II FORESTS OF DIFFERENT TEMPERATURE ENVIRONMENTS

1 How forests change from the tropical to the subarctic zone

Forests occupy only about a third of the land area of the earth. But their share of the total plant production on land is 64%. Forests are very efficient production factories of greenery on earth. They not only produce wood but also provide habitats for flora and fauna. Besides, they have huge pools of organic carbon on the ground surface or in the soil, such as the decomposing litter layer on the forest floor. Moreover, forests act as automatic regulators of carbon dioxide concentration [in the atmosphere], contribute to the circulation of water and play a crucial role in maintaining the global environment.

(1) Different temperature zones of the earth

Only about 35% of the land area of the earth is in the frost-free zone (A in Fig 56), where the temperature never goes below 0°C. The remaining 65% of the area is a zone that experiences freezing stress. Within this zone, about 48% of the area has a [mean] minimum annual temperature of $-10^\circ$C or lower (Fig 56, C). About 25% of this area has a [mean] minimum annual temperature of less than $-40^\circ$C (Fig 56, D).
Fig 56 Various temperature zones of the earth. A: Frost-free zone, B: Area where the temperature rarely drops below −10°C, C: Area where the mean annual minimum temperature is −10 to −40°C, D: Area where the mean annual minimum temperature is less than −40°C, E: Polar glacier area. The solid line represents a mean annual minimum temperature of −30°C.


Key In the Fig:
Arctic zone
Equator
Antarctica
(2) Changes in forests, from the tropical to the subarctic, caused by changes in the environment

As we move from the equator to the poles, the incident solar energy decreases, the temperature gets lower, the variation in daylength during the year increases, the growth period available to plants decreases and the precipitation decreases. These changes are accompanied by decreases in the height of forest trees, the number of forest canopy layers, plant biomass, i.e., the total weight of plants per unit land area, and the number of tree species, and also by impoverishment of the soil. In this manner, the environment gradually changes from a tropical low stress high energy environment to the high stress low energy environment of the subarctic regions. Forests, where tall trees are the main life form, cope with this change of climate from tropical to subarctic by changing their leaf habit the tree type, while maintaining the necessary amount of [photosynthetic] production to support the tall tree life form. But they change their leaf habit (evergreen or deciduous) and tree type (broad-leaved or needle-leaved). In other words, they change from evergreen broad-leaved trees to deciduous broad-leaved trees and then to evergreen or deciduous needle-leaved trees. Finally, when not enough production to support the tall tree life form is possible, i.e., from the tree line onwards, the vegetation changes to shrubs and then grasses.

One measure used to explain the relationship between climate and the forest belt is the warmth index (WI) suggested by Kira in 1946. This is the accumulated temperature that takes into account the length of the summer growth period and the temperature. To be more specific, 5°C is taken as the minimum temperature needed for plant growth and all the monthly mean temperatures in excess of 5°C are added up for the 12 months of the year. Fig 57 shows the values of WI. According to this concept, a WI of up to 15 fits the arctic tundra. From there, up to WI 45 corresponds to the subarctic forests, 45 to 85 to the cold temperate forests, 85 to 180 to the warm temperate forests, 180 to 240 to the subtropical forests, and more than 240 to tropical forests. In this Fig, the range of temperatures in a year in cities located in the different forest zones is given as the difference between the [mean] temperature of the warmest and the coldest month. We can see from this Fig that the temperature range during the year sharply increases as we move towards colder regions, from tropical forests (the temperature ranges from 24 to
to the warm temperate evergreen forests, cold temperate deciduous forests, and subarctic needle-leaved forests. The sharply decreased mean temperature in the winter contributes to the large temperature range in the cold temperate and subarctic regions, more than the change in the high mean temperature in the summer. To be able to survive the long severe winters, plants living in the cold temperate and the subarctic zones\textsuperscript{106} have a far higher frost hardiness compared to the evergreen trees in the warm temperate zone. Plants cannot live in those regions unless they are highly frost hardy. Fig 58 shows the number of pine species and their frost hardiness distributed in climatic zones having different WI\textsuperscript{76}. There are an overwhelmingly large number of the two-needle pine species in the warm temperate zone. Far fewer species are found in the subarctic and subalpine zones where the pines have the very high level of frost hardiness of about $-60$ to $-80^\circ C$. 
Fig 57  Monthly mean temperature range and the warmth index at locations in different forest zones.

FT: Freezing tolerance, *: Southern hemisphere
Abscissa (top): Warmth index
Ordinate: Range of monthly mean temperature in a year (°C)
In the Fig, upper level, left to right: Arctic tundra; Subarctic needle-leaved forest; Cold temperate deciduous forest; Warm temperate evergreen forest; Subtropical; Tropical
In the Fig, at the bottom of the bars, from left to right:
Syowa base; Barrow (Alaska)
Yakutsk; Fairbanks (Alaska) ← FT: -70° C or lower
Harbin; Montreal; Moscow ← FT: -30° C or lower; Chicago; Sapporo
Tokyo; Pusan; Arco (Italy); Katmandu; Rome; Kunming; Cape town; Christchurch;
Hobart (Tasmania); Punta Arenas (Chile)
Naha
Kuala Lumpur

Fig 58 The number of pine species and their frost hardiness in climatic zones with different warmth index values*76.

Key:
Abscissa: Warmth index
Ordinate(left): Number of species
Ordinate(Right): Frost hardiness (°C)
Inside the Fig at top, left to right:
i  Tropical forests

The area under tropical forests is only about 16% of the land area of the earth. But it is home to more than half of the plant species known to exist on earth. The tropical rain forests have a very stable physical environment. This is the world of evergreen broad-leaved trees. A stable ecosystem has existed here for ages. The tropical rain forests have high temperature and high humidity with little seasonal change. Plants have high productivity and many species coexist in a multi-layered canopy. In such forests, the density of individual tree species is very low. So, the great majority of the flowers are pollinated by animals, like insects and birds. A large variety of living things, including these animals, coexist with very complex interdependence, creating stable ecosystems (see II-5). However, in tropical forests, the leaf litter gets decomposed quickly and not much of it accumulates as a layer on the forest floor. Because of this, the soil is poor in inorganic nutrients. It was recently found that many tall trees of the family Dipterocarpaceae obtain inorganic nutrients like nitrogen and phosphorus through symbiotic relationships of their roots with ectomycorrhizae.

ii  Temperate forests

In the middle to high latitude areas of the Northern Hemisphere, there were major disturbances and destruction of the flora and ecosystems because of big changes in the climate that occurred from the second half of the Tertiary to the Ice Age. Most broad-leaved tree species, which are woody angiosperms, grow in the tropical zone. Only a few groups of tree species spread to the temperate zone after the Ice Age as evergreen or deciduous broad-leaved trees. Unlike the trees in tropical rain forests and subarctic forests, which can get established only in very specific thermal environments, the deciduous trees of the cold temperate forests have adapted to the wide range of temperature conditions of the mid latitudes, where human
habitation is concentrated. Cold temperate deciduous forests consist of groups of tree species belonging to three life forms. The first is that of pioneer species like white birch, *Dakekaba* (*Betula ermani*) and alder (*Alnus japonica*), which depend on wind for the dispersion of their seeds and pollen and colonize newly opened up bare land and recently disturbed areas in no time at all. The second is of trees with insect pollinated flowers like *Kaede* (*Acer* sp.), *Shinanoki* (*Tilia japonica*) and *Mokuren* (*Magnolia liliflora*), which are species of stable forests, and the third is that of tree species that are intermediate between the other two. In the cold temperate deciduous forests of Hokkaido, the ratio of insect pollinated tree species and wind pollinated ones is about 50:50. Tropical forests have very diverse tree species. But around any one tree you would hardly find another tree of the same species. On the other hand, in the natural forests of the temperate zone and further north, trees of the same species gather together, forming stands. Besides this, cold temperate deciduous forests have a thick layer of decomposing litter and a high soil temperature in the summer. This speeds up the decomposition of organic matter, which increases soil fertility and allows efficient absorption of inorganic nutrients by the roots.

