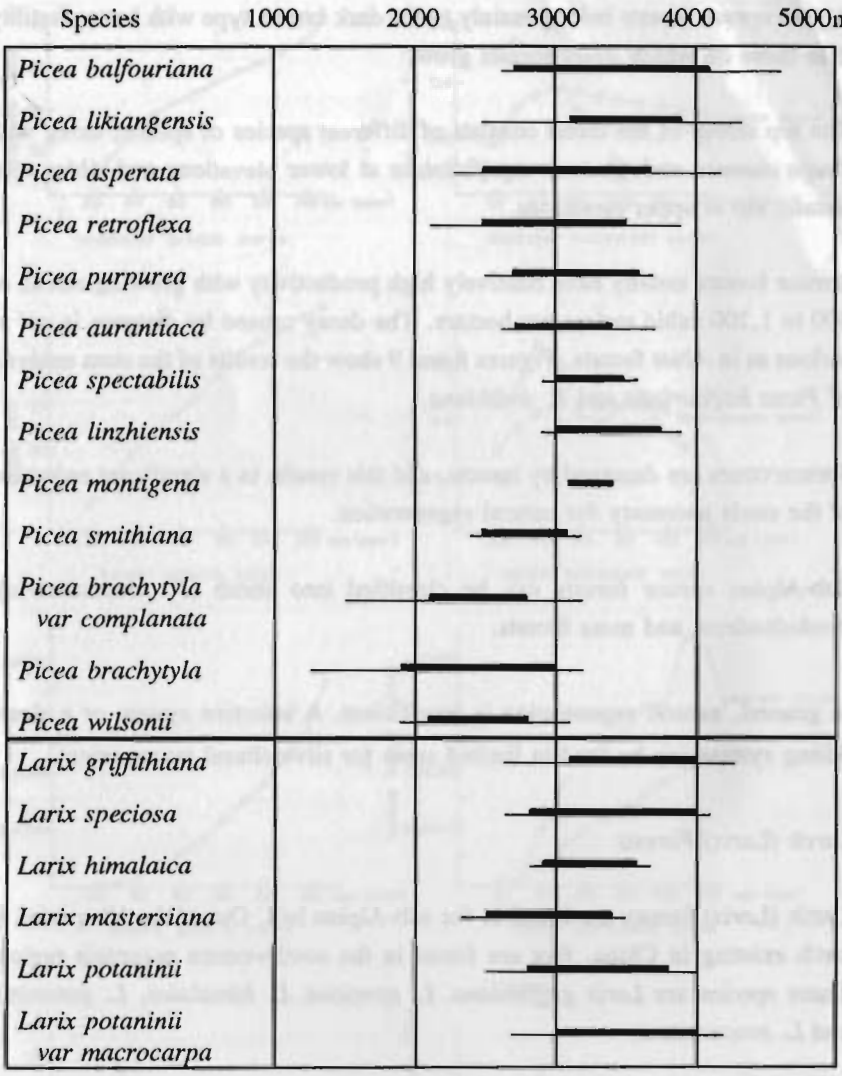


Fig. 7: Vertical Distribution of Species of *Picea* and *Larix*

The climatic indicators for the distribution of spruce forests are similar to those of *Abies* forests, although most spruce species need slightly higher temperatures than *Abies* forests. The soils which are favourable to the development of sub-

Alpine spruce forests belong mainly to the dark brown type with better fertility than those on which *Abies* forests grow.

The top storey of the forest consists of different species of spruce, along with *Tsuga dumosa* and *Quercus aquifolioides* at lower elevations and *Abies* spp, *Betula*, etc at upper elevations.

Spruce forests usually have relatively high productivity with growing stocks of 500 to 1,200 cubic metres per hectare. The decay caused by diseases is not so serious as in *Abies* forests. Figures 8 and 9 show the results of the stem analysis of *Picea balfouriana* and *P. smithiana*.

Spruce cones are damaged by insects, and this results in a significant reduction of the seeds necessary for natural regeneration.

Sub-Alpine spruce forests can be classified into shrub (*P. arunadinaria*), rhododendron, and moss forests.

In general, natural regeneration is insufficient. A selective system or a clear-felling system can be used in limited areas for silvicultural management.

Larch (Larix) Forests

Larch (*Larix*) forests are found in the sub-Alpine belt. Out of the 10 species of larch existing in China, five are found in the southwestern mountain region. These species are *Larix griffithiana, L. speciosa, L. himalaica, L. potaninii*, and *L. mastersiana*.

Larch forests usually occur in the treeline ecotone in newly exposed habitats (habitats made barren by natural hazards or human activities) or in a patchy form distributed along the river bed ranging from 2,600 to 4,300m in elevation, with distribution concentrated between 3,000 to 3800m. The climatic conditions for the development of larch forests are similar to those which are favourable for the development of sub-Alpine spruce and fir forests.

