Techniques for re-afforestation in Japan

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C O N T E N T S

§ 1 Major forest tree species in Japan

Vascular plants in Japan include about 4,000 species, of which about 1/4 (1,000 species) are woody plants. Those woody plants are divided into the following groups, taxonomically:

A. Gymnosperms — ca. 40 species in 7 families

Cephalotaxaceae, Cupressaceae
Cycadaceae, Pinaceae
Podocarpaceae, Taxaceae
Taxodiaceae

(Major 27 species are listed later.)

B. Angiosperms

a. Monocotyledoneae — 100 species +

(Pandanaceae, Bambusaceae, Palmae, ...)

b. Dicotyledoneae — 850 species +

(Major 32 species are listed later.)

(a) Choripetalous plants — ca. 600 species in 71 families

(b) Sympetalous plants — ca. 250 species in 27 families

(1) CONIFERS in Gymnosperms (d:deciduous)

(◇ planting species)

Cupressaceae			
◇	Hinoki		Chamaecyparis obtusa (Japanese cypress)
◇	Sawara		Chamaecyparis pisifera
	Nezuko		Thuja standishii
◇	Asunaro (Hiba)		Thujopsis dolabrata
Pinaceae			
	Momi		Abies firma
	Urajiromomi		Abies homolepis
◇	Todomatsu		Abies sachalinensis (Todo-fir)
	Shirabe		Abies veitchii
◇	Karamatsu	d	Larix leptolepis (larch)
◇	Akaezomatsu		Picea glehnii
	Tohi		Picea hondoensis
◇	Ezomatsu		Picea jezoensis (ezo-spruce)
◇	Akamatsu		Pinus densiflora (red pine)
	Chosenmatsu		Pinus koraiensis (Korean pine)
◇	Ryukyumatsu		Pinus luchuensis
	Goyomatsu		Pinus parviflora
	Haimatsu		Pinus pumila (creeping pine)
◇	Kuromatsu		Pinus thunbergii (black pine)
	Togasawara		Pseudotsuga japonica
	Kometsuga		Tsuga diversifolia
	Tsuga		Tsuga sieboldii
Podocarpaceae			
	Inumaki		Podocarpus macrophyllus
	Nagi		Podocarpus nagi
Taxaceae			
	Ichii		Taxus cuspidata
	Kaya		Torreya nucifera
Taxodiaceae			
◇	Sugi		Cryptomeria japonica (Japanese cedar)
	Koyamaki		Sciadopitys verticillata

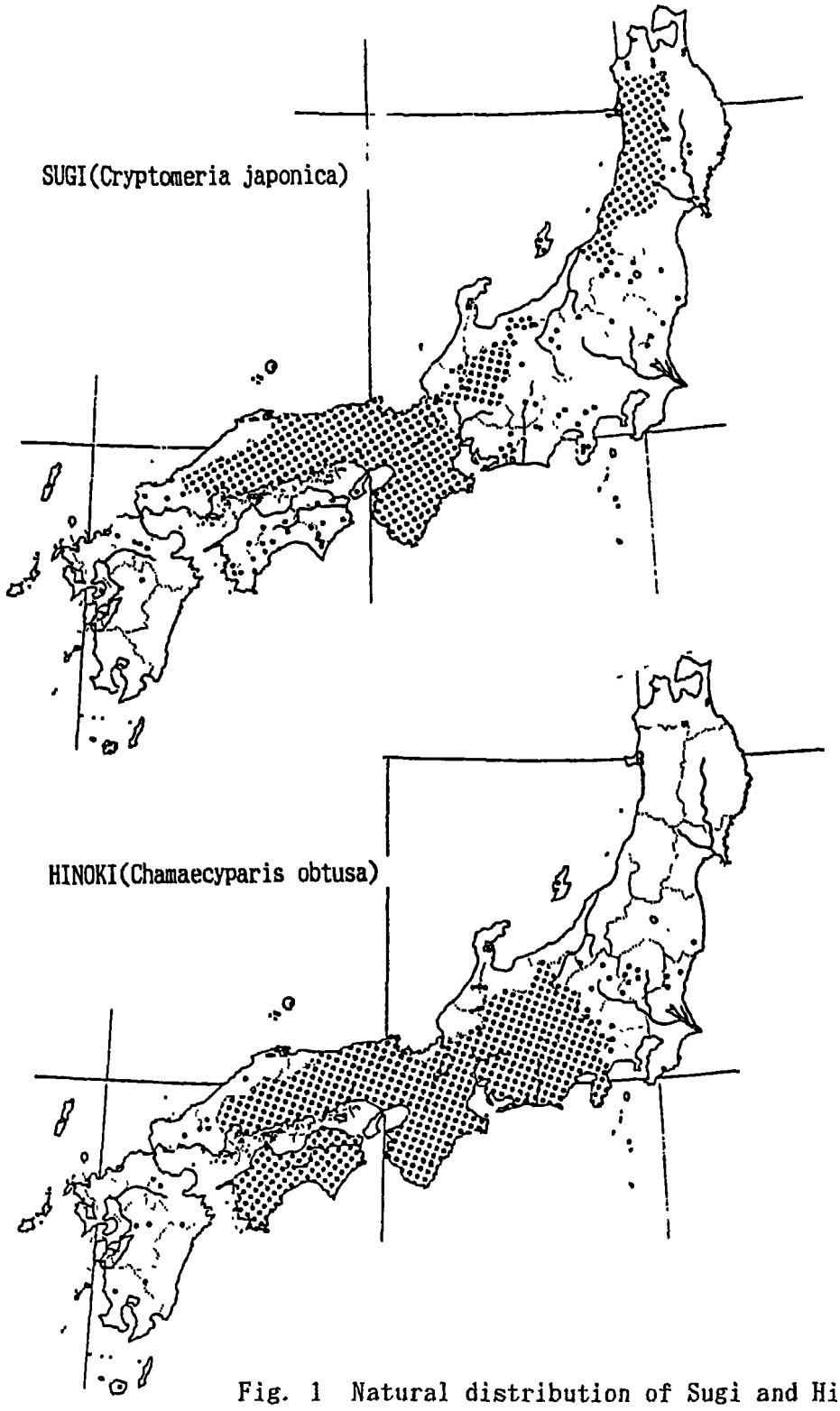


Fig. 1 Natural distribution of Sugi and Hinoki
(Kurata 1971)

(2) BROAD-LEAVED SPECIES (ev:evergreen)

Choripetalous plants

Aceraceae		
Itaya-kaede		Acer mono var. marmoratum
Betulaceae		
Han-noki		Alnus japonica (Japanese alder)
Dakekamba		Betula ermanii
Shirakamba		Betula platyphylla var. japonica (white birch)
Cercidiphyllaceae		
Katsura		Cercidiphyllum japonicum
Fagaceae		
Kuri		Castanea crenata (chestnut)
Kojii	ev	Castanopsis cuspidata
Sudajii	ev	Castanopsis cuspidata var. sieboldii
Akagashi	ev	Cyclobalanopsis acuta
Arakashi	ev	Cyclobalanopsis glauca
Shirakashi	ev	Cyclobalanopsis myrsinaefolia
Buna		Fagus crenata (Japanese beech)
Inubuna		Fagus japonica
Kunugi		Quercus acutissima
Mizunara		Quercus crispula
Kashiwa		Quercus dentata
Konara		Quercus serrata
Abemaki		Quercus variabilis
Juglandaceae		
Onigurumi		Juglans sieboldiana
Lauraceae		
Kusunoki	ev	Cinnamomum camphora (camphor tree)
Tabunoki	ev	Machilus thunbergii
Magnoliaceae		
Ho-onoki		Magnolia obovata
Salicaceae		
Doronoki		Populus maximowiczii
Yamanarashi		Populus sieboldii
Theaceae		
Tsubaki	ev	Camellia japonica
Tiliaceae		
Shinanoki		Tilia japonica
Ulmaceae		
Harunire		Ulmus davidiana var. japonica
Akinire		Ulmus parvifolia
Keyaki		Zelkova serrata

Sympetalous plants

Oleaceae		
Yachidamo		Fraxinus mandshurica var. japonica
Shioji		Fraxinus spaethiana
Paulowniaceae		
Kiri		Paulownia tomentosa (?)