### iii Subarctic forests

As we move from the temperate to the subarctic zone, the effect of the arctic air masses of the winter becomes stronger. The winter temperature decreases sharply and the seasonal variation of temperature increases. The winter dryness also becomes more severe. Besides, the soil freezes in the winter. The high latitude subarctic areas have several months of sunless dark season in the winter. The environment becomes increasingly unfavorable for plant growth as we move to the subarctic zone. This limits the number of tree species that can live in such areas. So, stands of a few tree species occupy large areas. Most of the trees of the subarctic zone are wind pollinated, whether they are needle-leaved or deciduous broad-leaved. For instance, in interior Alaska, two types of evergreen needle-leaved trees are dominant. A few white birch and poplar trees, both of which are broad-leaved, are intermixed here and there, to form the subarctic forests. In eastern Siberia, which has the most severe climate on earth, Dahurian larch dominates huge stands of a small number of tree species spread over vast expanses of permafrost area. This needle-leaved tree is a pioneer species with high capacity for individual tree regeneration and natural renewal of the forest. It gets adapted
to the worst geographical conditions and rapidly colonizes an area even after environmental upheavals like forest fires.

In these needle-leaved forests of subarctic and subalpine zones, a thick layer of decomposing litter covers the soil. But the decomposition occurs very slowly because of the low soil temperature and even if the litter is converted to the inorganic form, the nutrients are absorbed by the accumulated decomposing litter layer and do not get leached out easily by precipitation. Therefore, most of the needle-leaved trees have symbiotic ectomycorrhizae on their feeder roots. These mycorrhizae spread their hyphae into the decomposing litter layer and supply to the roots inorganic nutrients, which otherwise the roots cannot absorb, in a form that can be used by the plants.\textsuperscript{77, 126}

iv  The reason why needle-leaved trees can live on poor soils

The severely cold and dry subarctic and subalpine zones of the Northern Hemisphere are the world of needle-leaved trees of the pine family. About 760 species of needle-leaved trees, which are gymnosperms, are known to exist on earth. This is a very small number (about 3.7\%) compared to angiosperms (240,000 species). But in the subarctic and subalpine forests of the northern hemisphere, the small number of needle-leaved tree species form almost pure stands over vast areas, and in the number of standing trees also they far exceed the deciduous broad-leaved trees, which are angiosperms. In the Northern Hemisphere, about 15 species of needle-leaved trees are found in the subarctic zone and about 40 are found in the subalpine zone. But these are only about 2\% and 5\% respectively of the total number of needle-leaved tree species (760).

In general, needle-leaved trees can adapt better than broad-leaved trees to unfavorable conditions like infertile land, special soil types, arid land, etc. The evergreen and deciduous broad-leaved trees are more demanding. If the conditions at the site are good, they grow very well and overtake the needle-leaved trees. But they cannot grow when the conditions are poor, and are displaced by needle-leaved trees. For example, we mostly see pines on the ridges of mountains and cliffs of Honshu. This is not because pines like such locations but because these areas are infertile areas and prone to droughts and therefore, broad-leaved trees cannot grow well there, and the pines can thrive. Ectomycorrhizae live
symbiotically on the root hairs of pines and provide to the pines the inorganic nutrients and water that they absorb through their hyphae that spread through the infertile soil. In Honshu, when a warm temperate broad-leaved forest (laurel forest) is deforested randomly and the land becomes barren, Akamatsu (Pinus densiflora) appears and gets established, covering the mountain. Even in such Akamatsu covered mountains, after many years, when the fallen leaves accumulate and the land becomes fertile, the original broad-leaved tree flora starts reentering the forest.

Leaves of needle-leaved trees have a well-developed structure and functions adapted to droughts in summer and winter, strong winds and snow cover. In short, their leaves are thick, with small surface area and their surface cuticular layer secretes large amounts of wax making itself thick. The stomata are located at the bottom of depressions on the leaf surface and their surface is covered with wax, which prevents rapid transpiration from the leaves. This wax reduces the rate of photosynthesis to about 2/3rds and the transpiration rate to about 1/3rd.

Translator’s notes:

*Words added by the translator for clarity are given in [square brackets]*
2 Forests of the extremely cold region of Siberia

Two types of evergreen needle-leaved trees are dominant in the subarctic forests in the permafrost areas of Alaska and Canada. A few deciduous broad-leaved trees like white birch and two types of poplar, are interspersed with the evergreen needle-leaved trees, creating a succession in the forest (shinrin no seni o keisei). Similar subarctic evergreen needle-leaved tree forests exist in Western Siberia where there is no permafrost. But in the permafrost zone of Eastern Siberia, which has a dry continental climate that is the coldest on earth, the deciduous Dahurian larch (Larix dahurica ssp. cajanderi), which can live in a natural environment prone to disturbances, dominates over a large area forming a highly dense forest. In such forests, almost no evergreen needle-leaved tree species other than European red pine (Pinus sylvestris) grows. Also, white birch is the only deciduous tall tree that occurs intermixed with these needle-leaved trees. The subarctic forests of Eastern Siberia that exist in an extreme natural environment and special topographical conditions, maintain a balance with the environment, with only a few tree species and low ecological diversity. This is in stark contrast to tropical rain forests where numerous tree species coexist under a stable tropical environment. If Eastern Siberia gets warmer and its soil gets enriched in the future, increasing the diversity of tree species, the current ecosystem would probably collapse.

Forests of Eastern Siberia, where Dahurian larch dominates, were formed during the postglacial period (11,000 years ago) and are relatively new. At that time, rivers were often flooded and soil and mud got accumulated on the permafrost formed during the Ice Age. Forest trees that had been forced southwards during the last Ice Age (70,000 to 11,000 years ago) moved north again forming new forests. In this region, where a dry climate prevails throughout the year, damage by forest fires is particularly frequent. Dahurian larch and birch are both shade intolerant pioneer species and have a particularly high capacity for recovery and renewal after disturbances like forest fires.

When I surveyed the permafrost regions of Alaska and Eastern Siberia, I noticed that in the interior parts of Eastern Siberia, particularly Yakutsk and the parts east of it, had a larger temperature variation during the year than Alaska or Canada, and that its climate was dry and continental. This can be understood from
the fact that the larch of Eastern Siberia has a bark that is more than twice as thick as in needle-leaved trees of Alaska, to prevent dehydration, and that the soil pH in Eastern Siberia is abnormally high (8.9) as in deserts and arid areas. Compared to interior Eastern Siberia, forests of the permafrost zones in interior Alaska and Canada, where evergreen needle-leaved trees are dominant, are relatively warmer and more humid and may be said to have a coastal climate.

(1) The extreme cold of Eastern Siberia

During the long winters, Eastern Siberia comes under the influence of dry arctic air masses. Because of this, there is not much snow cover and dry weather prevails. The average monthly temperature during December to February is about –40°C in Yakutsk (N Latitude 62°) and mean the annual temperature is about –10°C, about the same as at the Syowa Base in Antarctica. The mean of the annual minimum temperature of the past 21 years is about –64°C, which makes Yakutsk the coldest place on earth. Its winter temperature is about 20°C lower compared to Western Siberia and interior Alaska, and the climate is very dry. Besides, most of Eastern Siberia has permafrost. In Yakutsk, the permafrost layer is almost 250m deep. This is because Eastern Siberia was not covered by the continental ice sheet during the Ice Age (about 1.6 million years ago), except in the mountainous regions. So, the land was cooled and the permafrost was created. In the summer, from July to August, the temperature is fairly high in Yakutsk. The mean temperature in July is 19.5°C, about the same as in Sapporo. The annual precipitation is 213mm, comparable to that in the steppes of Central Asia. Almost half of the precipitation falls during the growth period, i.e., July-August. Only about 35mm falls during the winter. The snow cover is about 30cm. It is difficult for us to imagine, from such data, the severity of the cold and dryness. I shall recall here a passage from the book “Oroshiya Kokusui Mutan” by Yasushi Inoue that describes the scary cold weather that the few Japanese seamen had to face when they reached Yakutsk after their ship drifted over, more than 200 years ago. “It was the 9th day of November when 6 Japanese, including Koudayuu (the protagonist), who had set out from the Okhotsk region and reached Yakutsk, a settlement on the banks of river Lena, after passing through endless primeval forests, sometimes on horseback and sometimes on foot. The coldest season had already set in. Koudayuu and his companions realized, for the first time in their lives, that there were different degrees of cold. There were quite a few travelers in the town. All
were wearing many layers of clothes made of animal hide, and fir caps. They also had large cylindrical gloves called *Mufta (Mufuta?)*, made of bear skin and lined with fox fur inside. They walked around placing their gloved hands on their foreheads, exposing their eyes only, as the nose and parts below it were also covered. All these travelers seemed to be accustomed to the cold of this area. Still it was not uncommon to lose an ear, the nose or a finger. Some were walking on a wooden leg with the help of a stick. Some others had faces that looked like one cheek had been scooped out. Such disfigurement from frostbite was seen both among the old and the children, and both men and women. Koudayuu, with firsthand experience of the incredible cold of the area, strictly prohibited his 5 men from going outdoors without a very good reason”.