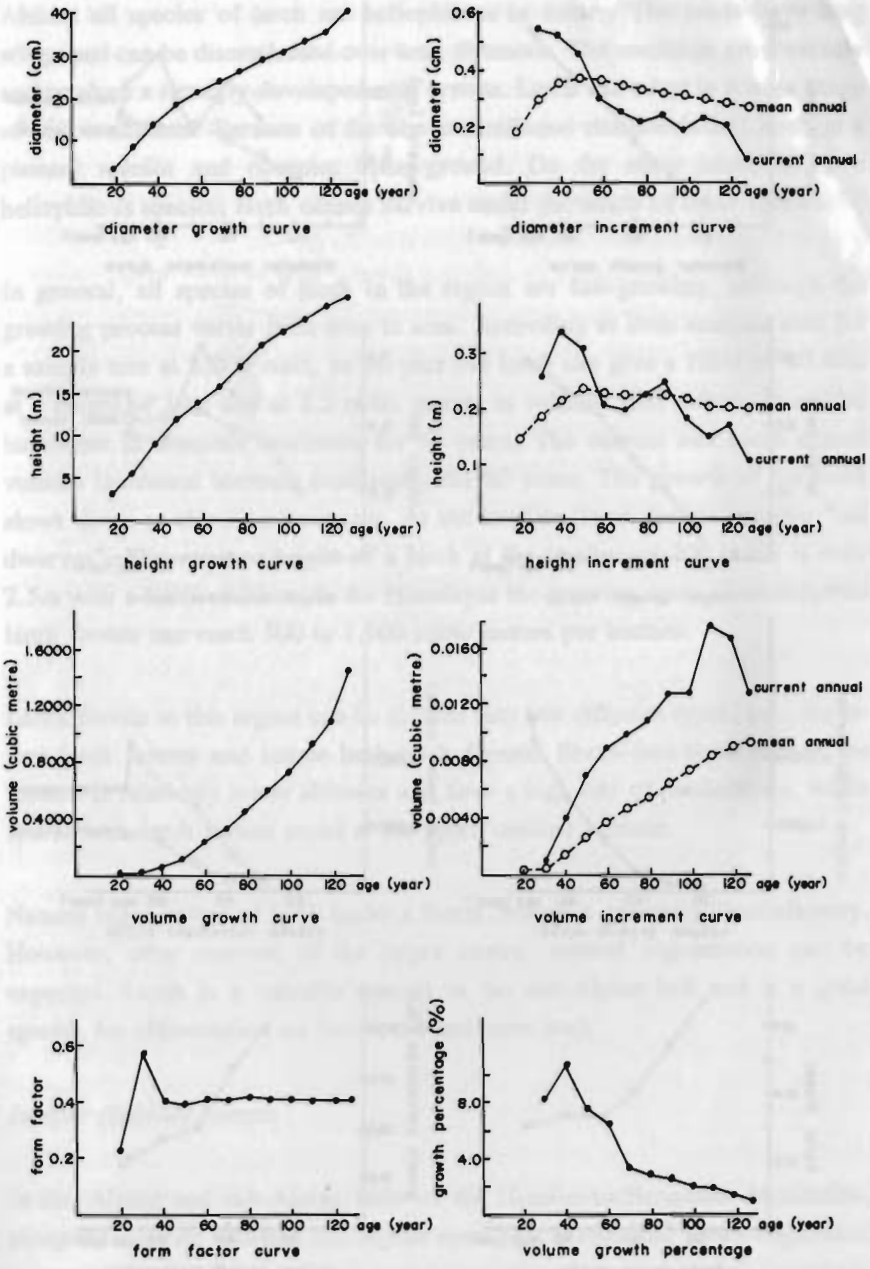


Fig. 8: Stem analysis of *Picea balfouriana*

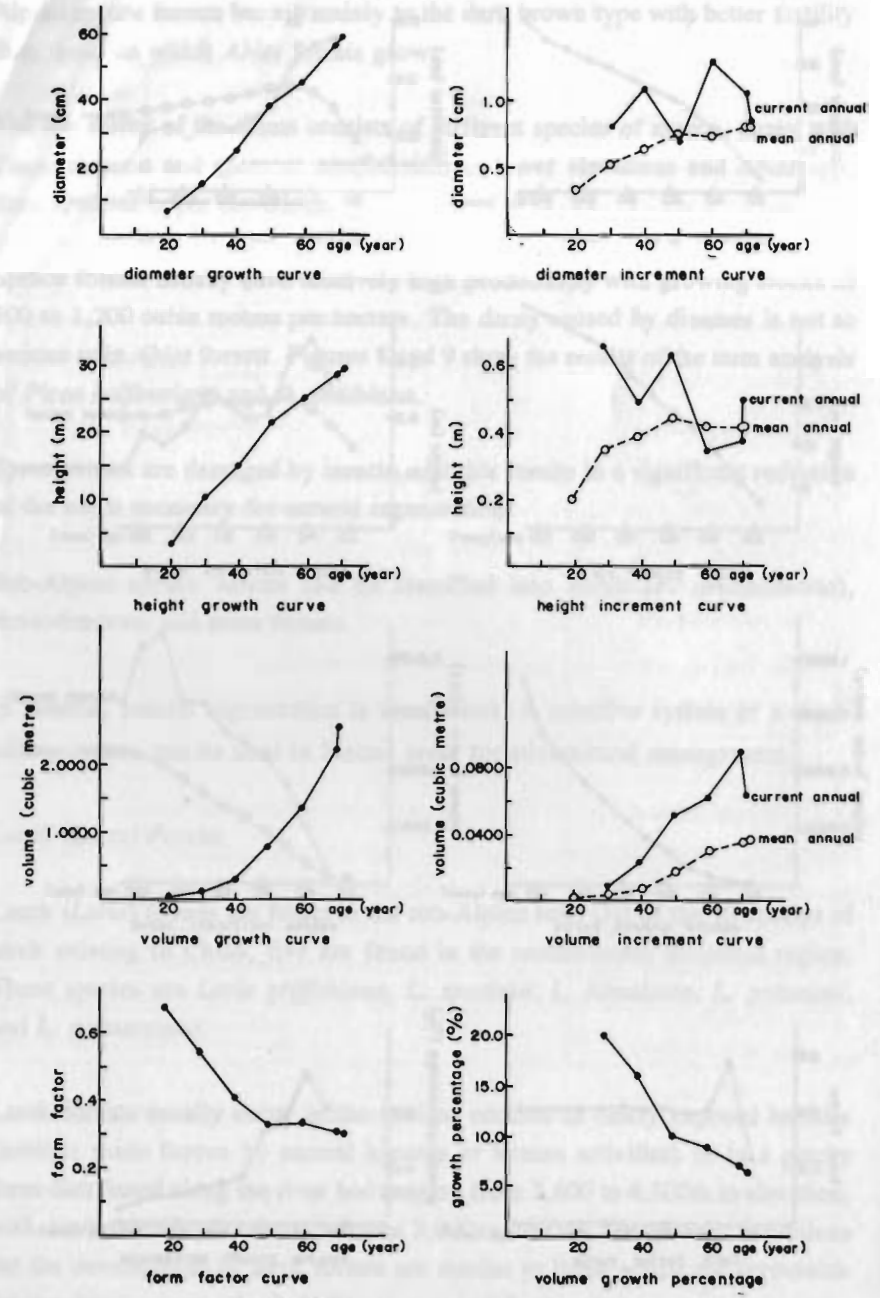


Fig. 9: Stem analysis of *Picea smithiana*

Almost all species of larch are heliophilous in nature. The seeds have long wings and can be disseminated over long distances. The seedlings grow rapidly and produce a strongly-developed root system. Larch can adapt to a wide range of soil conditions. Because of the above-mentioned characteristics, larch is a pioneer species and occupies open ground. On the other hand, being a heliophilous species, larch cannot survive under the shade of other species.

In general, all species of larch in the region are fast-growing, although the growing process varies from area to area. According to stem analysis data for a sample tree at 3,000 masl, an 80-year old larch can give a DBH of 40.4cm at a height of 39m and at 2.2 cubic metres in volume. The maximum annual increment in diameter continues for 30 years. The current and mean annual volume increment increase continually for 80 years. The growth of the larch slows down as elevation increases. At the treeline, larch forests become "old dwarves". The average height of a larch at the treeline (4,200 masl) is only 2.5m with a DBH of 22cm. In the Himalayas the growing stock of undisturbed larch forests can reach 500 to 1,000 cubic metres per hectare.

Larch forests in this region can be divided into two different types, i.e., shrub-fern-larch forests and sparse herb-larch forests. Shrub-fern-larch forests are located at relatively lower altitudes and have a high rate of productivity, while sparse herb-larch forests occur at the upper treeline ecotone.

Natural regeneration of larch under a forest canopy is generally unsatisfactory. However, after removal of the upper storey, natural regeneration can be expected. Larch is a valuable species in the sub-Alpine belt and is a good species for afforestation on barren mountainous land.

Juniper (Sabina) Forests

In the Alpine and sub-Alpine belts of the Himalayan-Hengduan Mountains, along the ecotone between sub-Alpine spruce-fir forests and scrub-vegetation, a special type of sparse forest, consisting of various species of *Juniperus*, (*Sabina*) occurs. There are about one million hectares of *Sabina* in the

Himalayan and Hengduan Mountains with a total growing stock of 34 million cubic metres. Many species of *Sabina* are found in this region, including *S. tibetica, S. saltunaria, S. convallium, S. wallichiana, S. recurva,* and *S. vulgaris*. The forests are mainly located in the eastern Himalayas and the northern and middle areas of the Hengduan Mountains. The altitudinal distribution of these forests ranges from an altitude of 3,400 to 4,400m, with distribution concentrated between 3,600 to 4,200m.

Sabina is one of the most cold-resistant species among the conifers. At the upper limits of its distribution the mean annual temperature is close to 0°C, the accumulated temperature for ≥ 10°C is 100°C, and the warmth index is < 5°C. The mean annual temperature of the warmest month is 8°C, while the mean annual temperature of the coldest month is -10°C, with a frost-free period of 63 days.

The annual precipitation in *Sabina* forests is between 400 to 600mm and the mean annual relative humidity is over 50 per cent. *Sabina* forests are always found on sunny slopes where radiation is high. The soil supporting *Sabina* forests is generally brown earth, with a pH value of from five to eight.

The growth of most species of *Sabina* is slow. The average age of *Sabina* forests varies between 100 to 200 years, with a maximum age of 400 to 500 years. *Sabina* usually occurs as a pure forest mixed with individual spruce and fir species. In hundred year-old *Sabina* forests, the average height of the stands is eight to 10 metres, the average DBH is 20 to 30cm, and the average growing stock is 20 to 100 cubic metres per hectare. Natural regeneration is usually satisfactory in mature forests. There are numerous young seedlings under the sparse canopy of the forests (4,000 to 5,000 per ha), however, only about 10 per cent of them can survive until the next phase.

Due to a relatively slow growth process, a low timber production rate, and a high rate of decay, Alpine *Sabina* forests cannot yield immediate economic benefits and are mostly used as firewood. On the other hand, as *Sabina* forests are distributed throughout the ecotone between forest, scrub, and steppe vegetation, *Sabina* forests play an important role in soil and water conservation. Over-

exploitation of *Sabina* forests will lead to general degradation of forest vegetation.

Hemlock (Tsuga) Forests

Hemlock (*Tsuga*) is another important coniferous forest type in the southwestern mountains of China. This species usually forms mixed stands in which Yunnan hemlock (*Tsuga dumosa*) and Lijiang hemlock (*Tsuga Lijiang*) predominate. Hemlock forests occur at middle elevations (2,400 to 3,200 masl) in western and northwestern Yunnan, southwestern Sichuan, and south Tibet. Hemlock forests are confined to areas with maritime climates having abundant moisture throughout the year, relatively mild winter temperatures, and cool summers. The total precipitation tends to be high throughout; 700 to 1,000mm precipitation and more per year is common. Average annual temperatures vary from 7.1° to 11.1°C, while the average temperature of the warmest month ranges from 14.3° to 18.0°C; the average temperature of the coldest month ranges from -1.8° to -2.9°C; and the warmth index is 44.2° to 77.4°C.

Both *Tsuga dumosa* and *Tsuga lijiangensis* are shade-tolerant species. They can survive for several years under the canopy of old-growth forests, but they are capable of rapid growth if the shade is removed.

Although small stands of pure forest can occasionally be found, hemlock usually forms mixed forests with other species such as *Quercus aquifolioides, Picea brachytyla, P. armandi, Betula albo-sinensis, Taxus chinensis, Acer* spp, *Celtis,* and *Acanthopanax*. Rhododendron, *Sinarundinaria, Vaccinium*, and *Berberis* are the most important components in the undergrowth layer. The growth indicators for Yunnan hemlock are average age 200 to 300 years; average height 22 to 35m, average diameter 36 to 130cm, and growing stock 146 to 410 cubic metres. Hemlock is not a fast-growing species, and the optimum growth period can last for a long time. According to stem analysis data, the rapid growth phase for hemlock was observed to be from 30 to 170 years with an annual increment of 18 to 20cm; the rapid growth phase for the diameter was from 70 to 170 years with an annual increment of 1.8 to 1.9mm. The annual increment in volume increases steadily until the tree is from 200 to 300 years old (Figure 10).

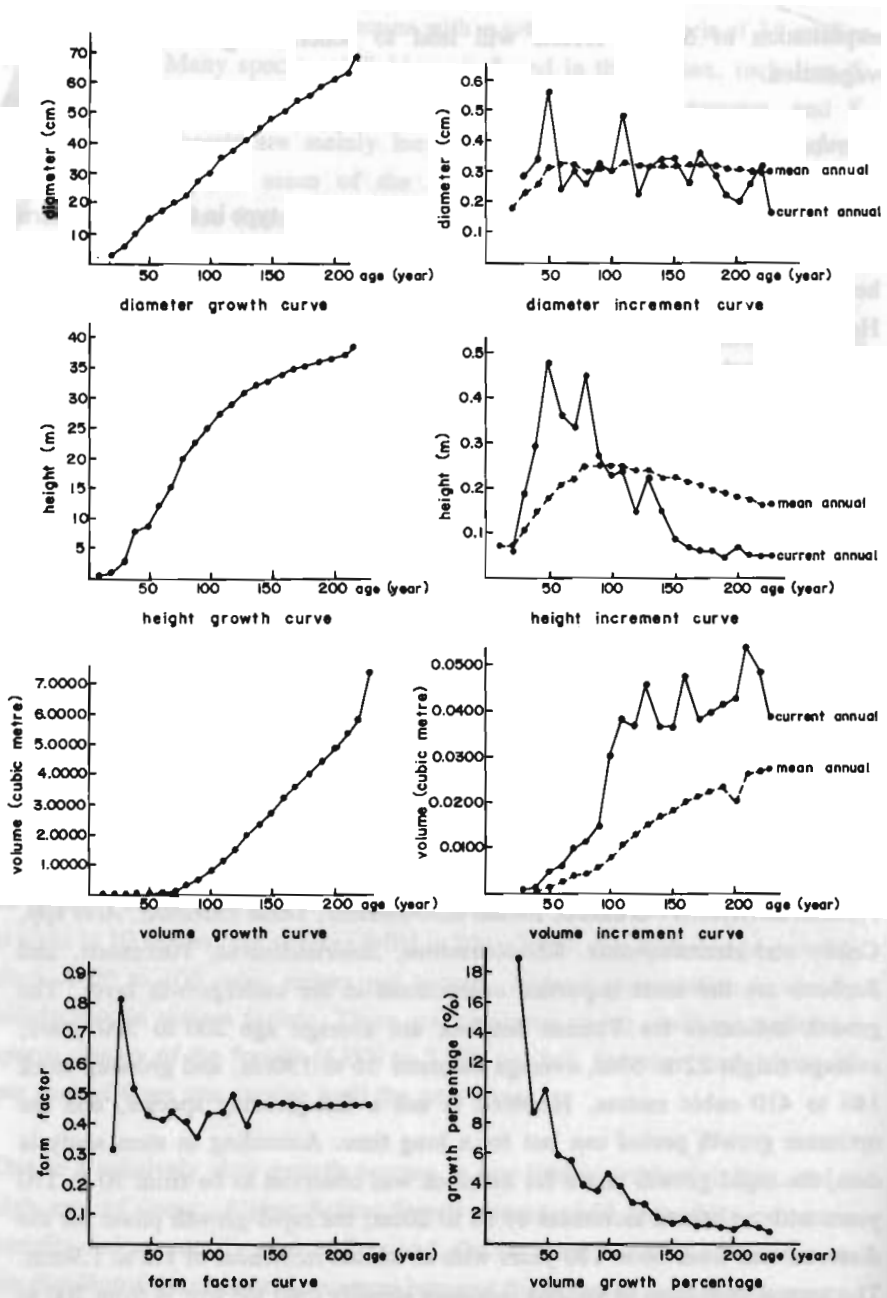


Fig. 10: Stem analysis of *Tsuga dumosa*

Yunnan hemlock is a valuable species that provides good quality timber. The wood is light yellowish-brown with a straight grain and fine texture. The wood is hard, durable, and easy to process.