(3) Characteristics of major planting species

①Conifers

●Sugi [Cryptomeria japonica] [Japanese cedar]

Sugi is distributed naturally from southwestern part of AOMORI Pref., its northern limit, to Yaku Island of KAGOSHIMA Pref., its southern limit --- roughly from 40°42' to 30°15' (Fig. 1). Its vertical distribution is from lowland to 1,850 m a.s.l., but it grows better between 300 and 1,100 m a.s.l.

Sugi is divided roughly into two types. One is called Ura-Sugi in the regions, facing the Japan Sea, with heavy snow in winter and the other is called Omote-Sugi in the regions facing the Pacific Ocean. There are differences in the morphological, physiological and ecological features of those two types. The former has a special variety with persistent lower branches from which new individuals are grown by natural layering. Including this variety, there are 23 geographical varieties (=ecotypes) [19 of Ura-Sugi and 4 of Omote-Sugi] and 31 cultivars [25 of Ura-Sugi and 6 of Omote-Sugi].

Sugi is the most important planting species in Japan, and followed by Hinoki. The former covers 44% and the latter does 24% of the total plantations amounting to 10,327 thousands ha (1990).

Sugi is usually reproduced by seedlings, but also by cuttings in warmer regions, especially in Kyushu, where many cultivars have been raised. Since our tree improvement program was started in 1957, cuttings have been used for cloning of selected superior trees.

Sugi prefers fertile site of colluvial soil, and so it usually grows better on the lower part of slope or the bottom of valley. As natural regeneration is difficult, clear cutting system is usually used for regeneration. In recent years, however, various trials have been done to induce multistoreyed forests instead of even-aged forests.

Sugi has a long life-span and occasionally there are giant trees, some of which are designated as natural monuments. In Yaku Island, south of Kyushu, there is still a thickly growing forest of huge Sugi trees more than 1,000 years old. Including this forest, natural Sugi forests are famous among the most beautiful forests in Japan. Others are located in Akita and Kochi Prefectures. The very old Sugi trees along the Nikko avenue in Tochigi Prefecture are also very famous. The groves or forests surrounding shrines or temples are formed very often with Sugi trees.

Sugi is one of the most important timber trees in Japan. The wood of Sugi is most commonly used for housing. Round poles with natural wavy surface are used for the interior decoration in Japanese style of room, but those poles are very costly. The trees are also planted as garden trees, as there are many horticultural varieties or forms.

●Hinoki [Chamaecyparis obtusa] [Japanese cypress]

Natural distribution of Hinoki is from Iwaki, Fukushima Pref., in the north (37°10'N), to Yaku Island, Kagoshima Pref. in the south (30°15'N). Its vertical distribution ranges from lowland to 2,180m a.s.l., although it grows better between 300 and 1,600m a.s.l. The famous Hinoki forests are located in the Kiso area of Nagano Pref., where there is one of the most beautiful forests in Japan.

There are few natural forests of Hinoki in the regions where there is much snow. Efforts to plant Hinoki in such areas have been unsuccessful, because the trees suffer from resin-exuding canker. Hinoki does not necessarily require fertile soil, and it can be grown in the sites where Sugi will not grow well. Hinoki forests are also regenerated usually by clear cutting, but selective cutting system is taken in moist podzolic soil or ridges in the Kiso national forest. Hinoki is also reproduced by seedlings usually, but cuttings can be used for some clones.

The wood of Hinoki is highly prized for its high durability and good luster, and used for high-grade housing, shrine construction, and so on.

● Akamatsu : Pinus densiflora, Japanese red pine

The natural distribution of Akamatsu extends from Shimokita, Aomori Pref. (41°31'N) in the north, to Mt. Maedake in Yaku Island, Kagoshima Pref. (30°15'N) in the south. Its vertical distribution ranges from seacoast to 2,300 m a.s.l., thriving best between 100 and 1,200 m a.s.l. There are many good natural forests, but tree forms are not good often. To grow trees of good form, plantations must be established densely on rich sites.

Akamatsu is liable to be attacked by shoot moth(Dioryctria spp.), and also suffering serious damage, in recent years, from pine wood nematode (Bursaphelenchus xylophilus), which is carried by pine sawyer(Monochamus alternatus).

Akamatsu is light-demanding and tolerant to drought. This pine is similar to Kuromatsu(black pine), but identified by reddish-brown winter buds, while Kuromatsu is identified by greyish-white winter buds.

● Kuromatsu : Pinus thunbergii, Japanese black pine

The northernmost limit of its natural distribution is Shimokita, Aomori Pref. (41°34'N), and the southernmost limit is Takara Island in the Tokara Islands, Kagoshima Pref. (29°00'N). The vertical distribution is between 0 and 950 m a.s.l. and its growth is best between 300 and 500 m a.s.l. near the seacoast. Kuromatsu is normally planted exclusively for the purpose to protect coastal areas from wind, sand, and sometimes fog, but also planted for scenery and amenity especially in recent years Trees of both Akamatsu and Kuromatsu are also an important component in golf courses.

Kuromatsu is also suffering serious damage from pine wood nematode.

● Todomatsu : Abies sachalinensis, Todo-fir

Todomatsu is one of the most important forest trees in Hokkaido. Regeneration is done usually by planting seedlings, but natural regeneration is also possible if treatments are appropriate. The wood is extensively used for paper-pulp, packing, civil engineering work, etc.

●Ezomatsu(Kuro-ezomatsu) : Picea jezoensis, Ezo-spruce

Ezomatsu is also one of the most important forest trees in Hokkaido. In the case of natural regeneration, Ezomatsu is regenerated very often on fallen trees. However, a thorough opening-up of the canopy is needed to stimulate and improve the emergence and growth of seedlings and young trees. The wood is also used for paper-pulp, housing, furnitures, etc.

②Broad-leaved trees

Plantation area of broadleaved trees is only 2 % of the total amounting to 10.4 million ha. Among the species planted are Keyaki (Zelkova serrata), Yachidamo (Fraxinus mandshurica var. japonica), Onigurumi (Juglans sieboldiana), Sawagurumi (Pterocarya rhoifolia), and Kusu (Cinnamomum camphora). Regeneration of Buna (Fagus crenata) and Inu-buna (F. japonica) may be done by natural seeding, while regeneration of Konara (Quercus serrata), Kunugi (Q. acutissima) and Kashi groups(Cyclobalanopsis spp.) may be done by coppicing although they can also be regenerated by natural seeding. Many of the important forests which had produced firewood and charcoal were composed of these species.

In recent years, there are targets to establish broadleaved forests or plantations, which are : (1) to produce bed logs for edible mushroom, (2) to produce materials for wooden works, and (3) to produce materials for medicines. For the latter two, however, we are still at a trial stage. Shiitake (Lentinus edodes), a species of wood rotting fungi growing on Quercus spp., Cyclobalanopsis spp., Castanea spp., Castanopsis spp., Pasania spp. (all in Fagaceae) and Carpinus spp. (Betulaceae) has been cultivated for many years in Japan. Usually, Kunugi and Konara are used for bed logs.

Consumption of fuelwood has been decreased very much these decades; for example, 30 % to the total consumption in 1955 was decreased to only 0.4 % in 1988. Major species for fuelwood, mainly charcoal, are Konara, Kunugi, and Kashi group (Cyclobalanopsis spp.). The hardest white charcoal is made from Ubame-gashi (Q. phylliraeoides).

Several important species, all deciduous, are described below.

● Buna [Fagus crenata] [Japanese beech]

Buna is naturally distributed from the southwestern part of Hokkaido to Mt. Takakuma in Kagoshima Pref. and from 600 m to 1800 m a.s.l. This is one of the major species to compose the cool-temperate deciduous forest.

● Kunugi [Quercus acutissima]

Kunugi is naturally distributed from Akita and Miyagi to Kagoshima Pref. and from lowland to 700 m a.s.l. This species is also found in Korea, a part of China, and Himalayan region.

● Konara [Quercus serrata]

Konara is naturally distributed in somewhat colder region than those where Kunugi grows and extends from the Kanto region to the southern part of Hokkaido. This species is also found in Korea and a part of China.

● Mizunara [Quercus crispula]

Mizunara is naturally distributed from Hokkaido to Kagoshima Pref. and from 1,000 m to 2,000 m a.s.l. The species is also found in the Kurile islands, south Sakhalin, and a part of China. This is also one of the representative species in the cool-temperate deciduous forest.

● Kusunoki [Cinnamomum camphora] [camphor tree]

Kusunoki is naturally distributed from the southern part of Kanto region to the Ryukyu islands, and also found in a part of Korea and China and even in a part of the Indochina region. This is one of the representative species in the laurel forest of the warm-temperate zone.