The winter conditions in Yakutsk 200 years ago would not have been very different from what they are today.

Permafrost is formed by a gradual freezing of the soil from the top down. Therefore, it would appear that the maximum depth of permafrost and the time needed for freezing to reach that depth would be determined by the surface temperature and the thermal conductivity of the frozen soil. According to the calculations of Fukuda”26 based on simple assumptions, if a ground surface temperature corresponding to a mean annual air temperature of -3ºC were maintained continuously for 1000 to 20,000 years, the permafrost would reach a depth of 200 m. The reason for the wide variation in time required for this is the difference in thermal conductivity of soils. Fig 59 shows a laboratory of the Permafrost Research Institute of Yakutsk, made by scrapping out frozen soil to a depth of about 10-15m.
First, I would like to explain how Dahurian larch forests were formed. In Eastern Siberia, from the middle of the Ice Age of about 0.2 million years ago, the area under larches of Siberian origin and evergreen needle-leaved trees shrunk and these species were forced westwards. It is believed that as the cold and dryness became more intense and the permafrost region expanded, from the second half this Ice Age to the last Ice Age, the Dahurian larch, suited for such extreme weather, evolved and expanded its distribution to Eastern Siberia.

The Yakutsk region is dry throughout the year. The annual precipitation is about 200mm, something like a day’s downpour in Japan in the summer. The roads are dry and the soil is ash-like up to several cm from the surface. Normally, only
grass can grow in such dry areas. Conditions are not suited for the establishment of forests. In spite of this, the taiga, which are Dahurian larch-dominated forests, exist in Eastern Siberia over wide areas spanning 1000 to 2000 km in the north-south direction. The secret lies in the permafrost. If there were no permafrost, the meager rain water and the snowmelt water of spring would have been absorbed deep into the soil in no time, leaving the surface absolutely dry and the area would have become a steppe or a desert. The frozen soil prevents loss of water by seepage. Besides, its loss by evaporation is also prevented in the forests, unlike on bare land. So, the rainwater and snowmelt water are stored in the active layer (thawed layer) of 60-80cm from the surface, which gets thawed in the summer and remains frozen in the winter. The water in this active layer is a reservoir for the Dahurian larch and other flora and the fauna living on the ground surface and underground. In a sense, the permafrost below the active layer is a dead world, whereas the active layer that melts in summer is the source of life and has an abundance of natural blessings. Also, the forest prevents the active layer from becoming abnormally deep and the settling of the ground that occurs when the large underground ice wedges melt (Fig 63). The forests and permafrost of Eastern Siberia have this type of interdependence. It is however, feared that this delicate balance could be disturbed by global warming, forest fires, large-scale felling of forest trees, etc.

(3) Survey of a forest near Lake Saldaha

On August 12, 1972, our survey team reached the shores of lake Saldaha (Suldaha), which is about 350km northeast of Yakutsk. This lake, which is about 4km in diameter, is located at a hilly site between the rivers Lena and Aldan. The lakeshore cliff edge is about 20m above the water level. A forest is established on these cliffs. The lake is about 6m deep. My first impression on entering this pure Dahurian larch forest (Fig 60) on the lakeshore, with its 10m tall trees, was very different from what I had imagined. I had an image of Siberian taiga being a dark dense forest with very tall trees. Although it was mid-August, the forest was bright, like a forest with fresh green spring growth in Hokkaido. There were no mosquitoes or horseflies, perhaps because all insects had already entered diapause. The ground surface had a 5-10cm thick litter layer of fallen larch leaves. Some cowberries, bog bilberries, arctic creeper willows, mosses and lichens covered the surface of the litter layer. A few Siberian irises could also be seen there. To determine the frost hardiness of plant roots near the ground surface, we brought
some of the irises to Sapporo and measured their frost hardiness in winter. We found that the leaves tolerated freezing to −70°C and the roots to −35°C. This meant that the roots of these forest floor plants could survive even when the soil temperature dipped below −30°C.

At 3pm in the afternoon, when the ambient temperature in the forest was 22°C, the soil temperature measured after removing the several cm thick litter layer was 8.5°C, which was fairly cold to my touch. The soil was sandy silt and could be easily dug up with a gardening trowel. I lay down on my belly and sampled the soil from every 10cm going down, and measured the soil temperature also. At 70cm from the ground the soil temperature was 0°C and I encountered a hard frozen soil layer. This meant that the ground in this forest floor had thawed to a depth of about 70cm at the end of August. Roots of the larches were mostly located 10-30cm below the ground, where the soil temperature was a fairly low (4-7°C). The soil pH was a highly alkaline 8-9, except near the ground surface. Analysis of the soil showed that this high pH was because of large amounts of calcium carbonate present in the soil. As the region receives very little precipitation in the summer, the moisture in the soil does not move downwards. Rather, it moves in the opposite direction, i.e., from the soil to the ground surface where it evaporates. Because of this, large amounts of calcium carbonate accumulate in the middle to upper portion of the thawed active layer. These measurements had been made in mid-August, where the ambient temperature was the highest, the thawed soil layer was the deepest, and the soil was the driest, in that region.

In the second half of May, after the spring thaw, the active layer is probably still very shallow and the soil fairly moist. The roots of Dahurican larch seem to possess a special ability to live in such excessively wet and cold soils. After mid-July, the active layer becomes quite deep, transpiration from the leaves increases and the soils become dry. The Dahurican larches have already stopped growing by this time. Soon, by the end of August, the soil starts freezing again. The Dahurican larches cannot extent their tap roots down more than 50cm or so because of obstruction by the frozen soil. But the lateral roots can become as long as 10m and get entangled with other lateral roots to form a network that supports the aboveground parts of the trees.

To find out the general conditions of this Dahurican larch forest, we measured the
chest height diameter and height of the trees, and took the tree counts at two locations A and B within the forest. We also cut down a few trees to study their growth and age and to cut out discs of the trunk at different heights. At location A, 65% of the trees had a mean height of 8m and mean diameter not more than 8cm. The tree count was 7,600 per ha and the trees were 70-80 years old. At location B, 80% of the trees had a mean height of 5m and diameter not more than 4cm, showing signs of suppressed growth. The tree count was 16,000 per ha and trees were 70-80 years old. A small percentage of trees at location A were very large, with diameter 20-22 cm. It appeared that this forest was one that got renewed after a forest fire 70-80 years ago. In this forest, even trees with the best growth had a tree ring thickness of not more than 2mm, the mean being 1 mm and the minimum 0.06mm. This data suggests the impoverished condition of the environment of these Dahurican larches.

Another surprising finding in this survey was that the proportion of the bark in the cross-sectional area of the trunk was as much as 25-30%, i.e., the bark was extremely thick (Fig 61). This is far higher than the bark ratio of 12% in the needle-leaved trees of the Alaskan permafrost region. This is a sign of the remarkable adaptation of Dahurican larches to the dry climate and forest fires. As in pines of arid areas, the cones of Dahurican larches open only when exposed to high temperatures in a forest fire. Then they disperse a large number of seeds and the forest gets renewed.

I had made these measurements myself, in about 5 hours. During these hours, I got engrossed in my work, like a person uncovering treasures in a treasure trove. When I had finished the observations, two other team members, who were physicists, and the interpreter were already at a supper of fish soup, made from fish caught in the lake and prepared by one of the two Russians who had accompanied us. We chatted happily, looking at the beautiful evening sky. The authorities had unexpectedly granted permission to us to conduct the survey and collect materials. Placing rucksacks full of soil and tree trunk specimens that I had collected, near my pillow, I slept contentedly in a tent in the forest. This was to become my first and last survey of a forest in Eastern Siberia.
Fig 60 A pure Dahurian larch forest near lake Saldaha. The mean tree height is about 10m and the age of the trees about 100 years.
Fig 61 Cross-sections of Dahurican larch trunks about 1m from the ground. (The bark area ratio is about 25%)^{92}. Left: A tree of age about 70 years. Right: A tree of age about 80 years.