The thin bark and shallow roots of hemlock make it particularly susceptible to logging injury, which can lead to decay. Losses from decay are high, especially in the old growth forests in Zayu and Nyalam. In general, fire poses less danger to these forests than to drier forest types. However, in specific localities where slash burning is practised, fire could damage hemlock forests, as in Nyalam some 20 years ago.

Natural regeneration under forest canopy is generally satisfactory. The dense *Sinarundinaria* and thick moss cover are usually obstacles to the process of natural regeneration. Many silvicultural methods, including the select system and the small-area clear-cutting system can be used for hemlock forests. Clear-cutting is recommended when timber production is the primary objective. Logging costs in the clear-cutting system are lower than in other systems. However, a certain number of seed-bearing trees should be left for natural seedfall. Direct seeding is necessary to supplement a poor seed crop. The natural regeneration of hemlock under a canopy of secondary broad-leaved species, such as *Betula* and *Carpinus*, is generally satisfactory.

Cypress (Cupressus) Forests

Several cypress (*Cupressus*) species are found in the Himalayan-Hengduan Mountain Region, in particular, *Cupressus ducloxiana, C. torulosa*, and *C. gigantea.*

Cupressus ducloxiana forests are found in northwestern Yunnan Province and southeastern Sichuan Province. Although this forest type is distributed over vast areas, the most concentrated distribution occurs in Lijiang County, Yunnan Province, from 1,700 to 2,400m.

Cupressus ducloxiana has a wide range of adaptations. The climate of the areas where these forests are distributed is characterised by a mean annual

temperature of about 13 to 15°C, an accumulated temperature at ≥ 10°C of about 3,000 to 4,500°C, an annual precipitation of about 900mm, and a mean annual relative humidity of 65 to 70 per cent. *Cupressus ducloxiana* can grow on different types of soil, although the best cypress forests are found in deep, fertile soils that are rich in limestone.

In natural forests, *Cupressus ducloxiana* occupies the first tree layer, with an average height of 16m while, in the second layer, *Quercus longispica* is dominant. In natural forests, the average height reaches 16m, DBH 20.8cm, and the growing stock 421 cubic metres per hectare. In the undergrowth, *Sinarundinaria* spp, *Wikstoemia cenenscens,* and *Osmanthus delavayi* are common species.

Cypress forests are rarely damaged by insects and diseases. The species is strongly resistant to pollutant gases such as the fluoride and sulphide gases. It is recommended for cultivation near factories and in limestone areas. Under favourable conditions, the following growth indicators can be obtained in a 20 - year old *Cupressus* plantation, i.e., average height -13.5m, average DBH - 15cm, and stem volume for a single tree -0.12 cubic metres.

Tibetan Cypress (*Cupressus Torulosa*). Tibetan cypress (*Cupressus torulosa*) is an endemic species in the Himalayan Mountains and is mainly located in Bomi, Linzhi, and Medong. Tibetan cypress forests occur in limestone areas at elevations between 1,800 to 2,700m.

Tibetan cypress is an evergreen conifer. In a natural forest environment, it can grow to 40m in height, with a DBH of 30 to 50cm. In an open habitat, it can achieve a diameter of over three metres, but the height is rarely over 15 to 20m.

Tibetan cypress requires a subtropical climate with a mean annual temperature of 10 to 15°C, an accumulated temperature at ≥ 10°C of 900 to 4,200°C, a warmth index of 48 to 110, and a frost-free period of 135 to 150 days. The annual precipitation varies between 500 to 800mm with a relative humidity of 50 to 69 per cent.

Tibetan cypress usually occurs in mixed forests. Commonly associated species are *Celtis titrandra, P. armandi,* and *Machilus yunnanensis*. The growing stock of the forest is about 300 cubic metres per hectare.

The shrub layer covers 60 to 70 per cent of the ground and may include *Hydrangea robusta, Daphne longibobata, Rhamnus tibetica, Ligustrum confusum, Acanthopanax cassifolius, Cotoneaster* spp, *Zanthoxylum tibetanum,* and *Lonicera acuminata*. The herb layer is well developed, covering 60 per cent of the ground.

Tibetan cypress is a valuable coniferous species and can be used for afforestation in the valleys of medium mountain regions.

Another species of Tibetan cypress is *Cupressus gigantea*. This species was identified in 1974 during an expedition carried out in the Nangshian area of the middle reaches of the Yalu Zangbu River. In the past, taxonomists had confused it perhaps with *Cupressus torulosa* and overlooked it. In fact, *Cupressus gigantea* is separately distributed throughout a rather wide area in Nangxian, Mainling, and Ningchi counties, and can occur as sparse cypress forest along the river valleys of this region. The sparse xerophilous forests consist of *C. gigantea*, an endemic forest type found in the transition zone from the mountainous conifer area in the east to the mountainous bush grassland in the west. Forests of *C. gigantea* are mixed with grassland components. The canopy density is about 0.2, and stands consist of pagoda-shaped giant cypresses with heights of from 6 to 10m and DBHs of from 5 to 100cm. *C. gigantea* is a rare and endangered species. Immediate measures for its protection are required in order to avoid the extinction of a valuable resource.

The humid monsoon from the Indian Ocean moves westwards along the valley of the Yalu Zangbu River and weakens in midstream, while the effect of the dry air circle coming from the plateau in the west gradually becomes dominant. Therefore, in the western part of Nanxian Forest, vegetation is completely replaced by grassland. The giant cypress forest is located in the ecotone between the two vegetation zones.

Pine (Pinus) Forests

Pine (*Pinus*) forests constitute another important forest type and are widely distributed throughout the Himalayan and Hengduan Mountains. The growing stock of pine forests ranks second in position to the spruce-fir forests. Out of 21 species and 11 varieties of pine in China, six species are found in the southwestern mountain areas. These species are: *P. armandi, P. griffithii, P. gerardiana, P. yunnanensis, P. roxburghii,* and *P. densata.* Of the above-mentioned species, *Pinus densata, P. griffithii*, and *P. yunnanensis* are the most important. The different species of pine belong to different sections of the taxonomic system with different ecological characteristics. According to the water requirements of the species, they are ranked in the following order (from xerophilous to hydrophilous): *Pinus griffithii, P. yunnanensis, P. armandi, P. densata, P. roxburghii,* and *P. gerardiana.* According to the temperature requirements of the species, they are ranked in the following order (from cold-tolerant to thermophilous): *Pinus densata, P. armandi, P. griffithii, P. gerardiana, P. yunnanesis,* and *P. roxburghii.*

Yunnan Pine (*Pinus yunnanensis*) Forests. Yunnan pine *(Pinus yunnanensis)* is a special forest type of this region, mainly distributed throughout the central, western, and eastern parts of Yunnan Province and the eastern edge of the Himalayas. The altitudinal range of distribution of Yunnan pine is from 1,200 to 2,800 masl. Under exceptional circumstances, it can reach as high as 3,200m. The average annual temperature varies from 13 to 19°C, the temperature of the warmest month from 21 to 29°C, and the temperature of the coldest month from 3 to 9°C, with an accumulated temperature at $\geq$ 10°C of between 4,000 to 5,000°C. Annual precipitation varies from 800 to 1,200mm and 80 per cent is concentrated in the monsoon season between May and October.

Yunnan pine can adapt to different types of soil, but the growth of this species varies significantly in accordance with the soil condition. For example, the best growth of Yunnan pine forests has been found to occur in the eastern Himalayas where 130-year old Yunnan pines can grow to 50cm in DBH, 32m in height, and three cubic metres in volume, with a growing stock

of over 1,000 cubic metres per hectare; compared to the Hengduan Mountains, where the best productivity rate is less than 460 cubic metres per hectare (Figure 11).

Yunnan pine is a shade-intolerant species and it usually occurs in forests with a canopy density of 0.5 to 0.6. The shrubby layer covers 20 to 30 per cent of the ground and is comprised mainly of *Indigofera balfouriana, Rosa sericea, Rubus ovalifolia, Lyonia biflora, Cotoneaster buxifolius, Desmodium oxyphyllum, Coriaria terminalis, Viburnum cylindricum, Smilax quadrata, Litsea cubeba, Vaccinium fragile,* and *Gaulteria semi-infera.*

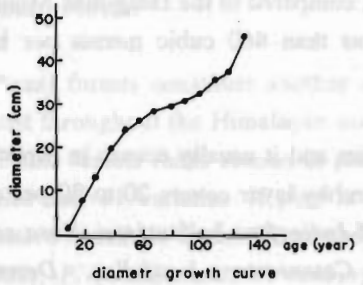
Ground cover develops quite well and consists of Meso-xerophilous species such as *Thalictrum* spp, *Astilbe rivularis, Athroxon prionodes, Agrostis* spp, *Capillipedium parviflorum, Artemisia* spp, *Sedum multicaule, Potentilla fulgens, Anemone rivularis, Galium asperuloides* var *hoffmeistre,* and *Ophiopogon bodineiri.*

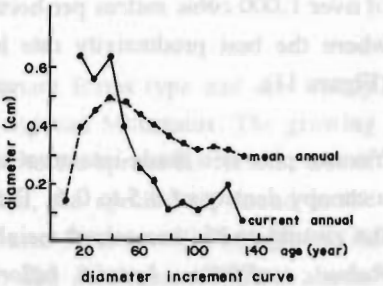
The natural regeneration of Yunnan pine under a closed canopy is difficult. After removal of the tree layer, Yunnan pine can always regenerate well.