●Keyaki [Zelkova serrata]

Keyaki is naturally distributed from Aomori Pref. to Kagoshima Pref. inc. Shikoku island. The species is also found in Korea and a part of China inc. Taiwan.

●Kiri [Paulownia spp.]

Kiri includes the following two major species: Nihon-giri (P. tomentosa) and Usuba-giri (P. taiwaniana). P. tomentosa is naturally distributed in Korea and a part of China (ca.34～40°N). This species was introduced from China long time ago and is now planted throughout Japan, except in the northern part of Hokkaido, mainly in Iwate, Fukushima, Niigata and Ibaraki Prefectures. P. taiwaniana, the species closely related to P. kawakamii, is said to be naturally distributed between 22° and 30°N. This species was introduced into Japan from Taiwan around 1935. This species grows much faster than P. tomentosa although its wood quality is inferior to that of P. tomentosa. There is another species called P. fortunei(Kokonoe-giri), which is naturally distributed between 20° and 30°N. This species also grows very rapidly.

●Yachidamo [Fraxinus mandshurica var. japonica]

Yachidamo is naturally distributed from Hokkaido to Nagano Pref. in the central part of Honshu. This species is also found in the northeast of Asia including Sakhalin, Korea, the northern China, and east Siberia. The species grows in moist sites along stream banks and the borders of swamps.

●Urushi [Rhus verniciflua]

Urushi distributing naturally in China to Viet-Nam was introduced to Japan long time ago. It is naturalized in some part of Japan, but there is another species native to Japan, R. trichocarpa. Lacquer of good quality is produced from selected strains of the species in several prefectures including Aomori, Iwate, Ibaraki, etc.

§ 2 Forest types in Japan

(1) Criteria for classifying major forest types in Japan

① Annual average temperature

6°C	between subfrigid and cool temperate zones
13°C	between cool and warm temperate zones
21°C	between warm temperate and subtropical zones

② Warmth and coldness indices (Kira 1945)

Warmth index (WI) = Σ (t-5)
[Sum up (t-5) for the months of $t > 5°C$]

Coldness index (CI) = Σ (5-t)
[Sum up (5-t) for the months of $t < 5°C$]

Table 1 How to calculate WI and CI for Tokyo

Month	J	F	M	A	M	J	J	A	S	O	N	D	Ann
Mean temp. (°C)	4.7	5.4	8.4	13.9	18.4	21.5	25.2	26.7	22.9	17.3	12.3	7.4	15.3

WI = (5.4+8.4+13.9+18.4+21.5+25.2+26.7+22.9+17.3+12.3+7.4)
- 5x11 = 179.4 - 55 = 124.4 m.d. (month-degree)

CI = -(5-4.7) = -0.3 m.d. (month-degree)

(cf. Ann: annual mean temperature)

(2) Horizontal distribution of major types with major tree species

[Climatic zone]	[Forest type]	[WI]	[CI]
Subfrigid zone		15～	(45-55)
	Evergreen coniferous forest		
	〈Hokkaido〉 Abies sachalinensis		
	Picea jezoensis		
	P. glehnii		
	〈Honshu〉 A. veitchii		
	A. mariesii		
	Picea 5 spp.		
	Tsuga 2 spp.		
	Deciduous broad-leaved forest		
	Betula spp., Quercus sp.		
	Alnus sp.		
Cool temperate zone		(45-55)～	85
	Mixed forest of broad-leaved and coniferous trees		
	[or "Pan-mixed forest"		
	(transitional type in Hokkaido)]		
	Conifers (Abies sachalinensis,		
	Picea jezoensis, P. glehnii)		
	Quercus spp., Ulmus spp., Acer spp.		
	Tilia spp., Fraxinus spp.		
	Deciduous broad-leaved forest		
	Fagus crenata, Quercus crispula		
	Fraxinus spp., Ulmus spp.		
	Acer spp., Tilia spp.		

Warm temperate zone

Deciduous broad-leaved forest 85～180 -10>

Castanea sp., Deciduous oaks

Fagus japonica, Carpinus spp.

Evergreen broad-leaved forest [or Laurel forest] 85～180 -10<

Machilus sp., Cyclobalanopsis spp.

Castanopsis spp.

Subtropical zone 180～240

Evergreen broad-leaved forest

Ficus microcarpa, Calophyllum inophyllum

Castanopsis sp., Machilus sp.

Cinnamomum camphora

Mangrove

Rhizophora mucronata

Kandelia candel

Bruguiera gymnorrhiza

Avicennia marina

3) Vertical distribution

[Vertical zone]	[Forest type]	[WI]	[CI]
Alpine zone:	Major species: Pinus pumila		
Subalpine zone:	Evergreen conifer forest	15～45	
Montane zone:	Deciduous broad-leaved forest(Summer green f.)		
	Cool-temperate deciduous forest	45～85	
	Warm-temperate deciduous forest	85～180;	-10>
Submontane zone:	Laurel forest(Evergreen broad-leaved forest)		
		85～180	-10<