(4) Characteristic features of forests of Eastern Siberia

i Habitats of Dahurican larch and European red pine

The active layer is very deep in Eastern Siberia in the sandy soil along the rivers and half way up the slopes. Pure stands of European red pine (Pinus sylvestris) can often be found in well-drained sites. Contrary to this, Dahurican larches dominate at the bottom of the slopes and on flat lands where the active layer is not very deep and the drainage is poor. These two kinds of needle-leaved trees occupy different habitats, depending on the depth of the active layer and the drainage and other soil conditions^{66}.
The Dahurican larch of Eastern Siberia has spread to all parts of that area where trees could possibly grow, whether on mountains or in valleys. Many of these forests have 10-20 m tall trees with chest height diameter 10-40 cm. They have mostly developed after forest fires (Fig 62). The trees in these forests look somewhat malnourished, reflecting the severe and unfavorable climate and soil conditions. When we remember the adverse conditions of Eastern Siberia, such as the complete freezing of the trunks and roots and the inability of roots to absorb water during the 7 months from October through April, the extreme cold of the winter season, the generally dry climate throughout the year, the excessively wet and cold soil during the growth period, and the shortness of the growth period, we come to believe that no trees other than Dahurican larch could have become the dominant species of these forests.

Around the Da Hinggang mountains of inner Mongolia, the Dahurican larch can surpass other species when the soil is excessively moist and cold. But it cannot compete with white birch in well-drained fertile soils. For this reason, these larches are often seen on the northern slopes or at the bottom of southern slopes where the active layer is shallow and the soil temperature is low. Contrary to this, white birch is distributed half way up the south-facing slopes where the active layer is deep and the soil is well-drained. The Siberian larch \( (Larix sibirica) \) widely distributed in Western Siberia prefers warmer and better drained land than Dahurican larch. Thus, these two larch species occupy different habitats, depending on the geoclimatic conditions. The Dahurican larch, white birch and European red pine of eastern Siberia are all shade intolerant tree species. They have a high capacity for natural renewal after forest fires (Fig 62).
(ii) Risks faced by overwintering evergreen needle-leaved trees

Spring is the riskiest time for overwintering evergreen needle-leaved trees in the subarctic zone. As spring approaches, the sunlight becomes stronger and the daylength increases. This makes the leaf temperature fairly high. But roots are still frozen and no water is supplied to branches and leaves. At this stage, the needle-leaved trees are forced to make a choice. They could keep the stomata on the leaves closed to prevent moisture loss and not carry out photosynthesis, or open the stomata and photosynthesize, risking moisture loss. Generally, pines keep their stomata closed, while spruces open them and photosynthesize. Larches, which are deciduous trees, completely avoid this serious dilemma. Larches have other
advantages also. Unlike the evergreen needle-leaved trees, they do not have leaves at the time of the spring thaw and therefore, the forest floor is exposed to more sunlight and the snow and frozen soil thaw faster.

(5) **Alases in forests**

A number of dish-shaped depressions, swamps and lakes of various sizes are scattered in forests on riverside hills along river Lena to the east of the city of Yakutsk. These are called *Alases* in the Yakut language. In the permafrost region of Eastern Siberia covered with forests and tundra, huge, almost 10m deep, ice wedges in fact exist hidden underground. The locals call them *Edoma* (I in Fig 63). These *Edomas* are frequently found near the estuaries along the coast of the Arctic Sea and at riverside ridges between the rivers Lena and Aldan. Quite a few are found in the forest areas near Lake *Saldaha*. The *Alases* of this region are peculiar topographical features formed by the huge underground ice wedges melting when the ground surface is exposed by felling of trees or forest fire and evaporation of the melted water, which causes the ground to sink and form thermokarst depressions (Fig 64). Many of the *Alases* have water in them and the surrounding areas are used by the Yakut people as pastureland. Lake *Saldaha* was also probably formed in a similar manner, i.e., a forest fire destroying the vegetation cover, melting of the ground ice, sinking of the ground and accumulation of melt water in the depression. It has no inlet from or outlet to any river. The thawing of ground ice by the sunlight and consequent falling over of trees continues even now near the southern shore of the lake. The *Edomas* are believed to have formed within the permafrost during the Ice Age when there was little vegetation. During the post-glacial age, when the rivers flooded, soil accumulated on the *Edomas* and larch forests grew on it, it is believed[26].

Lake *Saldaha*, which is about 6m deep, freezes to a maximum of about 2.5 m from the surface in winter. The water below this ice layer remains unfrozen all year round. Some fish also live there. Since the lake is not connected to any river, these fish were probably brought in by people. Currently, the melting of the ground ice at the lakeshores and the evaporation of water from the lake surface are more or less balanced and the water level remains almost constant. In many other lakes, the evaporation exceeds the melting of ground ice and the water body shrinks every year. Perhaps Lake *Saldaha* may also one day dry up because of evaporation, it
would be covered by mud and soil and a forest would then reemerge there. Such
natural processes have been continuing on an unimaginably vast timescale.

The gigantic masses of ground ice (Edomas) contain plenty of bubbles with a lot of
methane gas trapped in them. The Edoma layer is unstable under the current
climatic conditions. Probably, with the advancement of global warming, the
Edoma layer would melt, and the collapse of the forests, destruction of roads, and
the release of methane from the Edomas would emerge as new problems. These
possibilities are now being studied in relation to global warming.

(6) Shergin’s well

Since ancient times, Yakutsk had scarcity of drinking water in the winter. About
170 years ago, an entrepreneur named Shergin started digging a well with chisels
for obtaining drinking water for the winter. After digging about 28 m in about 3
years, he found only permafrost, as hard as cement. He had the well dug to a depth
of 116 m in about 10 years. Still there was no water, only frozen soil. Shergin
was finally forced to abandon the project as he had run out of funds. A few years
after that, Mittendorf, an explorer-scientist found out about this well and
measured the soil temperature at different depths. It was -6°C at 30 m and -3C at
116 m. He then extrapolated the temperature downwards and estimated that the
lower limit of the permafrost was about 250 m below the surface. No water was
ever to be obtained from this well, but unexpectedly, this Shergin’s well provided an
opportunity for studying permafrost in Siberia. It was decided to preserve the well
under the care of the Russian Academy of Sciences. I visited the well in 1972. I
bent forward carefully and peeped into the well. It was about 1 m wide and the
frost on the walls was shining white from the light of a naked bulb (Fig 65). The
bottom was blurred in the darkness of 116 m below the ground. I heard that water
entered this remarkable well during the 1988 flooding of the Yakutsk region and
froze it shut.
Fig 63  A larch forest and ice wedges at the shore of Lake Saldaha. 

Left: A cross-sectional diagram of the lakeshore. I: Ice wedge, about 40m deep. L: Loam layer. W: lake water. The height of the cliff at the lakeshore from the water is about 20 m.

In the Fig at the bottom: Frozen soil.

Right: A close-up of collapsed ground at the lakeshore. The roots (indicated by the arrow) are about 5m long and near the ground surface. An approximately 1.5 m deep soil layer is present above the ice. The ground has collapsed because of melting of the ice wedge.
Fig 64 Thermokarst depressions caused by melting and evaporation of ice wedges after felling of forest trees. A hexagonal pattern is seen about 3 months after felling of the trees. The ground has sunk by about 1 m. It would reach equilibrium after sinking to about 10 m, but the collapse of the forest continues on the southern slope because of [the melting of] the exposed ground ice.
Translator's notes:
1. Parts where the source text is ambiguous or apparently needs some modification are marked in pink.
   1# Different times have been specified for ice ages. This is somewhat confusing. Perhaps we should give the names of the different ice ages.
2. Words added by the translator for clarity are given in [square brackets]
3. The translation of the words marked in orange is uncertain. The corresponding Japanese words are given phonetically in parenthesis.
The evergreen forests of New Zealand with their shining glaciers

There are huge continents like Eurasia and North America now in the Northern Hemisphere around the Arctic Sea. The Southern Hemisphere once had Gondwanaland around Antarctica. But from the Jurassic to the early Tertiary (about 50 million years ago), the current continents of Africa, Australia, India and South America got separated from it one after another (see Fig 47). The parts vacated by these land masses became a large ocean in the Southern Hemisphere. Most of the land masses originating in the Southern Hemisphere later became attached, directly or indirectly, to the continents of the north. Nevertheless, the temperate areas of the Southern Hemisphere had long remained isolated from the Northern Hemisphere, and therefore, different species of plants evolved there, under the mild oceanic climate. Thus, the beautiful needle-leaved trees of Pinaceae, such as pines, firs, and spruces, which we in the Northern Hemisphere are familiar with, are not found there. Instead, the Southern Hemisphere has needle-leaved trees of Podocarpaceae some of which we can also see in the warm temperate areas of Japan. Besides this, the beautiful fresh green leaves and fall colours of deciduous broad-leaved trees that we see in the temperate zones of the Northern Hemisphere are almost nonexistent in the south, except for those transplanted from the Northern Hemisphere. The Southern Hemisphere, with its mild oceanic climate, is a world of evergreen trees, the uniformly dark green trees covering the area up to the tree line. The forests are relatively simple, showing very little change with the seasons. They look rather drab compared to the temperate forests of the Northern Hemisphere.