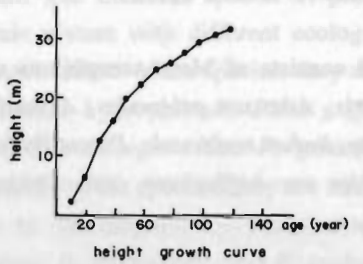
Yunnan pine typically forms pure and more or less even-aged stands. Its characteristic structure and composition result largely from two natural conditions, i.e., low soil moisture availability during the dry season and recurring wildfire.

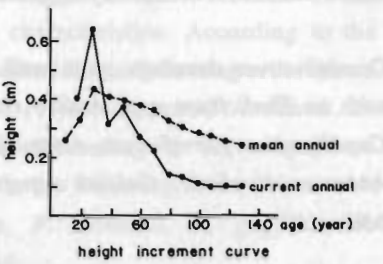
Even-aged silvicultural systems are well suited to Yunnan pine forests where wood production or species' consistency are primary objectives. The species' intolerance of shade favours even-aged stands. Regenerating stands by clear-cutting with prompt site preparation and planting, or, in some instances, seeding, is recommended. Natural seeding can be very effective if mineral soil is exposed and if the opening is not too large.

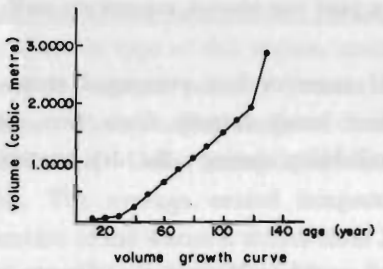
Yunnan pine grows slowly in the first few years. After five years, it grows faster. Under favourable conditions, the most rapid growth occurs at from 10 to 20 years of age. In well-managed plantations, an annual increment of 60 to

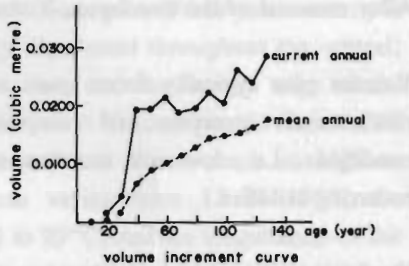


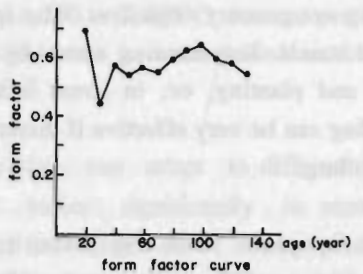












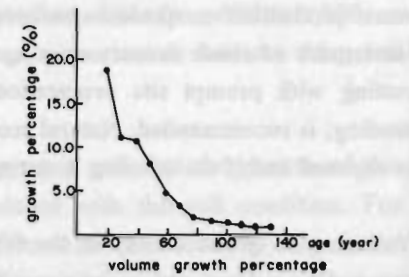


Fig. 11: Stem analysis of *Pinus yunnanensis*

100cm in height and one to two centimetres in diameter occurs. The growth rate slackens thereafter, but dominant trees can grow vigorously for the first 50 years.

Because of the pure composition and small density of the canopy, as well as the rich content of oil and pine gum, there is a risk of forest fires, particularly during the dry winter season.

Pinus densata Forests. *Pinus densata* or high mountain pine is another important pine species found in the Hengduan Mountains, Nianqingtangula mountains, and in the middle reaches of the Yalu Zangbu River in the eastern Himalayas. It extends from the Mingjian River of western Sichuan in the east to Gongbugjiangda in Tibet in the west and from south Dawu of Sichuan to northwestern Yunnan in the south, ranging from 27° to 32° in latitude and 92° to 103° in longitude. It usually occurs as pure forests on sunny slopes from 2,600 to 3,500m.

Pinus densata is a strong heliophilous species requiring sufficient sunshine for normal development. This species can adapt to a wide temperature range. The climatic indicators in the upper and lower boundaries of its distribution are as follows: mean annual temperature from 4° to 10°C; an accumulated temperature at $\geq$ 10°C of 1,000 to 2,800°C; a warmth index of from 25 to 72; the mean temperature of the warmest month from 12 to 17°C; the mean temperature of the coldest month from -5 to 2°C; and a frost-free period of three months. Mountain pine grows in humid and semi-humid climates with an annual precipitation of from 500 to 900mm and a relative air humidity of from 50 to 70 per cent.

In general, *Pinus densata* forms a pure stand with a single storey. Occasionally, individual samples of *Quercus aquifolioides, P. armandi, Larix potaninii*, and *Picea likiangensis* are mixed in the pine forest.

The growth of mountain pine, to a great extent, is dependant upon altitude and habitat. In Bomi County of Tibet, this species has achieved an excellent growth rate. The growth process of a sample tree (120 yrs) at 2,700m was as follows;

the total increment of DBH reached 58cm, the total increment in height 35m, and the total stem volume more than four cubic metres. Meanwhile, a sample tree of the same age growing in Nangxian gave the total increment as 32cm, 29m, and 1.5 cubic metres respectively. The average growing stock per unit varies from region to region. According to the survey, the growing stock can reach 358 cubic metres per hectare in Bomi, 296 cubic metres in Mainling, 240 cubic metres in Ningchi, and less than 100 cubic metres in Baxoi County.

The understorey develops well and covers 40 to 60 per cent of the ground. The natural regeneration process of *Pinus densata* is good. A felled forest can be restored by closing off the land and by supplementing it with artificial regeneration.

P. armandi Forests. This white pine grows at moderate and high elevations and has a scattered distribution. It is distributed throughout western and south-western China in Shanxi, Shaanxi, from Hubei to Sichuan, Yunnan, Guizhou, and Tibet. It also occurs on the islands of Hainan and Taiwan and on two islands just south of Kyushu, Japan, i.e., Yaku-Shima and Tanega Shima, and northern Burma. This five-needled pine is frequently found together with other coniferous and broad-leaved species. In the Himalayan-Hengduan Mountains, *P. armandi* usually grows from 2,100 to 3,400m, with the highest concentration being from 2,400 to 3,000m.

P. armandi requires temperate and humid climatic conditions. The climatic indicators for its distribution can be summarised as follows: mean annual temperature from 5 to 10°C; accumulated temperature at $\geq$ 10°C of 1,500 to 3,000°C; warmth index from 30 to 38°C; mean temperature of the coldest month from -1 to 3°C; mean temperature of the warmest month from 13 to 20°C; absolute minimum temperature from -1 to -8°C; and frost-free period from four to seven months. The mean annual precipitation in its distribution area varies from between 600 to 1,000mm and the mean relative humidity is $>$ 70 per cent.

Although a few pure forest plots can be found, most frequently this species grows together with *Carpinus viminea, Cyclobalanopsis oxyodon, Populus*

pseudoglauca, Alnus nepalensis, Acer spp, and *Quercus aquifolioides* and sometimes with other coniferous species such as *Pinus yunnanensis, P. densata,* and *Abies ernestii* var *salouensis*.

Most of the white pine forests are relatively even-aged, and near-mature forest stands have an average diameter of from 40 to 50cm, an average height of 40m, and a growing stock of 400 cubic metres per hectare. Figure 12 shows the growth process of a sample tree from Zayu. At the age of 70 years, its DBH, height, and volume were 45.4cm, 22.6m, and 1.5 cubic metres respectively. The growth curve tendency showed that most of the indicators demonstrated that the species has great potential for better use.

The understorey in *P. armandi* forests is of medium development with a total coverage of 50 per cent.

P. armandi is a valuable commercial species of this region. It has a slightly yellow sap wood, slightly-brown heart wood, and a straight grain. The timber of white pine is good for constructing furniture, buildings, and railroad sleepers.

In order to preserve this valuable resource and expand the area covered by *P. armandi*, forest management should be strengthened and a shelterwood-cutting system rather than a clear-cutting system should be employed.

Pinus roxburghii Forests. *Pinus roxburghii*, also known as *P. longifolia*, is confined to the monsoon belt of the outer Himalayas and is distributed throughout Pakistan, India, Nepal, and Bhutan. In China, it is only found in the southern part of Gyirong County at elevations of from 1,500 to 2,500m.

Pinus roxburghii is a heliophilous species. The climatic indicators at the upper limit of its distribution are as follows: a mean annual temperature of 10°C; an annual accumulated temperature at $\geq$ 10°C of 3,000°C; a warmth index of 77°C; temperature of the warmest month - 18°C; temperature of the coldest month - 3°C; and an absolute minimum temperature of -10°. The annual precipitation ranges from 600 to 1,000mm.

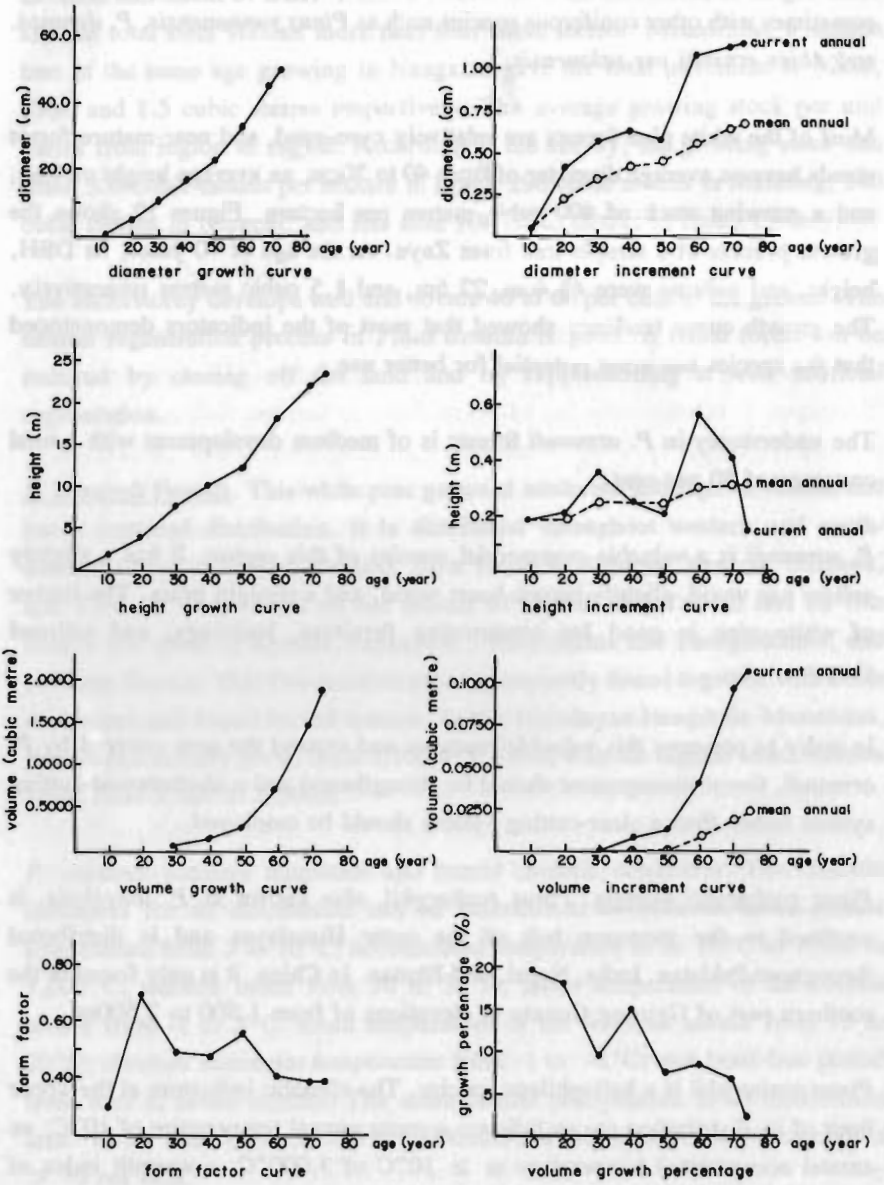


Fig. 12: Stem analysis of *Pinus armandi*

Pinus roxburghii usually occurs in pure stands. Sometimes it is associated with *Pinus griffithii, Quercus tunmaigensis, Populus ciliata*, and *Picea smithiana. Pinus roxburghii* is one of the fastest growing coniferous species in the Himalayas, especially in stands over 10 years old.