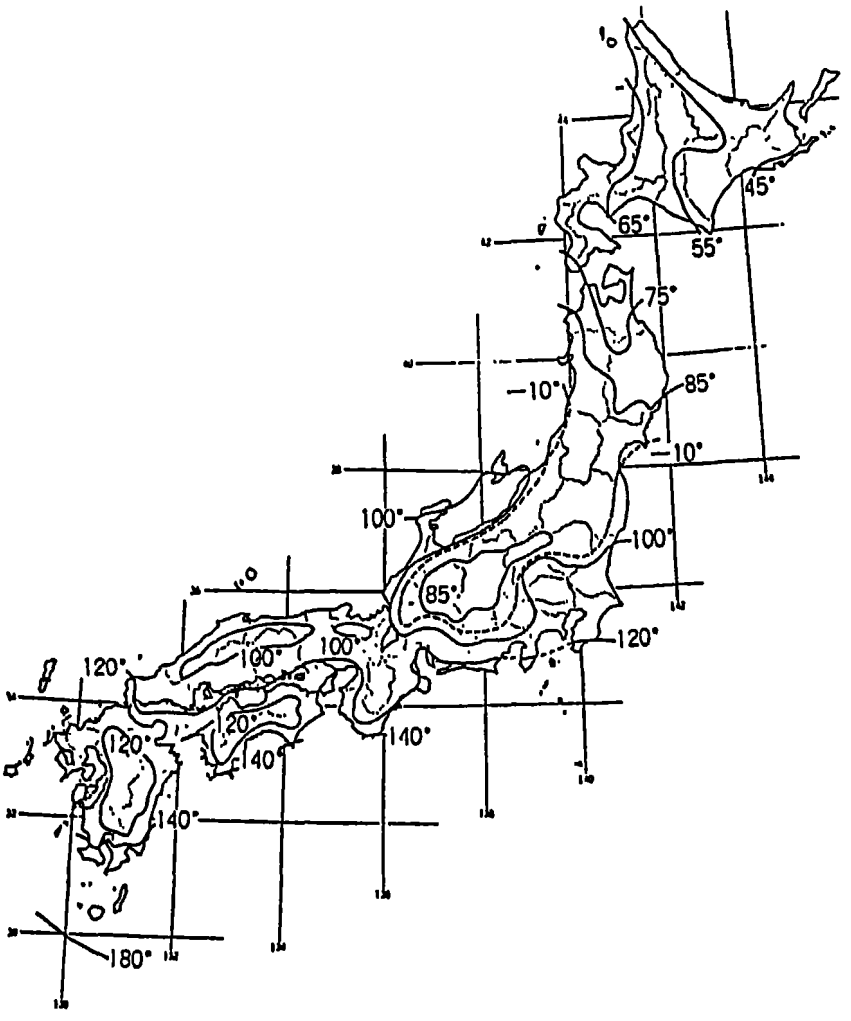


Fig. 2 Distribution of warmth and coldness indices

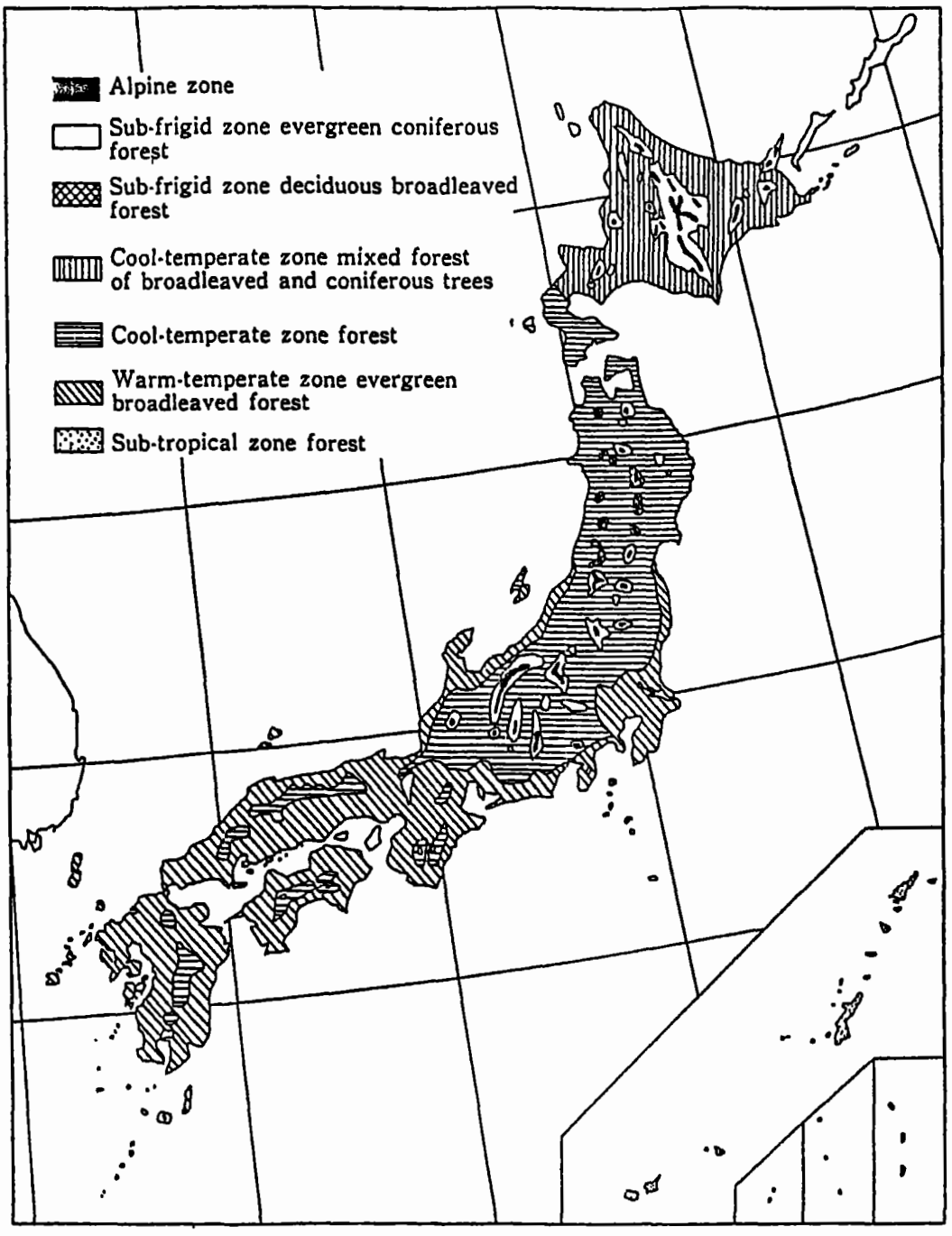


Fig. 3 Distribution of major forest types
(FORESTRY TECHNOLOGY IN JAPAN, 1981)

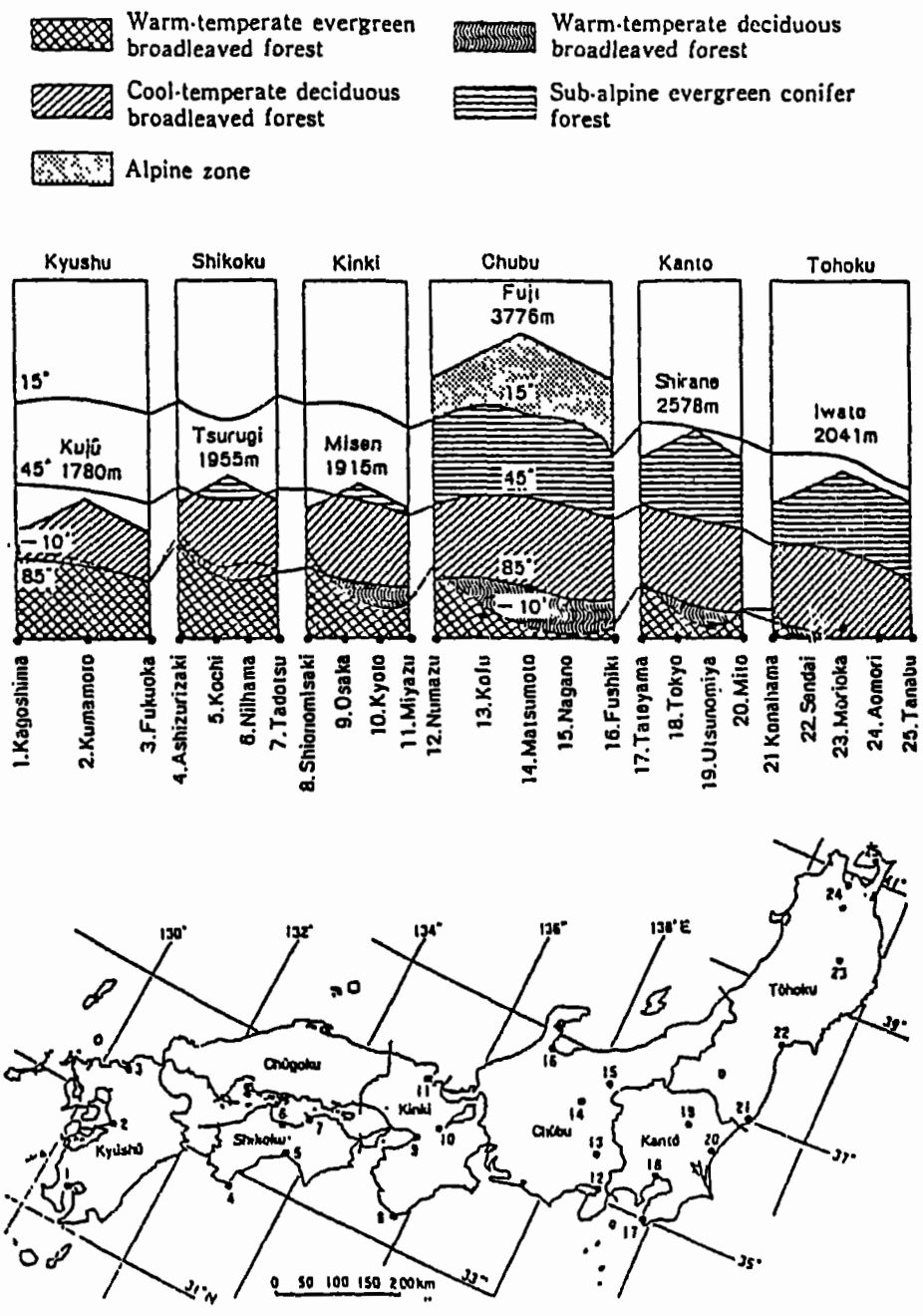


Fig. 4 Vertical distribution of major forest types in Honshu, Shikoku, and Kyushu as related to the 15-, 45-, and 85-[°C-month] isopleths of warmth index and -10-[°C-month] isopleth of coldness index (Kira 1949)
Each region is represented as a profile from south (left) to north (right), with the name and altitude of the highest mountain (Kira 1977).