(1) Glaciers and evergreen broad-leaved forests

Around 1975, I came to know that forests of Nothofagus solandri (Fagaceae), an evergreen broad-leaved tree of New Zealand, grew very close to glaciers. In my mind, somehow, glaciers were associated with severe cold and I could not connect them to warm temperate evergreen trees, which cannot withstand much cold. Besides, at that time, very little was known about the frost hardness of plants in the Southern Hemisphere. I therefore embarked on a study of cold acclimation of plants of the Southern Hemisphere, particularly those originating from Gondwanaland, to compare them with Northern Hemispheric plants. This was a 3-year joint study with Dr. Wardle, a well-known biologist of New Zealand.
I studied the climate data of New Zealand and learned about temperate glaciers from my glaciologist colleagues at the Institute of Low Temperature Science.

(2) The climate of New Zealand

Both the South Island of New Zealand (Fig 66) and Tasmania of Australia have high mountain ranges running in the north-south direction close to their western coast. In the winter, strong westerly winds blow against these mountains, bringing as much as 3500-5000 mm of precipitation per year to the area west of the mountain. This falls as snow in the mountainous areas. Besides, the summers are cool and the snow accumulated in the winter does not melt completely, resulting in the formation of glaciers. Unlike in polar glaciers, the temperature of the snow in these temperate glaciers is 0ºC. Similar glaciers exist in the central part of southern Chile and in Patagonia, which faces the Pacific Ocean in the Southern Hemisphere. The South Island of New Zealand is located at about the same latitude as the Japanese Archipelago on the other side of the Equator. But the former has glaciers on its backbone mountain and evergreen Nothofagus solandri growing even very close to the moraines of the glaciers, where these trees form the tree line (altitude 1000-1200 m) (Fig 67). Near the western coast, there is a warm temperate rain forest, which looks like subtropical forests with its dense growth of evergreen trees and ferns, including a few subtropical tree ferns. Glaciers originating in the mountains cross this forest and run into the sea. This is a scene found nowhere in the mid latitudes of the Northern Hemisphere. But similar landscapes can be seen in Patagonia. The mean temperature in winter is 6.6ºC at Hokitika (Fig 66) on the west coast (the January temperature of Kagoshima in southern Japan) and in the summer it is 15ºC (July temperature in Kushiro and Nemuro in the eastern tip of Hokkaido). Thus, the temperature difference in a year is only about 8ºC. The annual temperature difference is 20ºC in Kagoshima and as much as 25ºC in Sapporo.
Fig 66 South Island of New Zealand. M: The dividing mountain range running north south near the west coast. P: The tree line in this area.

Key:
In the Fig, clock-wise from top left: Hokitika; Christchurch
In the inset, clock-wise from top left: Auckland; Rotorua; New Zealand; Christchurch
(3) **Cold acclimation of plants of the southern hemisphere**

In the first year of our joint research, [shoots of] typical evergreen broad-leaved and needle-leaved trees were collected from different heights in winter, brought to Sapporo, and their frost hardiness measured after exposing to low temperature. From the next year, I requested my collaborator to send shoots from the same trees under cooling at 0°C by air to Sapporo, which took one day. We had also expanded our study to Australian plants. The findings were compiled and published in the international journal, *Ecology*[^103] after 3 years. This paper of ours gave a
momentum to the study of frost hardiness of plants of New Zealand and Patagonia and papers started to appear one after another.

Our study showed that temperate trees of the Southern Hemisphere, both needle-leaved and broad-leaved, had a frost hardiness of only about -18 to -20°C. Fig 68 shows the frequency distribution of the frost hardiness of two sets of 30 broad-leaved tree species each. One set (black bars) consisted of evergreen and deciduous trees of the warm temperate and temperate zones of Honshu, Japan and the other set (white bars) consisted of evergreen trees (and a few deciduous trees) from New Zealand, Australia and the south-central region of Chile. We can see that many of the broad-leaved trees from the Southern Hemisphere had a frost hardiness of about -15°C. This is about the same level as in the warm temperate evergreen trees of Honshu. None of the trees from the Southern Hemisphere could tolerate temperatures lower than -25°C, which the cold temperate deciduous trees from Honshu could withstand.

The needle-leaved trees from near the tree line in the Southern Hemisphere had a frost hardness of about -20°C, about the same as temperate needle-leaved trees, like Cryptomeria japonica, fir and Tsuga growing at about 1000 m on Yakushima Island (in Japan, about 30° N Latitude). These facts suggest that these trees did not evolve in the direction of high frost resistance with the ability to withstand temperatures lower than -25°C, unlike the cold temperate broad-leaved trees and subarctic needle-leaved trees of the Northern Hemisphere. Such high frost resistance is probably not required because the middle and high latitudes of the Southern Hemisphere have an oceanic climate with a small annual temperature difference and no dry intense winter cooling even near the tree line in the interior. Another possible reason could be that the needle-leaved trees of Pinaceae and the temperate deciduous trees of the Northern Hemisphere did not cross the equator to the south and therefore did not interbreed with the trees of the Southern Hemisphere.
(4) Mass planting of pines in the Southern Hemisphere

Needle-leaved trees of Pinaceae have not spread south beyond the equator. The needle-leaved trees of the Southern Hemisphere do not have much commercial value. Because of this, from around the 1930's, pines were planted on a large scale in the warm temperate zones of New Zealand and Australia. The trees have been improved by many years of breeding and New Zealand and Australia have become sites of huge experiments on pine breeding. They have now become major global producers of pinewood.

Annual precipitation in the parts of southeast Australia a little away from the coast is 500-800 mm. In this area, we often see forests of miscellaneous trees, such as naturally growing eucalyptus, acacia, etc, with somewhat poor growth and a height of a few meters only. Some of these forests have been cut down and replanted with pines from the northern Hemisphere, in large-scale experiments.
**Pinus radiata** was found to be the best suited for these areas. In Australia, where native broad-leaved trees do not grow because of insufficient precipitation, pines from the coastal dry areas of California, which can tolerate aridity and poor soils, were brought in and planted in large numbers in this manner. I was once taken in a helicopter from the capital Canberra to see these plantations. There were endless expanses of neatly laid out pine forests as far as the eye could see. These pines are cut down when they become about 30m tall, which takes 20-30 years. The pinewood is exported to Japan and many other countries. New Zealand and Australia have now become huge experimental farms of pine breeding and clone forestry†, which use conventional crossing and biotechnology for improving the pines and increasing wood production. Another objective is to contribute to ensuring sufficient biomass on earth in the future. One concern here is that we do not know the possible future effects of such large-scale planting of Northern Hemisphere trees in the Southern Hemisphere on the ecosystems of Australia and New Zealand. Finding the conditions under which artificially planted and natural forests can coexist is an important task for the future.

† Clone forestry: After crossing elite trees, lines that show good growth and have high disease resistance are selected. These are then mass-multiplied through tissue culture, allowed to grow into trees and planted as clones. Both conventional breeding through crossing and biotechnology are used in this method, and it yields high quality standardized wood in large quantities.

(5) **Christchurch, the flower garden of the world**

Christchurch (see Fig 66) is a city with a population of about 300 thousand people, in the South Island of New Zealand. It is a beautiful city, called the “Garden City of the World”, and located at about the same latitude in the Southern Hemisphere as Sapporo is on the other side of the equator. The summer there is cool, the temperature being about 16.5°C (as in Wakkanai at the northern tip of Hokkaido), and the winter is mild at 5.8°C (as in Kochi in southern Japan). It has an eternal spring like climate with an annual temperature difference of about 10.5°C.

The area was a wasteland about 150 years ago. But the new settlers tried their best to create a pleasant environment, like that of Oxford in their home country,
Britain. Spaces where the citizens could relax were created on the banks of the river Avon, which meanders through the center of the city. There are about 600 parks in the city. To mention the trees lining the streets, for instance, about 40,000 trees of 30 species were brought in from all over the world and planted. Many of its citizens have the hobby of gardening. Nearly 40 garden contests are held in this city alone in February, which is the main flowering season. It is like a flower festival of the Southern Hemisphere. It is a paradise of flowers created over many years by citizens who wanted a beautiful city.

The city's dry climate with a cool summer allows white birch, needle-leaved trees of the north, alpine plants and rhododendrons to grow there. Warm weather plants like camellias also grow there because of the mild winter. Thus, a wide variety of plants from both the hemispheres can be grown. It was impressive to see huge giant sequoias, the famous Californian trees, thriving in Christchurch.