In a moderate habitat, a *Pinus roxburghii* forest can attain an average height of 30m, a DBH of 52cm, and a growing stock of 400 cubic metres per hectare. The understorey of the forest tends to be only slightly developed. Figure 13 shows the growth process of *Pinus roxburghii* in the moderate conditions of Gyirong County.

The natural regeneration of *Pinus roxburghii* is determined by environmental conditions. *Pinus roxburghii* starts bearing seeds after about 30 years growth in natural forests. Although seeds can be produced every year, there is an obvious uniformity in the fruit-bearing phenomenon. There is an inter-seed period of from four to five years. Natural regeneration depends upon the quantity as well as the quality of the seeds. In general, natural regeneration under the forest canopy is insufficient, but it improves after the removal of the upper layer by either cutting or forest fire. Since *Pinus roxburghii* is distributed in very limited areas in the Himalayas of China, it has been suggested that nature reserves should be established in Liangchun and Gyirong to conserve this species. This proposal has been approved by the local government.

Blue Pine (*Pinus griffithii*) Forests. Blue Pine (*Pinus griffithii*) is also known as *Pinus excelsa* and *P. wallichiana*. It is an important species of the middle and high elevations and is found from Afghanistan to Pakistan and in India, Nepal, Myanmar, and Bhutan. In China, it is distributed along the Dulongiang River, in Yunnan Province, and in Gyirong, Yadong, Cona, Lhunze, Zayu, and Bomi counties at elevations of from 1,200 to 3,300m.

The climatic indicators in the areas most favourable to its growth are estimated as follows: the mean annual temperature is about 11°C; the annual accumulated temperature at ≥ 10°C is 3,000°C; the warmth index is 77; the mean temperature in the coldest month is 3°C; the mean temperature in the warmest month is 18°C; the absolute minimum temperature is -12°C; and the frost-free period

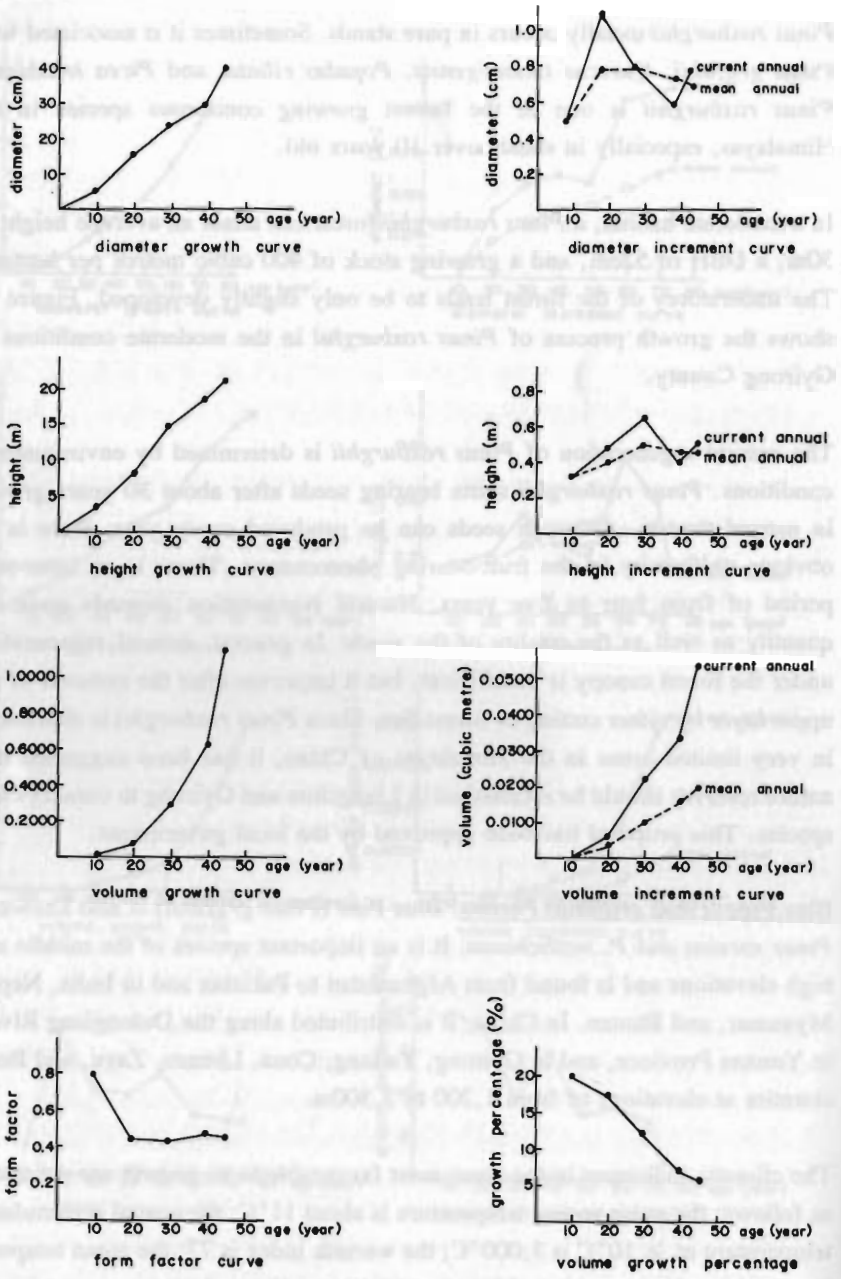


Fig. 13: Stem analysis of *Pinus roxburghii*

lasts for seven months. The annual precipitation in these areas ranges from 800 to 2,000mm, with a relative air humidity of from 60 to 80 per cent.

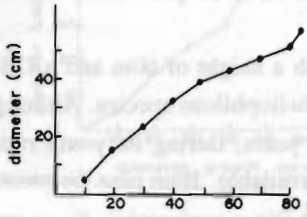
Blue pine is a tall evergreen conifer that can reach a height of 60m and a DBH of 1.8m under favourable conditions. It is a semi-heliophilous species. Although it can survive under shady conditions for a few years, during its youth rapid growth can be achieved only if overhead light is available. Blue pine frequently occurs as pure stands. Sometimes it is mixed with *Pinus roxburghii, Picea smithiana, Quercus tungmaiensis, Populus ciliata* var *gyirongensis, Cornus capitata*, and *Rhododendron arboreum*. At upper elevations, *Quercus semecarpifolia, Abies spectabilis*, and *Betula utilis* occur in forests dominated by blue pine.

In order to study the growth of blue pine, stem analysis was carried out in Gyirong County (Figure 14). At 84 years the diameter increment reached 50cm, height increment over 30m, and volume increment 3.5 cubic metres. Under favourable conditions, 100-year old blue pine stands can provide a growing stock of over 1,000 cubic metres per hectare.

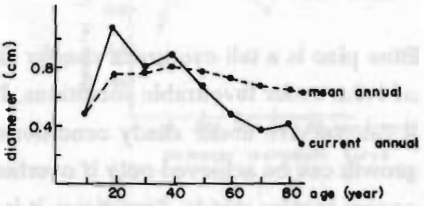
The understorey in blue pine forests is well developed (0.3 to 0.6). Natural regeneration before and after removal of the upper tree layer is difficult. It has been found that, because of unregulated harvesting and repeated forest fires, *Pinus griffithii* forests are being rapidly destroyed. As far as harvesting methods are concerned, clear-cutting in strips or shelterwood-cutting systems are recommended. In view of the rapid decrease in the area covered by blue pine forest, it is extremely necessary to establish a nature reserve in Gyirong County as well as to strengthen forest management.

Pinus gerardiana Forests. In addition to the above-mentioned pine forests, small patches of Tibetan white pine (*Pinus gerardiana*) are found at 2,700m elevations in Zhada County of Ali Prefecture in the Tibetan Autonomous Region. Elsewhere, this species is confined to the mountains of eastern Afghanistan, parts of Pakistan, and scattered localities in the dry inner valleys of the northern Himalayas.