§ 3 Silvicultural techniques

1. Planting materials

(1) Tree improvement programs

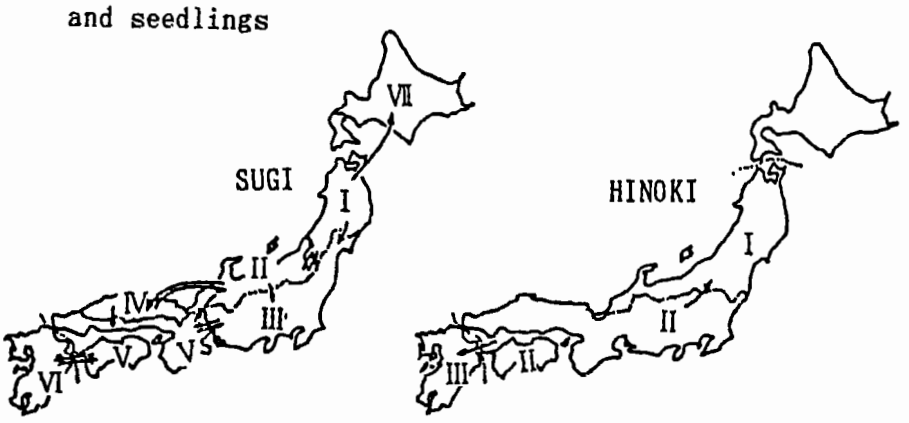
Selection of elite trees (since 1957): 9,130 trees
(Sugi:3,633; Hinoki:990)
Selection of trees resistant to climatic damages (since 1970):
primary selecton from the stands damaged seriously:
frost & cold wind: 5,430 trees (Sugi:3,500)
snow: 2,000 trees (Sugi:1,750)
Selection of pine trees resistant to pine wilt disease (since 1978):
26,100 trees were selected primarily from the stands damaged seriously, but only 108 trees passed an inoculation test.
(cf.) The disease is caused by pine wood nematode carried by pine sawyers.
the nematode: Bursaphelenchus xylophilus
major sawyer: Monochamus alternatus
Selection of trees for bed logs of mushroom (Shiitake) (since 1978):
Quercus acutissima: 590 trees
Q. serrata: 310 trees
Selection of trees resistant to specified insects (since 1985):
primary selection from the stands damaged seriously:
a beetle (Semanotus japonicus): ca. 700 trees
a midge (Resseliella odai): ca. 80 trees
Selection of larch trees less twisted (since 1980):
ca. 240 trees of ca. 4,500 trees selected primarily
(Figures shown above are as of 1987.3.)

(2) Forestry Seed and Seedling Law

Species described: Sugi (Cryptomeria japonica)
Hinoki (Chamaecyparis obtusa); Akamatsu (Pinus densiflora)
Kuromatsu (P. thunbergii); Ryukyumatsu (P. luchuensis)
Todomatsu (Abies sachalinensis); Ezomatsu (Picea jezoensis)

Designation of superior seed sources:
Designation of mother trees: improved mother trees
ordinary mother trees
special mother trees
(Seed stands, Seed orchards)
Registration of producers and/or dealers

Fig. 5 Examples of Sugi and Hinoki for the distribution of seeds and seedlings



(3) Seed and scion production

Seeds: (mother trees)
seed stands
seed orchards: mainly by clonal grafts but also possibly by seedlings from seeds of selected trees

ca. 1,540 ha of ca. 650 orchards as of 1988.3

Those seed orchards may produce enough seeds for re-afforestation. In case of Cryptomeria, flower differentiation may be promoted by gibberellin (GA_3) whenever necessary.

Scions: (mother trees)
scion gardens: mainly by clonal materials (stecklings/grafts)
ca. 400 ha mainly for Sugi and Hinoki

(4) Seed handling

Collection
Cones of major conifers should not be collected before:
1 September …… Karamatsu, Todomatsu
10 September …… Ezomatsu
20 September …… Sugi, Hinoki
Akamatsu, Kuromatsu, Ryukyumatsu

Preparation
Some mechanization has been tried in each procedure of drying, extraction, cleaning, and selection.

Seed testing: Standard germination methods
Quick methods
X-ray photography only for research
Biochemical method
Potassium Tellurite (K_2TeO_3)
Potassium Tellurate (K_2TeO_4)
2,3,5-Triphenyltetrazolium Chloride

Storage: Early studies: for species with a long interval between good crop years
Recently: more for gene conservation at subfreezing temperatures

Germination/Pretreatment
Most studies have been concentrated on conifer seeds, and studies for broad-leaved species have been increasing.

(5) Kinds of planting stock

Sexual reproduction:

seedlings	bare-root*	ca. 92 %
	potted	ca. 1 %

* standard size :
1 year old: more than 6 cm to 12 cm
2 years old: more than 15 cm to 45 cm
3 years old: more than 25 cm to 60 cm
[2～3 years old for outplanting]

wildlings very rare

Vegetative reproduction:

rooted cuttings (stecklings)
mainly with Sugi ca. 7 %
standard size :
1 year old: more than 20 cm to 60 cm
2 years old: more than 30 cm to 70 cm
[1～2 years old for outplanting]

layered materials
Hiba (Thujopsis dolabrata) only

grafts for special purposes
ex. for establishing seed orchards

2.Plantation establishment

(1)Choice of species [Right tree for right site]

How to evaluate site conditions

① Site index based on the growth of previous plantations
Average height at 40 years old for ordinary conifers
and at 60 years old for some broad-leaved species

② Floor vegetations and/or soil types

③ Site index based on different environmental factors
Scores are added for the categories of the site concerned in respective items by Table 2. For example, the index of the site having the scores with asterisk is 19.412.

(2)Major planting species: see page 9 for conifers.

Many for broad-leaved species but in small scale
For the production of bed logs for mushroom:
Quercus acutissima and Q. serrata

(3)Site preparation:

whole area preparation (complete preparation)
strip preparation, spot preparation

manual, mechanization, and/or herbicides
[Herbicides are listed on pp.22～23.]

terrace preparation: special work for steep slopes

(4)Planting

Spacing: standard - 3,000 seedlings/ha
Planting: ordinary planting, group planting, underplanting

(5)Other methods for establishment

Direct sowing
Direct cuttings only with Sugi
Direct layering only with Hiba
Rhizome planting only with Kiri(Paulownia spp.) and bamboos

Table 2 Score table for the factors to estimate the site index of larch (Karamatsu : Larix leptolepis) stand [Mashimo 1967]

Factor		Score	Range	Partial correlation coefficient
Item	Category			
Depth of A_1 horizon	Bl_B Shallow	16.096	5.007	0.604
	Bl_B Deep	15.975*		
	Bl_C Shallow	14.475		
	Bl_C Deep	15.948		
	Bl_C V.Deep	15.838		
	Bl_E Deep	18.203		
	Bl_E V.Deep	19.482		
Effective depth	0 ~ 30 cm	0.000	3.686	0.524
	31 ~ 50 cm	2.648*		
	51 cm <	3.686		
Humus content	S:Rich;L:Rich	0.000	4.575	0.629
	S:Rich;L:Ord.	3.756		
	S:Rich;L:Poor	1.757*		
Sedimentation type	Residual soil	0.000	5.482	0.694
	Creeping soil	4.209		
	Creeping(Gra.)	2.905		
	Colluvial soil	5.482*		
	Colluvial(Gra.)	3.608		
Soil structure	S:Crumb;L:Crumb	0.000	7.223	0.632
	S:Crumb;L:Ang.	-2.540*		
	S:Crumb;L:Mass.	-7.223		
	S:Gran.;L:Gran.	-3.458		
Elevation	1,200~1,400 m	0.000	6.243	0.732
	1,401~1,600 m	-3.370*		
	1,601 m <	-6.243		
Direction	North	0.000	2.786	0.379
	East	-0.270*		
	Southeast	-1.203		
	South	1.582		
	Southwest	-0.109		
	West	0.358		
Inclination	0 ~ 8°	0.000	0.608	0.155
	9 ~ 22°	-0.270*		
	23 ~ 35°	-0.338		

Note. Bl:black soil; S:surface(ca.10cm); L:lower layer(ca.20 cm)
V.: very; Ord.:ordinary; Gra.:gravel
Ang.:angular; Mass.:massive; Gran.:granular

◎ Major herbicides in use in Japan

A. Plant hormones

(a) Phenoxycarboxylic acids

MCP (2-methyl-4-chlorophenoxyacetic acid)

(b) Pyridine derivatives

Picloram (4-amino-3,5,6-trichloropicolinic acid)

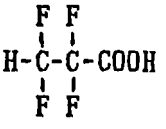
Usually a wooden stick, called "K-pin" on whose sharpened tip 6 mg of picloram is coated, is inserted into a base of stem: one stick for stem less than 5 cm in diameter and two for 5 to 10 cm in diameter. The stick can be applied at any time, but usually from fall to spring.

Triclopyl (3,5,6-trichloro-2-pyridyloxyacetic acid)

B. Metabolic inhibitors

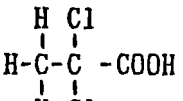
(a) Fatty acid halogenides

Tetrapion (TFP, 2,2,3,3-tetrafluoropropionic acid)

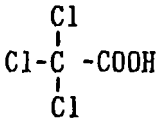


There are three types of granules, powders, and solutions. Usually the granule type of 10 % is applied by 30 kg/ha. The effect is different with the time of application, and the strongest effect may be expected by the application after weeding in February (later part of dormant season) when the perennial grasses have not sprouted yet.