Translator’s notes:
1. Words added by the translator for clarity are given in [square brackets]

Dr Sakai’s suggestions
p1, dark trees---dark-green trees
non existent --except transplanted from Northern Hemisphere
P.2 Kagoshima (southern part of Japan)
page 3: Kushiro, Nemuro -Eastern tips in Hokkaido
Page 4--Yakushima islnd (in Japan latitude about 30o)
Page 6 Wakkanai  Northern tip of Hokkaido
page 6, Kochi--southern part of Japan
Thank you, Sakai
4 Warm temperate forests of Mother Himalayas with a monsoon climate

The southern slopes of the Himalayan mountain range that runs over a long distance in the east-west direction, northeastern India south of this range, Bhutan and the Yunnan province of China, are rather warm with a small annual temperature difference during the year, something like the eternal spring like climate of the Southern Hemisphere (Fig 69). The temperature of Darjeeling (North Latitude about 27º and altitude 2127m) in northeastern India, famous for its tea production, is about the same as in Christchurch (North Latitude about 43º), New Zealand. Kunming (North Latitude about 25º, altitude about 1800m) in the highlands of Yunnan has a mean temperature of 21ºC in the summer and 9.5ºC in the winter. Thus, the annual temperature difference is only 11.5ºC. The outskirts of Kunming have many evergreen broad-leaved trees that are also found in the warm areas of Japan.

The Indian sub-continent is said to have been formed by fragmentation of Gondwanaland in the Jurassic period (150 million years ago) of the Mesozoic era when a land mass broke off leaving behind the central part that is currently Antarctica. It moved northwards, a few cm each year over a period of 100 million years and collided with the Eurasian continent in the early Tertiary (about 50 million years ago), it is said. As a result, the tropical Tethys Sea† that had connected Southeast Asia and England via the Mediterranean Sea disappeared and Tibet and the Himalayas started to rise in its place. Their rise became faster after the Ice Age (about 2 million years ago) of the Quaternary. This long mountain range that lies along the east-west direction blocks the cold waves from the north in the winter. So, the area south of this mountain range came to have a mild climate and quite a bit of rain. But the area north of the Himalayas, where the monsoon cannot reach, became dry. The Indian subcontinent played a major role in transporting plants of Dipterocarpaceae from the south and in the tropical rain forests of Asia.

† Tethys sea: This is a tropical sea that existed between the continent of Laurasia in the north and Gondwanaland in the south, in the area from Southeast Asia to what is currently occupied by the Himalayas, reaching as far as Europe. The current Aral Sea, Caspian Sea and Mediterranean Sea are its remnants. The sedimented remains of organisms that flourished in this shallow tropical sea
turned into the oil deposits of Central Asia and the West Asia.

Fig 69 A map of the area around the Himalayan mountain range

Key:
Clock-wise from top center: Himalayan mountain range; The Tibetan plateau; Mt. Everest; Southwestern (Nansei) Highland; Kunming; Bhutan; Darjeeling; Kathmandu; New Delhi; Shimla; Pakistan

(1) The Southwestern Highland of China

The Southwestern Highland of China is a region that extends from the northwest part of Yunnan Province and southwest of Sichuan Province to the southeastern part of Tibet. The major rivers, Yangtze, Salween and Mekong run from north to south creating gigantic gorges. In this Southwestern Highland, the cold waves from the north are blocked and the winters are mild. During the monsoon, the seasonal winds from the southwest blow into the valley and bring in about 2000mm of precipitation even at 4000m altitude. This is the reason for the existence of forests at this height. The environment of the Southwestern Highland is complex and diverse. Moreover, because it is warm and receives a lot of rain, very diverse
plant and insect life exists there. This is also the place of origin of many plant species of eastern Asia, including rhododendron and rice.

The needle-leaved trees and rhododendrons of the Himalayan region, for instance, have spread from the Southwestern Highland, which is a treasure trove of plant species. For example, about 250 varieties of rhododendron can be found on this highland at a height of about 3000m, whereas the Himalayas have only about 30 varieties. This highland also has about 20 types of needle-leaved firs of Pinaceae, whereas the Himalayas have only one species each of fir, spruce, larch and Tsuga. The leaves the evergreen oaks, Castenopsis sieboldii, Camellia and related species, shine in the sunlight. Therefore, in Japan, they are called “Shoyoju” (trees with shiny leaves). Forests of these trees start from the southern slopes of eastern Himalayas, extend eastwards to the coastal warm areas of the Japanese archipelago, passing through Yunnan and other southern parts of China.

(2) Frost hardness of Himalayan fir (Abies spectabilis) growing at the tree line

Suburbs of Kathmandu (1337m), the capital of Nepal, have dense forests of trees with shiny leaves. Tsuga and pines become predominant at heights above 2000m in the forests of eastern Himalayas. Himalayan firs form forests at the tree line. Deciduous broad-leaved trees can be found only on the northern slopes, at around 3000m where the soil freezes [in winter]. The Namche bazaar (altitude 3450m) in eastern Himalayas has a mean temperature of -0.3°C in January (the same as in Miyako). Shamboche, located above that (altitude 3900m) is at the tree line. The mean temperature in January is -4°C here (about the same as Karuizawa). This area has many foggy days in winter, and rime ice forms easily on trees because of updrafts. All this seems to suggest that the tree line in the Himalayas is not a very cold place after all. Himalayan fir growing at the tree line is a temperate needle-leaved tree like the firs and Tsuga growing naturally at 1000-1500m in Yakushima Island. So, I guessed that the Himalayan fir would have a frost resistance of only about -20°C. To verify this, I decided to measure the frost resistance, by differential thermal analysis, of buds collected in winter at the tree line.

Around 1978, little was known about the frost hardiness of Himalayan plants. I therefore, embarked on a study of their frost hardiness, together with Dr. Malla, a
renowned biologist of Nepal. In the first survey, in December 1979, we collected plants from different heights, trekking on the mountains for 2 weeks. They were placed in a corrugated cardboard box. These got warmed during the several hours it took for change of flight at the Bangkok airport, which was at more than 30°C even in the winter, and became useless. So, I visited Kathmandu once again after a month and waited there for 2 days to catch a regular flight from Kathmandu to Shamoche, and arrived at the Shamoche airport on a clear day. From there I climbed the steep slope for about 20 minutes, stopping occasionally to catch my breath and reached the Everest View Hotel at the top of the slope. This hotel provided a majestic view of Everest and it was in the midst of a Himalayan fir forest at a height of 3900m (Fig 70). I collected buds of Himalayan fir from this forest and flower buds of about 1m tall rhododendrons from the same forest. I brought the samples to Sapporo in a cool condition, exposed them to -3°C for 2 weeks and carried out differential thermal analysis. I found that the frost killing temperature of the buds of Himalayan fir was -18°C (Fig 71) and that of the Rhododendron cinnamomeum flower buds was -17°C. The frost killing temperatures of the buds of Nikko fir (Abies homolepis) from the mountainous region of central Honshu and flower buds of Rhododendron fauriae from Hokkaido, which were also tested in the same experiment, were both about -30°C. This confirmed my guess that Himalayan fir growing at the tree line in the Himalayas, at a height of 3900m, had about the same level of frost hardness as firs growing at 1000-1500m in Yakushima Island⁴¹⁴.
Fig 70  The tree line near Shampoche (altitude about 3900 m). The Himalayan fir (*Abies spectabilis*), tree height: about 8 m.*102

Fig 70  The tree line near Shampoche (altitude about 3900 m). The Himalayan fir (*Abies spectabilis*) trees are about 8m tall*102.
Differential thermal analysis of winter buds of Himalayan fir (Abies spectabilis) and Nikko fir (Abies homolepis) form the mountainous area of Honshu. Measurement was done after exposing the specimens to -3°C for 2 weeks. T: Cooling curve of the bud. Spikes 1-11 represent frost killing temperatures of individual buds. H: Frost killing temperatures of Himalayan fir (1-5) M: Frost killing temperatures of Nikko fir (6-11).