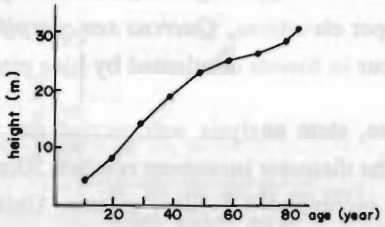
Tibetan white pine is characterised by its xerophilous features. The annual precipitation in the area of distribution is usually less than 400mm with a mean



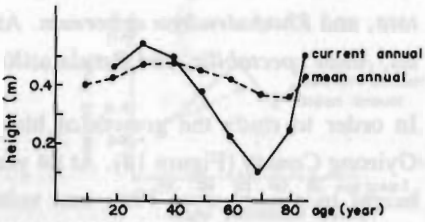
diameter growth curve



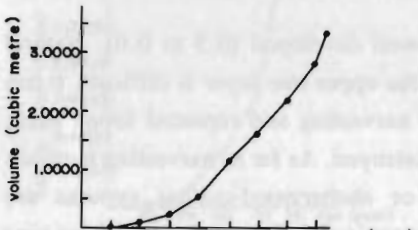
diameter increment curve



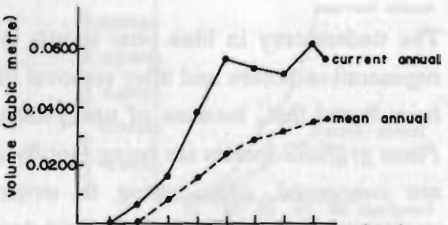
height growth curve



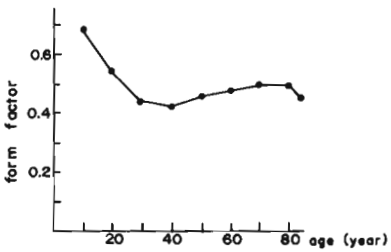
height increment curve



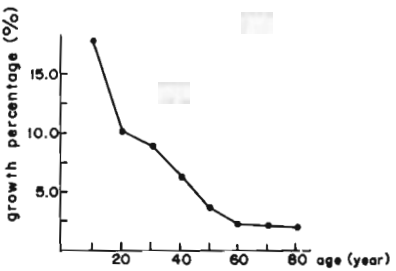
volume growth curve



volume increment curve



form factor curve



volume growth percentage

annual temperature of from 7 to 13°C. The accumulated temperature at ≥ 10°C is from 2,000 to 3,000°C, the warmth index is 45 to 100, the mean temperature in January is 15 to 20°C, and the area is frost-free for five to seven months per year. *Pinus gerardiana* is typified by group growth, but the canopy density is sparse and sometimes it is associated with *Fraxinus xanthoxylloides, Pinus griffithii*, and *Quercus aquifolioides*. The understorey is slightly developed and the ground layer consists of xerophytes such as *Daphne tangutica, Desmodium gamblei*, etc.

The characteristic feature of this species is its large edible seeds. According to reports, the productivity of the seeds is closely correlated to the diameter of the tree. A sample tree with a DBH of 50 to 70cm can produce 50 to 80 cones each year. There are 30 to 50 seeds in each cone. The mean weight of a 100 seeds is about 30 to 35gm. The seeds of the white pine are not only edible but also have medicinal value.

Pinus gerardiana is a rare and valuable species in Tibet and special measures should be taken for its protection and propagation.

Taiwania Forests

Taiwania flousiana is a rare and valuable forest type found in the Nushang and Gaoligangshan mountains of the western Hengduans between 2,200 to 2,400m in elevation. The climate of the areas to which *Taiwania flousiana* forests are native is temperate and humid, with an annual mean temperature of 15 to 17°C, at ≥10°C an accumulated temperature of from 3,500 to 4,500°C. The mean temperature of the coldest month is 7°C, the annual precipitation is from 1,200 to 1,700mm, and the mean annual relative humidity is 80 per cent. The soils belong to the mountain, yellow-brown or mountain, yellow-red category.

Taiwania flousiana commonly comprises 60 per cent of the tree layer in mixed coniferous, broad-leaved forests, with other species such as *Tsuga dumosa, Pinus griffithii, Cyclobalanopsis glauca, Magnolia compbelii, Exbucklandia populnea, Schima wallichina, Rhodeleia forrestii, Cinnamomium glanduliferum, Machilus kurzii*, and *Lithocarpus* spp.

Taiwania consists of unevenly-aged multilayer stands, with a canopy coverage of 0.7 to 0.9. *Taiwania* is 35 to 40m in height and has a DBH of 50 to 60cm, with individuals having DBHs of over 80cm. The productivity of *Taiwania* forests is relatively high. It was reported that, in a favourable habitat, the growing stock of the forest can reach 1,097 cubic metres per hectare.

Taiwania flousiana is a fast-growing species. Based on the stem analysis of a 72 year old *Taiwania*, the height was 30.4m, DBH - 52.5cm, and stem volume - 3.056 cubic metres. The timber of this species is of good quality and it has long been cultivated locally on shaded and partially shaded slopes with good deep drainage. The germination rate is relatively low (25 to 30%). For reforestation, nursery-raised seedlings or cuttings are preferable. *Taiwania flousiana* belongs to the first category of protected national tree species. Some old trees in Tenchueng County have a DBH of 2.6m. It is important to take the necessary steps to protect this valuable and rare species and these unique ecosystems.

Deciduous Broad-leaved Forests

Deciduous broad-leaved forests are generally defined as forest communities composed of broad-leaved trees, the leaves of which fall in the winter. In the Himalayan-Hengduan Mountains, these forests mainly consist of birch, poplar, and alder and occur widely at different elevations, ranging from the sub-Alpine to subtropical belts. Most of the trees belong to secondary forests. According to a preliminary inventory, the deciduous broad-leaved forests in southwestern China occupy five per cent of the area and account for four per cent of the growing stock of total forest resources. Although there are many species of birch in this region, the most common species are *Betula utilis, B. platyphylla, B. delavayi*, and *B. albo-sinensis* at higher altitudes and *B. cylindrostachya* and *B. alnoides* in the subtropical belt, in the sub-Alpine belt, *Populus davidiana* and *P. rotundifolia* are the common species, while in the subtropical belt *P. pseudogluca, P. ciliata*, and *Alnus nepalensis* are the important representatives.

The climatic indicators of cold tolerant birch and poplar forest are as follows: a mean annual temperature of 1 to 6°C; a warmth index of 10 to 45; the

temperature of the coldest month varying from 8 to 13°C; and a frost-free period of from 80 to 150 days. The climatic indicators for distribution of the subtropical group of birch and poplar species are: a mean annual temperature of from 11 to 15°C; an accumulated temperature of the mean temperature of >10° of from 3,000 to 4,000°C; a warmth index of from 77 to 110°C; the temperature of the coldest month varying from 3 to 7°C; the temperature of the warmest month varying from 18 to 21°C; and a frost-free period of 200 to 240 days.

Birch is a heliophilous species. It grows very rapidly in the early stages and can adapt to severe environmental conditions. In the southwestern mountain regions of China, birch and poplar forests occur in the middle stages (40-50 years) of development with very rare instances of over 80 years' growth. Many birch forests can be found growing in the upper regions of the sub-Alpine belt with average DBHs of 30cm, average heights of 15m, canopy densities of 0.6, and growing stock of 50 cubic metres per hectare.

Betula cyrindrostachya and *B. alnoides* are associated with other broad-leaved species such as *Rhus punjabensis, Tetracentron sinensis, Corunus* spp, *Acer* spp, and *Rhus* spp. *Betula cyrindrostachya* is a fast-growing species. Data on the growth analysis of a sample tree show that the peak height is reached in four to five years, while the maximum annual diameter increase is reached by the time the tree is 12 years old. Under favourable conditions, 17 year stands can grow as high as 18m, with an average DBH of 13cm, and growing stock of 157 cubic metres per hectare.

The elements in the understorey of birch forests consist of thermophilous species such as *Debregiasis edulis, Plagiogyria*, and *P. gentiana.*

Betula alnoides and *B. cylingdrostachya* are good timber and fodder species. They are also used to produce matches. The female catkins are collected during December and January. The cones are sun-dried until they break up, then directly sown into containers (a pinch of seed to each). Germination takes two to five weeks and seedlings can later be planted during the monsoon season.

Poplar (*Populus davidiana*) typically grows on all aspects and slope positions in the southwestern mountain region and is associated with sub-Alpine vegetation along an elevational gradient of from 3,000 to 4,100m. This type of forest does not play an important role in forest resources. The productivity and development of poplar are largely dependent upon the water available, which, in turn, is related to weather patterns, elevation, physiographic position, and edaphic characteristics. Most productive poplar forests are found on deep, well-developed soils with abundant soil water. The soils are found to have a higher organic content and water-retaining capacity than the surrounding vegetation. The nutrient content of leaf litter under poplar stands is higher than coniferous litter and it decomposes rapidly, thus recycling nutrients to the soil. Poplar begins to bear seeds between 10 to 20 years of age and produces a large crop every four to five years. The small light seeds are wind-disseminated. The seed is not dormant and usually germinates well under a wide range of temperatures, requiring bare mineral soil, a continuous supply of abundant moisture, and relatively cool temperatures for survival. Such requirements preclude the practical regeneration of poplar by seed under natural conditions. Poplar reproduces almost exclusively by suckering, whereby a number of stems are produced asexually by adventitious roots sprouting from a single parent root system to form a clone.

Poplar is more intolerant of shade than many other tree species. It demonstrates dominance and restricts the development of understorey stems, and this, in turn, leads to its ability to naturally thin itself. However, understorey stems are capable of recovering from suppression when the competitive overstorey has been removed.

Decay and forest fire are the most serious causes of volume loss in this area. During research expeditions, no poplar forest has been found older than 30 years, although the natural mature age could be far older than that. In the subtropical belts, along the river banks on alluvial soil, sometimes one can find broad-leaved forests consisting of *Populus pseudoglauca* in the eastern Himalayas and *P. ciliata* var *gyirongensis* in the middle and western Himalayas.

Alder (*Alnus nepalensis*) - the alder forest is one of the most common forest types found in the subtropical belt of southwestern China. It occurs in the wet areas along streams and ravines and as a coloniser of soil newly exposed by landslides. It is also frequently found on areas of abandoned cultivation. *Alnus nepalensis* is distributed at from 500 to 2,700 masl and thrives in a warm and humid climate. The mean annual temperature in its distribution area varies between 10° to 18°C; the accumulated temperature for a mean daily temperature of ≥ 10°C is 2,800 to 5,600°C; the warmth index is 72 to 175; and the mean temperatures of the coldest and warmest months are 2° to 11°C and 17° to 24°C respectively. It is usually found in areas with annual precipitations of more than 700mm and a relative air humidity of > 70 per cent.

Alnus nepalensis is a heliophilous species; only when it is young can it endure slight shade. Most alder forests in the region are middle-aged. This is a fast-growing species. Even under normal conditions, at 50 years old, the mean DBH of the stand reaches 30cm and the mean height of the stand is 25m.

The undergrowth vegetation does not develop well under the forest canopy. A few species are found in the shrub layer such as *Hypericum uralum, Meliosma cuneifolia, Zanthoxyllum tibetanum, Rubus biflorum, Spiraea velutina*, and *Lonicera tomentella* but none of them are dominant or have a high coverage. The herb layer covers 70 per cent of the ground.

Alder is well known, not only as an important species in commercial forestry, but also for its capacity to fix atmospheric nitrogen and for its role as a pioneer species contributing to soil development and forest succession. It is an important species for afforestation at elevations of from 1,000 to 3,000m.