Dalapon (DPA, 2,2-dichloropropionic acid)



TCA (trichloroacetic acid)



(b) Organic phosphides

Glyphosate [N-(phosphonomethyl) glycine]
Phosamine ammonium (ammonium ethylcarbamonyl-phosphonate)

(c) Triazine derivatives

Simazine [CAT, 2-chloro-4,6-bis-(ethylamino)-s-triazine]

This is used exclusively for nursery practices.
Application rate 50 to 100 g/10 a as 50 % hydrated chemical.

(d) Carbamates

Asulam (methyl sulphanilylcarbamate)
Karbutilate [3-(3,3-dimethylureido) phenyl tert-butylcarbamate]

(e) Toluidine derivatives

Trifluralin (2,6-dinitro-N,N-dipropyl-4-trifluoromethylalanine)

(f) Diphenyl ether derivatives

Chlornitrofen (2,4,6-trichlorophenyl-4-nitrophenyl ether)

C. Oxidizers

Sodium chlorate ($NaClO_3$)

There are three types of granule, powder and solution.
Usually the granule type of 50 % is applied by 100 kg/ha
in growing season.

Ammonium sulfamate (AMS, $NH_4OSO_2NH_2$)
Sodium cyanate (NaCNO)

3. Tending

A. Before Closure:

(1) Weeding — Manual
Mechanized: Portable Machines (Bush-cleaners)
Herbicides

(2) Vine Cutting — Manual
Herbicides

[Major herbicides are listed on pp.22～23.]

(3) Improvement cutting (Cleaning cutting, Salvage cutting)

This is nearly equal to non-commercial thinning.

Table 3 Standard schedule for weeding and vine cutting

Species	Work	Year after planting 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sugi	Weeding	○	○	○	○	○									
	V/C								○				○		
Karamatsu	Weeding	○	○	○											
	V/C						○				○				

V/C: vine cutting

Table 4 An example of silvicultural system with herbicides

Year before(-) or after planting	Kind of work
-3	Herbicide application
-2	-
-1	Ground preparation
0	Planting
1	Partial weeding
2	Weeding
3	Weeding
4	Herbicide application
5～7	-
8	Cleaning cutting

B. After Closure:

(1)Thinning

Various tending patterns have been developed mainly for Sugi and Hinoki in different areas of the country. Major patterns are outlined in Table 5 on page 26. These practices are to control both yields and quality of the wood produced, so as to meet the objectives of forest management.

In 1960s, the relationship between mean stem volume or stand volume and density was studied mainly with Sugi and Akamatsu on the basis of the principle about the density effect developed with annual crops by Kira and his coworkers(1953 and others). Eventually the stand density control chart was devised, an example of which is shown in Fig. 6 on p.27. Lines (or curves) in this figure are explained below the figure.

If the growth conditions are the same except for density, the following relationship may be found between stand volume (V) and stand density (ρ):

$$1/V = A + B/\rho$$

where the constants A and B are determined by species and growing stage. As the stand volume is expressed by $V = v \times \rho$, the following relationship can also be found between mean stem volume (v) and stand density.

$$1/v = A\rho + B$$

The full-density line is expressed either by $v = k\rho^{-a}$ or $V = k\rho^{1-a}$. The self-thinning curve is expressed either by $1/\rho = Av + B$ or $\rho = (1 - AV)/B$. On the other hand, the yield index (Ry) indicates the crowdedness in volume of the stand concerned as compared with the stand volume in full density on the same mean height curve.

Table 5 Typical tending systems in Japan (after Sakaguchi 1961)

Forestry area (Location)	YOSHINO (NARA)	KITAYAMA (KYOTO)	NISHIKAWA (SAITAMA)	National forest (Northern KANTO)		OBI (MIYAZAKI)
Objective of production	H. quality timber for housing	H. quality log for spec. posts	H. quality timber for housing	Ordinary timber for housing		Ship build. & ordinary timber
Species	SUGI	SUGI	SUGI	SUGI	HINOKI	SUGI
Number of trees planted per ha	6,000 ~ 10,000	5,000 ~ 8,000	4,000 ~ 6,000	3,000 ~ 4,000	3,000 ~ 5,000	1,500 ~ 2,500
Number of trees per ha at final cutting	800 ~ 900	2,500 ~ 2,800	1,600 ~ 2,000	700 ~ 800	800 ~ 900	400 ~ 600
Rotation (yrs)	60~80	25~35	35~45	40~50	50~55	40~50
Thinning ①	18 yrs	15 yrs	16 yrs	20 yrs		30 yrs
Thinning ②	4~8 times	4 times	2~3 times	2~3 times		2 times
Thinning ③	5~10 yrs	4 yrs	10 yrs	10 yrs		10 yrs
Pruning	2 or 4 times	6 times	2 or 4 times	None or Twice	2 or 4 times	None

3 items in thinning: ① years after planting to start thinning
② times of thinning
③ interval between thinnings

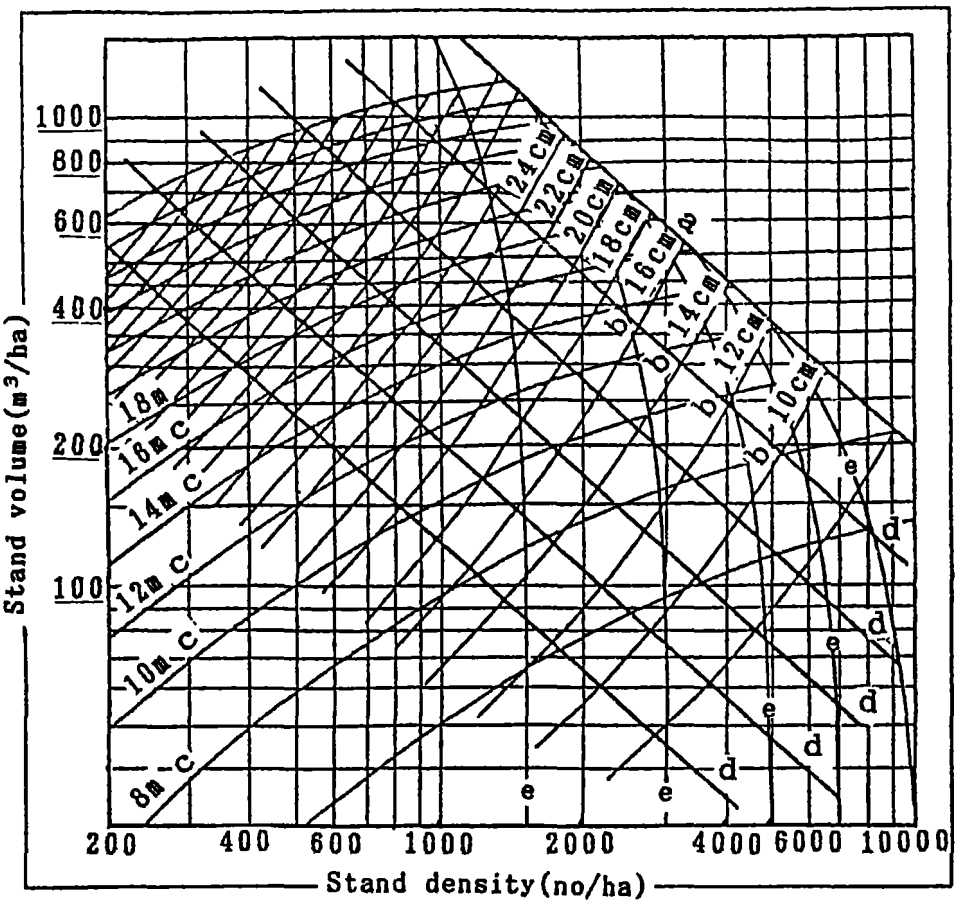


Fig. 6 An example of stand density control chart for SUGI (after Forestry Technology in Japan, 1981)

Equivalent mean height line(c): Each line running from the lower left to the upper right expresses the relationship between stand density and stem volume per hectare according to the mean height of the dominant trees.

Equivalent mean diameter line(b): Each line running from the upper right (full-density curve) to the lower left portion of the chart expresses the mean diameter at breast height in connection with mean height and stand density.