**Key:**
- **Abscissa:** Time (Each scale division is 30 minutes)
- **Ordinate:** Latent heat of freezing, relative values
- **Inside the Fig, from left to right:** Himalayan fir; Temperature; Nikko fir
A trip to Shimla

I was requested by the National Bureau of Plant Genetic Resources (NPGR) in New Delhi and the Central Potato Research Institute (CPRI) in Shimla to deliver lectures at the end of February 1996, on the preservation of genetic resources in liquid nitrogen. So, I decided to visit Shimla, which I had wanted to do for a long time. After getting out of my hotel in New Delhi before 5 in the morning one day, I boarded the express train, Himalayan Queen, at 6. Around lunch time, the train reached Kalka where I changed to the narrow gage mountain train the track for which had been laid at the time of British rule. The train passed through dry lowland areas with cacti and arrived at Shimla, which still had some snow. I met my friend Dr Sukumaran and his wife, after a gap of 24 years. He, after obtaining his doctorate from the University of Minnesota, had spent one year at our laboratory in the Institute of Low Temperature Science, and returned to India at the end of 1972. Since then he had been doing research work at CPRI, Shimla.

There are virgin forests of deodar cedar (Cedrus deodara), a needle-leaved tree of Pinaceae, within Shimla. This tree is a well-known garden tree in warm areas of Japan. Red-flowered Rhododendron cinnamomeum trees grow on the forest floor. Shimla is a town, on a slope, at a height of 2300m, which was developed as the summer capital of British India. During the day, in late February, the temperature was about 20ºC, but the nights were quite cold and I could not fall asleep easily. I was reminded that after all, this was a hill station built as an escape form the heat of the summer. This town, developed on a slope, has mixed scenery, with a main street with mostly western style buildings and a downtown area that looked more traditionally Indian and Tibetan. Its population was about 70,000 and it was a favorite destination of honeymooners of North India. I could see the silvery white western Himalayas that extended to Pakistan from a hill near a ski slope on the outskirts of Shimla. Shimla falls in the monsoon zone and the rainy season is in July and August.

Mrs. Sukumaran, who hails from Hokkaido, told me, "Felling of trees is prohibited in Shimla. You cannot cut the tree without special permission even if one of its branches protruded through your window." During my stay in India I sensed a
general attitude of coexistence of people with animals and plants. Computer network infrastructure was not well developed in India. I had the hard experience of many of my flights being cancelled or delayed by several hours during my two weeks in India. In spite of that, I was deeply impressed by the diversity of peoples, languages, culture, religion and natural environments, the simplicity of the lifestyles of the people, their boundless gentleness towards nature shown through their efforts to live in harmony with all other living things, and their spiritual richness. India, with its diverse climate, is rich in plant genetic resources. The exploration, collection and preservation of plants have been actively pursued since ancient times.

(4) Mother Himalayas with its monsoon climate

In the summer, moist air blows into the subcontinent from the Indian Ocean and hits the Himalayan mountain range, which spans a long distance from west to east. This creates a very strong ascending airflow near the Himalayan Mountains of India and Nepal. The monsoon further advances to the east and northeast, riding on the strong jet stream. This brings monsoon rains to South Asia and the whole of Southeast Asia and the so-called Bai'u (the rainy season) in the Japanese archipelago. Without the Himalayas, the monsoon would have reached only the southern part of India and the biodiversity of the forest flora and rice cultivation in Southeast Asia and the monsoon zones of the rest of Asia would have been very different from what it is today.

This monsoon climate extends to the Swat Himalayas at the western end of the Himalayan mountain range. The high Hindu Kush mountain acts as a divider near the international border between Pakistan and Afghanistan, with a Mediterranean climate with dry summers and wet winters to the west of it\textsuperscript{133}. By the way, the plants distributed in Japan and China (the Sino-Japanese floristic region) are found growing naturally on the southern slope of the Himalayas (the Himalayan corridor) up to its western end, in a band-like distribution. There are three types of cedar: one can be seen around Shimla. The other two types are seen in the coastal regions of North Africa, Lebanon and Syria, all of which have a Mediterranean climate.
Translator’s notes:
1. Words added by the translator for clarity are given in [square brackets]

Dr Sakai’s suggestions

Chapter 4: Himaラヤスギ Cedrus deodora
himalayan spruce Abies spectabilis  urajiromomi: Abies homolepis,
hakusansyakunage R. fauriae  himarayashakunage R. cinamomeum
Sakai
5 Tropical rain forests with high biodiversity that never faced cold weather

Tropical rain forests are forests that have evolved in hot and humid environments with little seasonal change, where the growing conditions are stable and high production is possible throughout the year. Characteristic of tropical rain forests are giant trees that are sometimes as tall as 70m and other tall evergreen broad-leaved trees that form a complex multi-storied structure, and the coexistence of the diverse tree species and other living organisms, each in its own niche. Although tree species of tropical rain forests have a high production capacity, they depend on symbiotic relationships with ectomycorrhizae for obtaining inorganic nutrients needed to support such high production\(^{71}\). The area covered by tropical rain forests is only about 16% of the total land area of the earth. But they are packed with more than half of the known plant species. The tropical rainy zone is a paradise for evergreen broad-leaved trees.

(1) High biodiversity in tropical forests

The tropical zones of Central and South America and Africa, unlike other tropical zones, have a few months of dry period each year and clear-cut seasons, as in Thailand and Myanmar. However, in the Malay Peninsula, Sumatra and Borneo, which are almost directly at the Equator, have little variation in precipitation round the year. There are tropical rain forests in the low altitude areas below 1000m in Southeast Asia, where tall trees belonging to Dipterocarpaceae constitute the main flora. These Asian Dipterocarpaceae plants came in on the Indian subcontinent, which carried them from the Gondwanaland, and they spread over Asia. The tropical rain forest of Lambir National Park of about 52 hectares in Borneo is said to have about 1200 tree species. In comparison to this, the temperate Fagaceae forest around Kyoto has about 50 species and the almost natural mixed forest of needle-leaved and broad-leaved trees near the Tokyo University Experimental Forest in Hokkaido, has about 40 species. We can see that tropical rain forests have 20-30 times more tree species than temperate forests of the same land area. Why is it that so many different tree species can grow together in a rain forest? Firstly, there is the high level of incident solar energy. Also, the huge tall trees that reach a height of 50-70m allow the development of a complex multistoried structure (Fig 72) below their crowns and the members of each level show advanced ecological segregation\(^{55, 56}\). In such forests, it is important for
plants to grow fast so that they can get their share of the available light. There must be stiff competition through [acquisition of special] germination characteristics. But if competitive success alone was involved, only the efficient ones should have survived and driven away the other species. Thus, we cannot explain the high diversity of tree species in tropical rain forests in terms of the canopy heights and the number of stories alone.

Tropical rain forests characteristically have many different tree species, but the frequency of each species is very low. High species diversity and low frequency of individual species are two sides of the same coin. Under such conditions, the plants need effective multiplication systems for maintaining groups of scattered individuals of a species, and interdependence with other plant and animal species plays an important role. Many complex aspects have to be studied to clarify these relationships. These include the time of flowering of each species in the Dipterocarpaceae forest, pollinating behavior of insects, interdependence of plants with insects and other animals and the kinds of insects living in the forest.

In 1982, Erwin lifted a sprayer to the crown of a tree in a tropical rain forest of Cuba with the help of a pulley and sprayed Surin E to collect the insects available there. Only 2% of the insects collected were known species. The following year, Erwin confirmed this in the tropical forest of Amazon. It thus became clear that a huge number of so far unknown insect species live in the tropical forest canopies. Erwin’s report triggered similar studies in other tropical forests, which yielded similar results. This work has opened the door to an unknown world and new field of study called Canopy Ecology. The forest canopy at a height of 70m from the ground gets the maximum sunlight. The productivity is highest, and the ecosystem must be the most diverse. But no one had noticed it because of the height.
The fact that Dipterocarpaceae forest trees flower on an approximately 5-year cycle was known from the quantities of seed and fruit that fell down. Professor Tamiji Inoue and his team from Kyoto University fashioned observation towers and hanging bridges and climbed up to the top of the canopy of the forest of the Lambir National Park in Sarawak, Borneo, to observe flowering. There was no flowering for 4 years. But finally, in March 1996, they observed flowering for the first time, and it continued up to July. They subsequently clarified the time of flowering, interrelationships between plants and insects, and pollination by insects and animals in about 500 species. In the forest surveyed by them, even among the
Dipterocarpaceae trees, which were the largest in number, only about 2 trees of each species flowered in a 100m$^2$ area. The approximately 1200 tree species of the forest did not all flower simultaneously in the 4-month long flowering season; they appeared to flower in a certain sequence. A surprising fact was that the trees of the same species flowered in a synchronized manner. For instance, even if there were only a single tree in a 1km$^2$ area, it would flower at the same time as other trees of the same species. This was probably because pollination cannot occur if they were to flower at different times and there would be no progeny. Flowers of some trees opened during the day. But most flowers opened in the evening and dropped in the morning, lasting only for a short time. The pollinating insects visited the flowers when they were open, whether at day or night, to transfer the pollen. Insects did the pollination in about 80% of the cases, and the rest was done by birds and mammals. Among the insects, the most common pollinator was sawfly, which accounted for about 50% of the pollinations, followed by beetles, about 20%. It is not an easy task to stay awake all night and make observations at the height of the canopy, collect the insects that fly into the canopy, identify them and confirm that they actually did the pollination. During this simultaneous flowering, 402 tree species belonging to 189 genera of 65 families were seen by about 35 researchers to flower at the same time. Out of these, the pollinators of 141 species have been identified.$^{141}$