The seeds germinate in four to six weeks and grow rapidly. They are ready for planting after one-year when the seedlings are about 40 to 50cm tall. In an ordinary habitat, a seven-year old plantation reaches an average height of 13m with an average DBH of 11cm; 20 year old stands can attain an average height of 20m and an average diameter of 23cm, with a growing stock of 250 to 300 cubic metres per hectare (Figure 15).

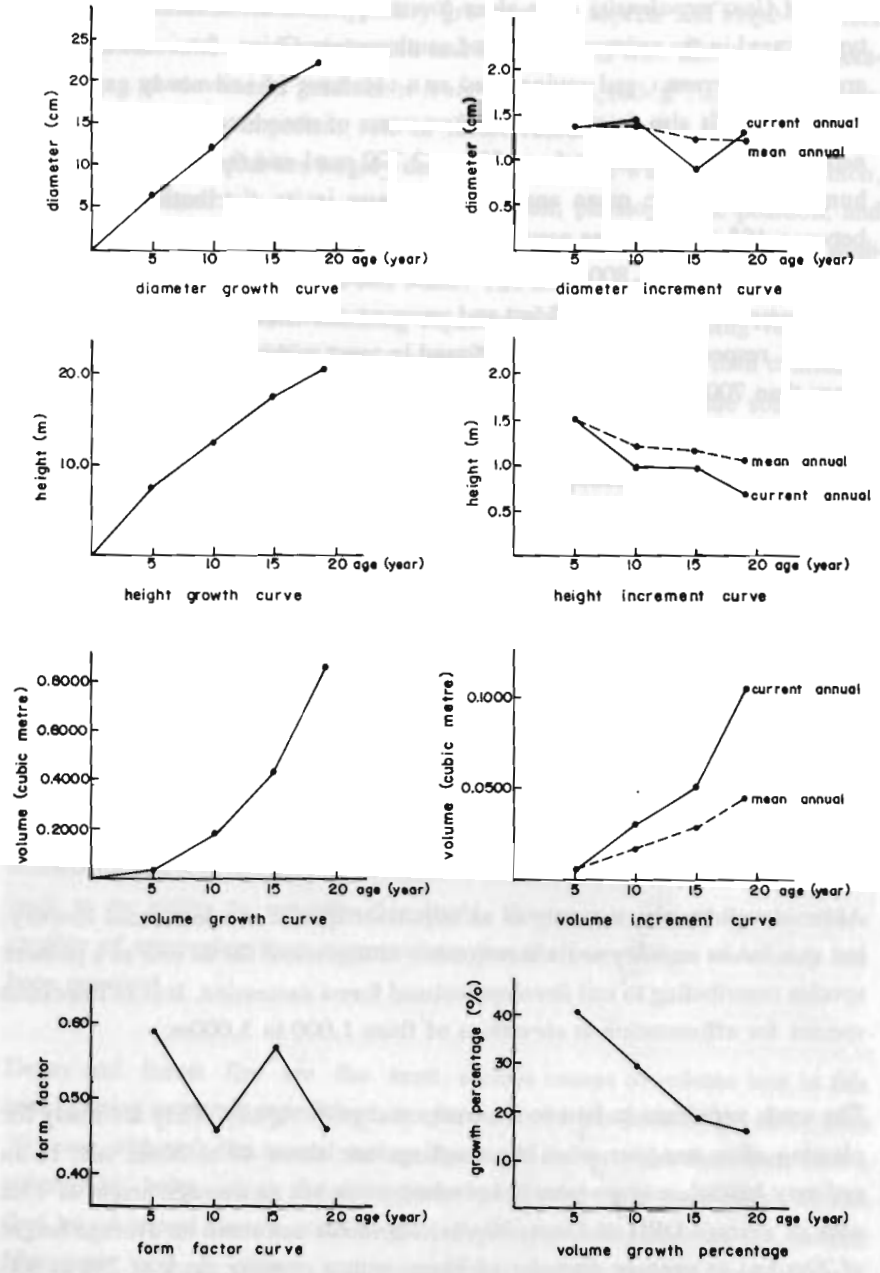


Fig. 15: Stem analysis of *Alnus nepalensis*

Alnus nepalensis stands can be established and managed for purposes other than, or in addition to, wood production. Because of the species' tolerance of poor drainage and flooding, *Alnus* is commonly recommended for plantation in degraded zones. Although alder is not a preferred browse species, its presence in pure stands, small clumps, or stringers and mixed stands, within extensive conifer forests, provides edges and adds structural diversity. It may therefore be used to enhance the forest habitat of many wildlife species.

Evergreen Sclerophyllous Oak Forests

Sclerophyllous oak forests are defined as forests dominated by the *Quercus* species of *Sec. semecarpifolia*, characterised by evergreen and sclerophyllous leaves. This type of vegetation is to some extent similar to the evergreen oak forests of the Mediterranean type, hence some affinity could exist between these two different regions.

Sclerophyllous forests in southwestern China occur mainly in areas of the Hengduan Mountains and in the Himalayas where there is a monsoon climate. There are a number of *Quercus* species belonging to the *semecarpifolia* branch. They play an important role in the construction of forests. For example, *Quercus pannoa* is mainly found in the Hengduan Mountains between 2,600 to 3,700m. *Q. aquifolioides* is widely distributed throughout the eastern Himalayas at altitudes of from (1,900) 2,400 to 3,400m (3,800) and *Q. semecarpifolia* is found in Gyirong, Nyalamu, Cona, and other areas of the Himalayas between 2,400 to 3,000 masl. In the western areas, distribution extends to considerably higher altitudes of 3,700m. The species tends to be more prevalent on south-facing slopes but is not confined to them. In the areas of distribution, the mean annual temperature ranges between 2 to 10°C; the accumulated temperature for the mean daily temperature of $\geq$ 10°C is between 600 to 2,800°C; the warmth index is 16 to 72; the absolute minimum temperature is from -12°C to -15°C; and the frost-free period is from 90 to 190 days. The annual rainfall in such forests is usually more than 500mm and the relative air humidity is more than 55 per cent. The ecological scope of the species is wide; the composition and structure of the communities and the productivity of the forests differ significantly.

Subtropical Evergreen Forests

Subtropical evergreen forests range from 1,000 to 2,400 masl. The composition of the species is rather complicated but the dominant species are mainly from the families of *Fagaceae, Lauraceae, Magnoliaceae*, and *Araliaceae*. Subtropical evergreen forests account for about eight per cent of the total forest resources and have important economic, ecological, and scientific values.

According to the composition and structure of the forests, they can be further divided into *Castanopsis* + *Lithocarpus* + *Schima* and *Cinnamomium* + *Machilus* + *Quercus* associations.

Annual precipitation in the area is between 1,000 to 2,000mm, with a relative air temperature of > 70 per cent; the mean annual temperature is 15 to 18°C; the accumulated mean annual temperature of the daily temperature of ≥ 10°C is 4,200 to 6,000°C; the warmth index is 110 to 160; the mean temperature of the coldest month is 7 to 12°C; the mean temperature of the warmest month is 21 to 25°C; the absolute minimum temperature is -6 to 0°C; and the frost-free period is 290 days.

In this type of forest, representation of these species is abundant but less than in tropical forests. *Epiphytes* and *lianas* still exist, but in limited numbers. There are a few species with buttresses, less grand in scale than in tropical forests, and cauliflory is absent, although strangulation may still occur.

Subtropical forests contain a lot of valuable timber species such as *Cinnamomum* spp, *Phoebe* spp, *Michelia* spp, and *Toona ciliata* as well as many other valuable economic species. Only a few of them have been studied so far. The subtropical evergreen forests have a large number of endemic species as well as primitive groups (in terms of plant evolution); hence they provide an unusual natural laboratory for theoretical studies.

Tropical Monsoon Forests

In the lower part of the Himalayan Mountains, where elevations are below 1,000m, and in the valleys of southeastern Tibet, one can find luxuriant tropical virgin forests. The far-northern boundary of this type of forest reaches a latitude of 29°N. This is the northernmost tropical forest in Eurasia. Such forests can be found in southern Zayu, Cona, and Medog counties.

According to meteorological data and supplementary calculations from experimental formulae, at 600m the mean annual temperature is 21.5°C; the mean annual temperature of the coldest month is about 15°C; the mean temperature of the warmest month is 27°C; the accumulated mean annual temperature of the daily temperature of ≥ 10°C is 7,200°C; the warmth index is 198; and the frost-free period is 11 months. These indicators are very similar to those for the northern boundary of the tropical zonation used in the natural regionalisation of China. At 1,000m, the mean annual temperature is about 18°C; the accumulated temperature at ≥ 10°C daily is 6,000°C; the warmth index is 160; the mean temperature of the coldest month is 12°C; the mean temperature of the warmest month is 25°C; the absolute minimum temperature is around 0°C; and the frost-free period is more than eight months.

The rainfall pattern in this region is determined by two main monsoons, i.e., a "summer" monsoon (May-October) and a winter monsoon (November-April). In "summer", the sun passes directly over northern India and southern China, and a belt of low pressure builds up over the hot Asian mainland. Rain-bearing winds blow north from the high pressure zone over Australia and the Indian Ocean. These winds pick up moisture as they pass over wide areas of sea, but, when they reach the mainland or islands, they rise to cross the mountain ranges and, as they climb, the air cools and drops the moisture as rain. In tropical rain forests the annual rainfall is not less than 1,000mm. The abundant precipitation and high temperatures create favourable conditions for the development of tropical forests. The uneven seasonal distribution of rainfall causes differences in composition and structure between the forest communities in Tibet and those in equatorial rain forests. The tropical forests of Tibet are frequently associated with more or less deciduous elements; representatives of

Dipterocarpaceae exist, but not in the numbers characteristic of humid tropical forests.

The composition of tropical forests is unusually rich and the forests mainly consist of representatives of *Meliaceae, Anonaceae, Guttiferae, Tetrameaceae, Dipterocarpaceae, Myristicaceae, Flacourtiaceae, Melastomaceae, Combrataceae, Sterculiaceae, Lauraceae, Fagaceae, Magnoliaceae*, and *Araliaceae*.

Tropical forests can be further divided into tropical evergreen rain forests, tropical evergreen forests, and tropical monsoon forests, depending on the structure of the communities and on environmental conditions.

Tropical forests are complex as well as fragile ecosystems. As a result of the impact of human activities, tropical forests have deteriorated and have been replaced by secondary growth, dominated by *Ficus crytophylla, Schima parviflora, Alnus nepalensis*, and *Sauraria griffithii*, or even replaced by tall grasses such as *Saccharum arundinacerum*, and *Themeda triandra*.