Yield index line(d): Each line running parallel to the full-density curve expresses the yield index(Ry), which corresponds to the ratio of the stem volume of a stand at a given density to that of one at full-density where the mean tree heights of the respective stands are identical.

Full-density line(a): The oblique line at the upper right.

Self-thinning line(e): Lines running from the base upward with a slight incurvation to their left.

By using this chart, various patterns of tending systems may be designed to meet the expected size and volume of products. Here an example of tending system is shown in Fig. 7.

The stand is planted by the density of 3,000 seedlings/ha, which will be decreased to 2,700 trees/ha because of mortality of 10 % by the time when the stand is established. Then the density is further decreased to 2,450 trees/ha because of natural thinning by the time when the mean height of trees reaches 10 m (point A in Fig. 7). At this time, the stand volume could be about 225 m^3/ha and the average diameter at breast height be 14.7 cm.

If 30 % (750 trees/ha) of trees are thinned away, the remaining is about 1,700 trees/ha. Assuming that ordinary thinning removes smaller trees, then the mean height of predominating trees will not change, unless the ratio of thinning exceeds 40 % in tree number. Therefore, point B can be located on the same 10 m equivalent mean height curve even after the first thinning and the then stand volume decreases by 25 m^3/ha.

The second thinning is done when mean tree height reaches 12 m (point C). In the same way as in the first thinning, the condition of stand moves to point D after thinning is done. The third thinning is done when mean tree height reaches 14 m (point E). Again the condition of stand moves to point F after the thinning.

Final felling is done when mean tree height reaches 16 m. Then the trees to be cut are 840 per ha. Their average diameter at breast height would be 26 cm and the stand volume be 360 m^3/ha.

All the figures are shown in Table 6. As seen in this table, the total volume including three thinnings will be 465 m^3/ha.

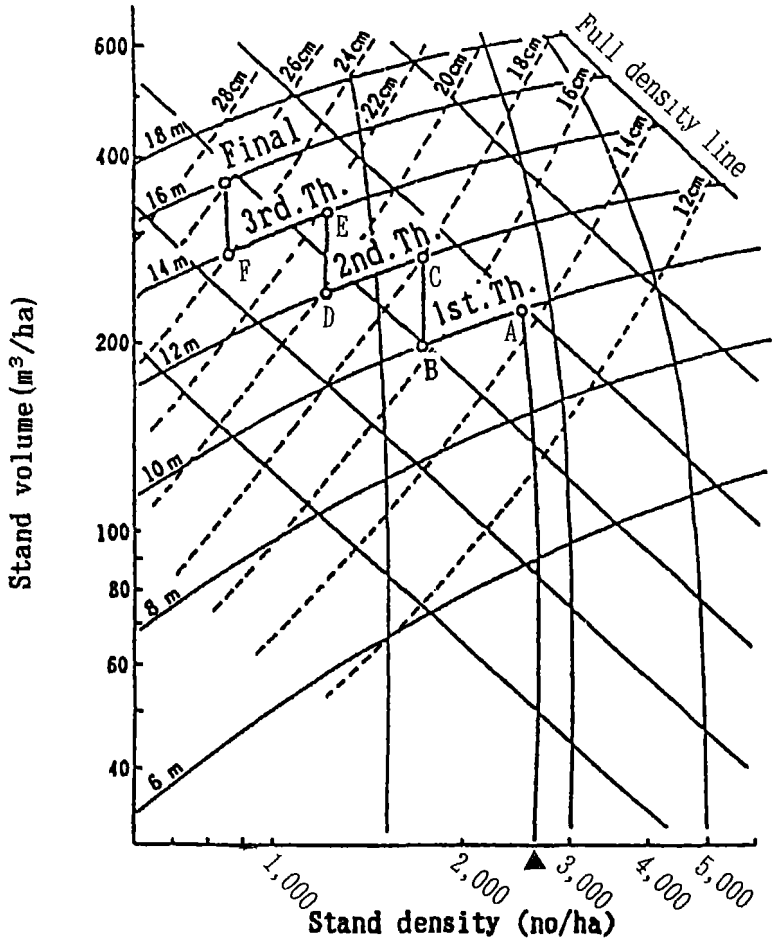


Fig. 7 An example of stand density control (thinning schedule) shown in the chart of Fig. 6

Table 6 Volume in three thinnings and final yield resulting from the stand density control pattern as shown in Fig. 7 (Ando 1982)

Felling	H (m)	before thinning density (no/ha)	dbh (cm)	volume (m^3/ha)	thinned trees (no/ha)	volume (m^3/ha)	after thinning density (no/ha)	volume (m^3/ha)
1st. Th.	10	2,450	14.7	225	750	25	1,700	200
2nd. Th.	12	1,700	18.0	275	500	35	1,200	240
3rd. Th.	14	1,200	21.8	325	360	45	840	280
Final	16	840	26.0	360	(1,610)	(105)		

Notes. Th.:thinning. In each thinning, 30 % of existing trees is cut.; Final:final cutting; H:height of upper layer (dominant trees); dbh:diameter at breast height; volume:stand volume

(2)Pruning

The objectives of pruning are described as follows: ①to produce the timber with less knots, ②to control tree growth, ③to control the characteristics of stem, ④to control the light condition under the canopy, ⑤to protect trees from biological agents, ⑥to improve the operational efficiency in the stand, and ⑦others: ex. to reduce evapotranspiration of trees, to reduce the fire hazard at early stage of the stand established, etc.

In Japan, the so-called "high pruning" for the first objective is especially important. Because less-knots or knot-free square posts are preferred in Japanese housing. To produce such posts, lower stems used for timber have to be pruned before their diameter reaches a certain size.

The relationship among the diameter to be pruned(d_1), the size of post(d_2) and the diameter to be cut(d_3) is expressed by:

$$d_1 < d_2 - 2\Delta d; \quad d_3 > d_2 \times \sqrt{2}$$

where Δd is the thickness to be required for covering the basal part left of branch pruned.

By pruning living branches, tree growth, especially the growth of stem, can be reduced. The stem becomes less taper. Removing the dead branches on the lower stem is an effective way to control a longhorn beetle, which seriously attacks Sugi. It is important from the viewpoint of preventing forest from fire to remove dead branches on the lower stem, but for this purpose pruned branches must be moved out from the forest floor.

§4 History of re-afforestation in Japan

Re-afforestation was first started around 1400, in the middle of the MUROMACHI ERA (1392～1573).

Since about 1700, in the middle of the EDO ERA(1603～1867), some lords had conducted the activities in re-afforestation for improving their financial situation and also for stabilizing the life of the public in their feuds.

Sometime in the MEIJI ERA(1867～1912), modern type of re-afforestation was started by large financial groups and also by large forest owners. On the other hand, frequent occurrence of flooding let the government start re-afforestation onto public forest lands from the viewpoint of soil and water conservation.

In 1907 and '08, a regulation about subsidies for re-afforestation was established to encourage the planting of [Cinnamomum camphora, Zelkova serrata, and Rhus verniciflua], and of [Castanea crenata, Populus sieboldii, Juglans sieboldiana, Magnolia obovata, etc.], respectively.

In 1910, another regulation about subsidies was established to encourage the re-afforestation onto public forest lands.

In 1920, a law about governmental re-afforestation on public forest land was established.

In 1927, re-afforestation on unstocked lands of private forests and of shrine & temple forests was added to re-afforestation subsidy in order to encourage water conservation.

In 1929, ordinary re-afforestation for private forest lands was added to the subsidy system.

In 1932, the subsidy system was applied for planting Rhus verniciflua, Paulownia tomentosa, and Rhus succedanea to improve the life of village farmers.

In 1939, the subsidy system was applied for seed collection from mother trees and seed stands registered.

After the World War II:

In 1950, the special order was enforced to accelerate re-afforestation onto the designated areas to be covered with forests.

In 1951, the forest law was revised substantially, aiming at sustained culture of forest resources and improvement of forest productivity. This is the existing forest law.

In 1956, the Forest Development Corporation (semi-governmental) was established to take over the activities for government re-afforestation on public forest lands, including the establishment of forests for water conservation, etc.

In 1957, the enlarged re-afforestation program, inc. species conversion, was started.

The 1st phase was: from 1958 to 1962.
The 2nd phase was: from 1963 to 1980 for private forests and
from 1963 to 1995 for national forests.

Target area was: 8 million ha for private forests.
3 million ha for national forests.