The standing stock of the tropical forests is not high, about 200 cubic metres per hectare. Nevertheless, the rich biological diversity with extremely valuable economic resources render this type of forest of very high value in the context of conservation. In order to conserve the rare tropical forest ecosystems and their contained biological diversity, a nature reserve was established in Metuo in 1985.

Bamboo Forests

Sub-Alpine Bamboo Forests

Sub-Alpine bamboo forests occur at between 2,500 to 3,600m, with distribution concentrated from 2,800 to 3,400m. The dominant species of this forest group are those from the genus *Sinarundinaria.* There are more than 20 species of *Sinarundinaria* distributed throughout the Himalayan-Hengduan Mountains. Sometimes two or three species of *Sinarundinaria* exist in one area.

Sinarundinaria is a monopodial bamboo and grows naturally as a dense thicket in the sub-Alpine coniferous forests consisting of spruce and fir. *Sinarundinaria* also occurs under the canopies of mixed, broad coniferous forests dominated by hemlock and many other deciduous broad-leaved species. The average height of bamboo is from one to two metres with a DBH of from one to 1.5cm. Occasionally, one can find small areas of pure *Sinarundinaria*. Rapid development of *Sinarundinaria* always takes place after selective cutting. After clear-cutting of forests, most *Sinarundinaria* deteriorate.

Well-developed *Sinarundinaria* undergrowth is used in manufacturing paper. It can also play an important role in binding and stabilising soils against erosion. A so-called red bamboo fungi that grows on the branches and leaf stalks of *Sinarundinaria* is a valuable medicinal material.

Subtropical and Tropical Bamboo Forests. More than 100 species of bamboo are mostly planted along the foothills and in valleys below 2,500m in altitude. The altitudinal limit is lower in the Hengduan Mountains and is higher in the Himalayas. Most of these bamboo forests are planted by local people, although a few have developed naturally. Among these bamboo forests, the most widely distributed and the most valuable for rural development are the forests dominated by *Phyllostachys heteroclada, F. nidularia, Sinocalamus affinis, Bambusa intermedia, Fagesia yunnanensis*, and *Dendrocalamus strictus*.

Man-made bamboo forests are single-layer monospecies. Some natural bamboo forests consisting of *Ph. heteroclada* and *Ph. nidularia* can be found between 1,000 to 2,000m in the hilly areas of Sichuan Province. These bamboo forests occur as secondary forests after the deterioration of subtropical, evergreen broad-leaved forests. Regions for development of this forest type have an average annual temperature of 15-17°C, an annual precipitation of from 1,200 to 2,000mm, and a relative humidity of 80 per cent. Forests developing under natural conditions can grow up to one to three metres (height) with a DBH of one to two centimetres. Under cultivated conditions, these indicators can reach five to 10m (height) and two to four centimetres (DBH). In natural *Phyllostachys* forests, some broad-leaved species such as the species from the genera *Lindera, Cinnamomiun, Rhus, Eurya,* and *Hydrangea,* are mixed with bamboo.

Bamboo is a valuable, multipurpose, and fast-growing plant species which is used for scaffolding. It is strong, lightweight, and extremely durable. Bamboo pipes are very useful for irrigation and bamboo also provides materials for baskets, mats, fodder, food, fences, and many other minor products. Moreover, it can play an important role in controlling soil erosion.

Alpine Scrub

Sub-Alpine scrub is distributed throughout the Alpine and sub-Alpine belts, and grows at elevations higher than the treeline, usually above 3,800 masl. As a rule, high mountain scrub is adjacent at its upper limit to Alpine meadows, while, at the lower boundary, it lies along sub-Alpine forests consisting of different species of *Abies, Larix, Spruce,* and *Betula*. Sometimes high mountain scrub occurs at elevations lower than 3,800m. The latter usually occurs as secondary vegetation after deterioration of climax vegetation as a result of human activities or special micro-climates.

The climate supporting this vegetation is characterised by low temperatures, long periods of snow cover, strong winds, high solar radiation, and a wide daily variation in temperature. According to estimates, the climatic indicators of this belt can be briefly summarised as follows: the annual temperature is from -1° to -2°C; the warmth index is from 1 to 13; the temperature of the coldest month is from -11° to -8°C; the average temperature of the warmest months is -7° to 10°C; and the frost-free period is from 50 to 85 days.

The major dominant species of Alpine scrub include various species of *Rhododendron* (*Rh. adenogynum, Rh. railleanum, Rh. hippophaeroides, Rh. racemomum,* and *Rh. siderophyllum*, etc), *Caragana frunchtiana, Sabina* (*Juniperus*) *squamata, Dasiphora fruticosa, Sibiraea angustata*, and *Quercus monimstricha*. Along the river bed, the scrub is dominated by seabuckthorn (*Hippophae rhamnoides*) and willow (*Salix vaccinioides*).

Alpine scrub is a good fodder resource and has long been an important source of fuelwood. Many Alpine plants, such as fritillary (*Fritillaria*), medicinal

rhubarb (*Rheum officinalia),* pilose asiabell (*Codonopsis pilosula*), and *Cordyceps sinensis*, possess important medical properties. A number of medicinal plants are used in traditional Tibetan medicine. The leaf of some species of *Rhododendron* containing aromatic oils is a cure for bronchitis; snow lotus (*Sausuria*), growing on Alpine scrub is an effective remedy for rheumatism and certain gynaecological complaints, whilst *Meconopsis*, scaphoid helmet monkshood (*Aconitum naviculare*), figwort-flower (*Picrorhiza scrophulariiflora*), and rockfoil (*Saxifraga*) are all effective cures for a wide range of common illnesses.

Moreover, Alpine scrub plays an important role in stabilising debris at high altitudes where the rock-weathering process takes place very rapidly. Alpine scrub and the adjacent Alpine meadows are covered with colourful flowers during the blooming season, and the cold Alpine belt is transformed into a beautiful natural garden.

Subtropical and Tropical Scrub

Subtropical scrub grows mainly from 1,000 (600) to 2,500m. The major types of scrub are given below.

1. *Phillanthus-Glochidion* Scrub. *Phillanthus-Glochidion* occurs between 800 to 1,500m in the De Hong and Lincang districts of the Hengduan Mountains in Yunnan Province. The scrub is 1.5 to 2.5m in height. Other species usually associated with *Phillantus emblica* are *Glochidionlon daltonii, G. hirsutum* var *glabrum, G. velutinum, Melastoma normale, Rhus chinensis, Callicarpa bodinieri, C. arborea, Diospyrus molifolia*, and *Urenea lobata*. Several tree species of *Castanopsis* and *Lithocarpus* exist and can extend to subtropical forests if the vegetation is protected through mountain enclosures and other protective measures.

2. *Sophora-Bauhinia* Scrub. *Sophora-Bauhinia* usually grows in the valleys of the Jinshajiang and Lanchangjiang rivers. The general elevation of the valley is between 1,300 to 1,800m (2,300m) with steep slopes and dry and poor soil. The unique combination of a dry and warm climate

characterises this special habitat. The composition of the scrub community is relatively poor.

The major components of the dry-warm valley scrub are *Sophora vicifolia,* and *Bauhinia fabri* var *microphylla* with a height of 0.5 to 0.8m. Other common components are *Osteomeles, Rosa* spp, *Vitex* spp, *Ceratostigma minus*, and *Leptodermis pilosa*. On rare occasions, *Opuntia monocantha* is present.

3. Dodonaea-Osteomeles Scrub. *Dodonaea-Osteomeles* grows in the valleys of the Jinshajiang River up to the lower slopes at an elevation of from 900 to 1,400m. The habitat is characterised by dryness and warmth.

The scrub, primarily composed of *Dodonaea viscosa* and *Osteomeles schwerinae*, is 0.4 to 0.8m in height. The coverage of the scrub community is about 30 to 60 per cent. Other mixed components vary from place to place. The common species are *Pistacia weinmanifolia, Xylosma japonicum, Rhamnus* spp, *Phyllantus embilica, Sophora vicifolia, Desmodium* spp, *Bauhinia faberi, B. delevayi, Zizyphus moritiana,* and *Indigofera* spp.

4. Vitex-Terminalia Scrubs. *Vitex-Terminalia* are mainly distributed in the valleys of the lower reaches of the Jinshajiang River. The habitat covers the alluvial river bed and extends to the foothills at altitudes between 800 to 1,500m.

Vitex negundo var *laxipaniculata* is the most conspicuous species and is usually associated with *Terminalia franchetii, Phyllanthus emblica, Paliurus orientalis,* and *Pistacia weinmenifolia*. The height of the scrub is about three metres, with a coverage of 65 to 85 per cent. In the lower layer of the scrub community *Waltheria indica, Wendlandia subalpina, Maytenus royleana,* and *Barleria cristata* are found and reach 0.5 to 1.5m in height.

5. *Jatropha* Scrub. Scrub composed of *Jatropha curcas* is distributed in the valleys of the Jinshajiang and Lanchangjiang rivers in the Hengduan Mountains. It grows well on the fine deposits of alluvial fans and between farmlands and foothills at elevations lower than 1,800m. *Jatropha* exhibits a wide environmental tolerance. It is found on warm sunny slopes with poor quality soils which are subject to long periods of drought. It is suitable for cultivation within the vast areas of marginal and degraded lands in the semi-arid and arid tropics as well as in the subtropical belt.

   Jatropha curcas usually forms small patches of pure scrub. Sometimes, *Bombax malabarica, Celtis yunnanensis, Dodonia viscosa*, and *Osteomeles schmerinae* scrubs, as well as sclerophyllous grasses, are associated with *Jatropha curcas*.

   Jatropha is a species widely used as hedges for protecting crops or pasturelands. The ability of *Jatropha* to flourish and be productive across a wide range of sites with poor quality soils and long periods of drought makes it a desirable medicinal species. The oil extracted from *Jatropha* seeds is known as "curcas oil" and is widely used in the manufacture of candles and soaps. It has great potential for use as a petroleum substitute.

Pinus yunnanensis, var *pygmaea* Scrub. The coniferous scrub *Pinus yunnanensis*, var *pygmaea*, grows from one to two metres in height with a crown diameter of one to 1.5m. Yunnan pine scrub is distributed along the southeastern periphery of the Hengduan Mountains at altitudes between 2,000 to 2,500m. The soil is poor and dry. This type of scrub normally occurs in pure stands with a few other scrub plants such as *Rhododendron microphylla, Lyonia ovalifolia, Myrica nana, Gauteria yunnanensis*, and *Vaccinium dunnianum*. Yunnan pine scrub plays an important role in protecting slopes against soil erosion and also provides fuelwood. In places with good soil, this type of scrub can be replaced by high quality Yunnan pine forests through afforestation and proper management.