In 1958, the proceeds-sharing forest special measure law was enforced to promote re-afforestation (planting) by proceeds-sharing system.

In 1983, the law was revised to include the tending for growing stands with the participation of the public. (Incidentally, since 1976, similar system for tending had been practiced in the public plantations.)

In 1980 to '81, the forests in the region facing the Japan sea were damaged seriously by heavy snow. In the fiscal year of 1981, therefore, the system for restoring damaged forestlands was established. This is the system to provide with "subsidy" for restoration. This system can be also applicable to other calamities such as typhoon, forest fire, eruption, etc.

In 1973, the new forest management system was enforced for further re-afforestation. Major points of the management were as follows:

A. Clear-cutting system

A-1. Planting after clear-cutting

Areas for clear-cutting should be scattered as much as possible.

Protective belts should be left along ridges, valleys, etc.

Size of each clear-cut area:

Less than 20 ha for ordinary forests

Less than 5 ha for protection forests

Location of clear-cut areas

Ordinary forests: adjacent areas should have been planted before clear-cutting.

Protection forests: adjacent stands should have been closed before clear-cutting.

Wildlings, regenerated naturally, of useful species should be left.

A-2. Natural regeneration after clear-cutting

Possible species: Pinus densiflora, Fagus crenata
Abies veitchii, Abies homolepis
Abies sachalinensis

Unfavorable sites: Floor vegetation, esp. dominated with Sasa, is luxuriant.

Size of each clear-cut area:

Ordinary forests: less than 10 ha

A-3. Coppicing after clear-cutting

Size of each clear-cut area: same as the case for planting

B. Shelterwood system

Possible species: Abies sachalinensis, Picea jezoensis
Thujopsis dolabrata

C. Selective cutting system

The system to induce the multi-storied type of stand

In 1986, the new policy for natural forest management and multi-storied forest management was enforced to maintain and improve the functions of forests. The former is the regeneration to utilize as much naturally regenerated plants as possible. The latter is the regeneration to form multi-storied stands mainly by planting seedlings raised in the nursery after selective cutting.

Table 7 Comparison among different proceeds-sharing systems

	Private forests	National forests	For.Develop.Corp.
Kind of Contract	①Planting ②Tending Others	①Planting ②Tending	Planting only
Objective	To develop forestry & To maintain & improve various benefits	①To stabilize economic basis of rural people ②To improve resources with the participation of the public	For water conservation
Rate* of sharing	Approximate conditions ① A : B = 6 : 4 ② A : B = 5 : 5	① a. The public A : B = 3 : 7 b. Corp., etc. A : B = 2 : 8 ② A : B = 3 : 7	[Municipal] 3* 2* / [Others] 3* 2* A 5 4 6 5 B 1 1 C 4 4 5 5
	A: Those who implement B: Land owners	A: Government B: Those who implement or those who share costs	A: Land owners B: Those who implement C: FDC 3*: in case of 3 parties 2*: in case of 2 parties

* : Rates are almost fixed to the figures indicated above, but can be modified considering the estimated costs, the amount to shoulder, the rental fee of surrounding lands, etc.

App. 1 Chronological events related to silviculture in Japan

1500± YOSHINO forestry started.

1868 [MEIJI era started.]
German forestry was introduced around 1880.

1882 Tokyo Forestry School was founded, which was incorporated into Tokyo University in 1890.

1897 "Forest Law" was established.
(Amended in 1907, 1939, and 1951.)

1899 Special management project for national forests started.

1905 Govt. For. Expt. Sta. was established in Tokyo, the predecessor of which had been established in 1878.

1920 Natural regeneration systems were introduced.

1934 Distribution areas for seeds and seedlings were established.

1939 "Forestry Seed and Seedling Law" was established, into which the revised distribution areas were incorporated.
(Amended in 1951.)

1947 Soil survey started for national forests.

1957 Enlarged re-afforestation program, inc. species conversion.

1st phase: 1958～1962
2nd phase: 1963～1980(17 years) for private forests
1963～1995(32 years) for national forests
Target area: 8 million ha for private forests
3 million ha for national forests

Forest tree improvement program started.

1973 New forest management

1978 Govt. For. Expt. Sta. was renamed as Forestry & Forest Products Research Institute(FFPRI), which moved to Tsukuba Science City.

1986 Natural forest management & multi-storied forest management

1988 FFPRI was reorganized.

App. 2

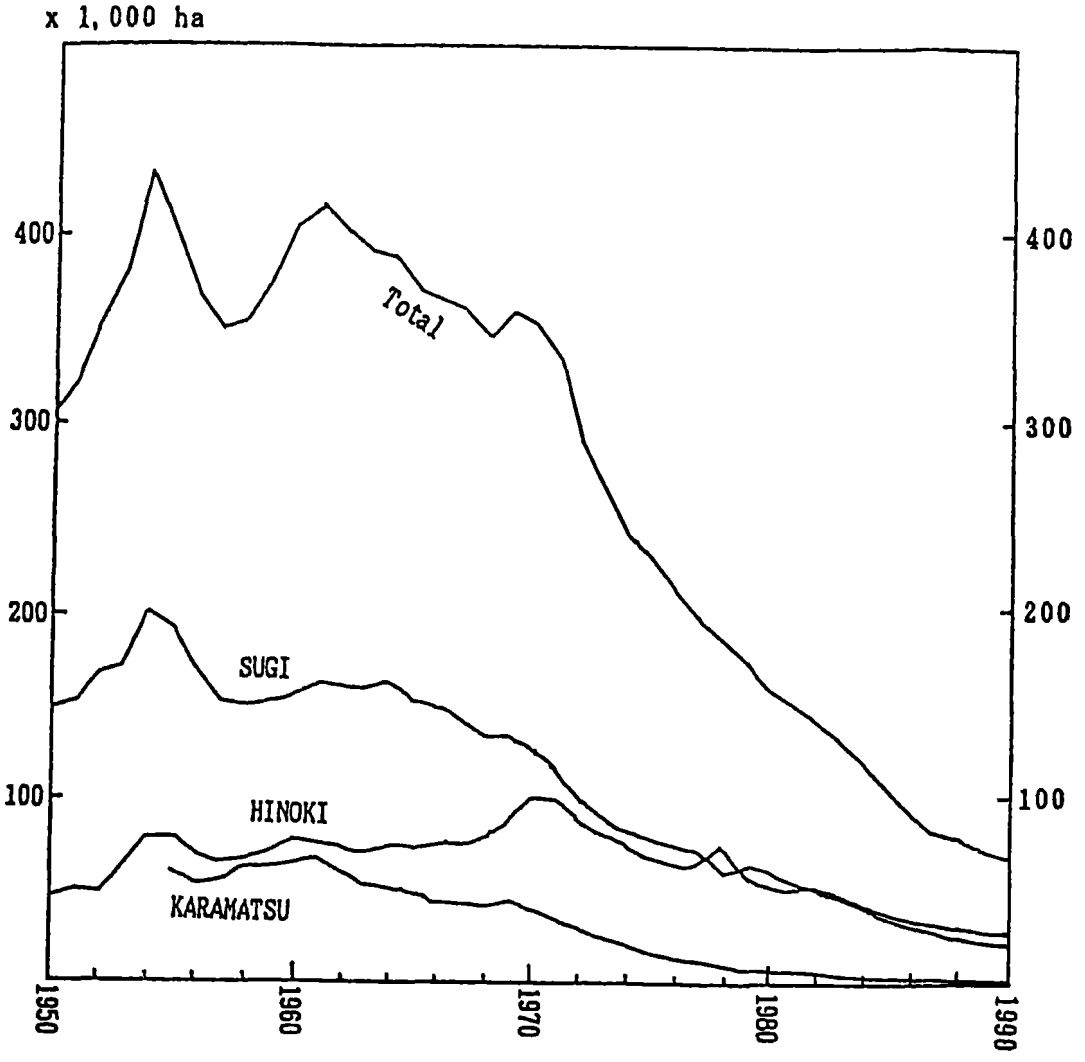


Fig. 8 Annual increase of plantation areas

Plantations as of 1990.3

Total area of plantations: 10,327,000 ha(41 % of forest land)

Species	Area	Ownership	Area
Cryptomeria japonica	44 %	National forests	24 %
Chamaecyparis obtusa	24 %	Others	76 %
Pinus species	10 %	(Public forests	11 %)
Larix leptolepis	10 %	(Private forests	65 %)
Other conifers	10 %		
Broad-leaved species	2 %		