Tropical rain forests have high diversity of tree species but very low frequency of trees of any one species. For all these tree species to survive, they must produce seeds and leave progeny. It was a mystery why they had to flower at the same time and in 5-cycles. During simultaneous flowering, all buds become flowers and no new leaves at all are formed. According to Professor Inoue, trees invest a lot of energy for bearing large numbers of flowers in this infertile tropical forest with not much humus in the soil. Therefore, they probably store nutrients for 5 years (it is not known in what form) and produce a large number of flowers for 3-4 months once in 5 years. Probably, these many flowers are required to attract the insects. Once flowering occurs, large numbers of bees and other insects arrive there, feed on the nectar and pollen and multiply. At this stage, bees divide their hives. After this, the bees live on meager resources until the next flowering 5 years later. The massive simultaneous flowering, once in 5 years, appears to be a Festival of Reproduction for both the plants and the insects. The details of the life of the pollinating insects, which is synchronized with the flowering cycle, are
gradually being understood. In places like tropical rain forests, where there is little seasonal change, there are a very limited number of environmental cues that can trigger flowering, and afford the opportunity for exchange of genes. In January 1996, days with a minimum temperature of less than 20°C continued for a week. This abnormal low temperature occurred because of strong radiative cooling during a long span of clear weather caused by the El Niño phenomenon. It would be interesting to speculate that this low temperature became a trigger for the simultaneous flowering of the trees of the tropical rain forest that had never known such cold weather. But observations over a longer period would be needed to verify this.

The energetic studies of Professor Inoue and his team had shown that a tremendously large number of insect species, nearly 100 of bees alone, existed along with the 1200 tree species in this forest. Even the relationship between the plants and the bees itself appears to be very complex. After the flowering, the trees would produce fruit simultaneously, around October, and the animals would gather from over a wide area to consume these fruits. Newspapers of September 7, 1997 had this report: “A small plane with 10 persons on board, including two Japanese, had crashed after hitting a hill inside the Lambir National Forest, near Miri, Sarawak State, Malaysia at 7:44 PM on September 6, killing everyone on board. Professor Tamiji Inoue (49) of the Center for Ecological Research of Kyoto University was among them”. The next day’s papers carried the confirmation by Kyoto University officials that Professor Inoue had indeed died. Professor Inoue met with sudden death in the Lambir forest, the very land that he had been studying, just before the trees would bear fruit in October.

Pollen has to be dispersed for plants to survive. How they survive in different parts depends on whether the pollen is randomly dispersed as in wind-pollinated plants or whether it is carried to appropriate places by animals following certain rules. Needle-leaved trees, which are gymnosperms, are wind-pollinated. But most angiosperms have advertising devices called flowers to attract insects, which transfer the pollen. This system was perfected around the second half of the Cretaceous Period of the Mesozoic Era (about 100 to 80 million years ago). The emergence of insects, flying insects in particular, and adaptation of the angiosperm flowers for pollination by them were the prerequisites for this to happen. These developments enabled a rapid increase in the variety of angiosperms and a spurt of
diversification and differentiation of species. This is because a kind of contractual relationship had been established between flowers and insects. Birds and mammals were almost non-existent at that time. When they appeared later, they mainly played a role in dispersing the seeds. For monkeys, which emerged after the birds during the Oligocene (about 30 million years ago) of the Tertiary, finding tasty fruit (the hard seeds are dispersed with the feces (Shushokugata)) became a means of survival.

I cannot forget these words of professor Inoue: “Rain forests, which hold such diverse life forms, are so valuable because only there can we perceive the history of co-evolution of living organisms during the last 100 million years”134. I sincerely pray for the peace of his soul.

At the time of simultaneous flowering of the forest trees of Lambir, studies were undertaken on 64 species of wild fruit dispersed through frugivory (Shushokugata), including mango and durian. The day-foraging primates of the forest that used to disperse the seeds of these fruits had already been eliminated by humans. So the fruits were rotting where they had fallen or their seeds were eaten by animals other than those that had originally dispersed them. So, the forest had already lost the seed dispersers needed for maintaining it. Thus, even though the biodiversity of trees is still maintained, the network of living organisms that created this diversity does not function any more and the forest is well on its way to becoming a relic forest141. Tropical forests can remain stable only when a wide variety of animals and plants form complex ecosystems.

(3) Mount Kinabalu

Mt. Kinabalu (altitude 4100m)(Fig 73) in [Malaysia] the highest peak in Southeast Asia, is located near the Equator (about N Latitude 5) at the northeastern end of the island of Borneo, which was once a part of Sundaland. The mountain is rich in plant diversity and has a very diverse flora, besides having many primitive angiosperms. It is the center of differentiation of the evergreen genera, Castanopsis, Pasania, Castanea (Kurigashi Zoku) and Quercus of Fagaceae. Side by side with these plants of the Northern Hemisphere, the needle-leaved trees and angiosperms of the Myrtaceae from the Southern Hemisphere also grow there.
Many groups of plants can coexist in tropical mountainous regions because the temperature and moisture conditions are mild and seasonal changes are small. Because of this, even incompletely differentiated species can survive without being eliminated by competition. As a person studying cold adaptation of plants, I wanted to see such a forest where living organisms coexisted in the environment in this manner. So, in 1980, 3 years before my retirement, I climbed Mt. Wilhelm (4510m) (Fig 73) of Papua New Guinea, a high mountain in the tropics. A local person guided me up to its tree line (about 3500m), where there was a glacial lake. I surveyed the area for 3 days on my own. The night before I left the mountain, I stood wearing winter clothing under a clear starry sky to experience the cold of the tropical highlands. There was extensive frosting, the frost shining white. The minimum temperature was -1°C.

In early February of 1997, I had received an invitation from Dr Emiko Maruta of Toho University. She asked me whether I could accompany her to Mt. Kinabalu of Borneo in late March of that year, as she wanted to study the frost resistance of alpine plants of that region. I decided to climb up to the rest house at Pana Laban near the tree line, at an altitude of 3350m, to commemorate my 77th birthday. We boarded a direct flight that operated only once a week, from Narita airport to Kota Kinabalu airport. From Kota Kinabalu, it took us about an hour and a half by car to reach the Kinabalu Mountain Reception Office. The Sabah State where Kota Kinabalu is located has a rich natural environment. The protection and management of nature were well-organized. Plenty of provisions of all sorts were also available.
Fig 73 Sundaland. The stippled area is the part that had become land during the Ice Age because of regression of the sea level. K: Mt Kinabalu, L: Wallace's line, W: Mt Wilhelm in New Guinea. The arrow indicates the path through which Khasya Pine (Pinus khasya) migrated south during the Ice Age.

Key:
Abscissa: East Longitude
Ordinate: North Latitude
In the inset: Sundaland
In the Fig, left to right: Khasya pine; Borneo; Philippines; Wallace's line
Mt. Kinabalu has the least rainfall in March. So, that seemed to be the best time for climbing. I got a shock when I looked around at the lowland oak forests near the Reception Office at the height of 1650m (mean temperature 19.9ºC) of Mt. Kinabalu because many of the trees were putting out new shoots. It looked like spring. At the height of 3000m also many plants had new shoots. I had thought that plants grew following their own internal growth rhythms in the tropics because there were no seasons. At the front of the Reception Office, I met Professor Kihachiro Kikuzawa of Kyoto University, who was studying the phenology of leaves there. I was meeting him after a long time and he was kind enough to introduce me to the forest vegetation around there.

On the first night, after having dinner at the top-class restaurant near the Reception Office, I returned to the Rest House and tried to sleep wearing a lot of clothes. But the single light blanket was not warm enough and the cold kept me awake almost the whole night. The day time was comfortable at about 25ºC but at night the temperature dips below 10ºC at the height of 1600m even though it was in the tropical zone. This night time cooling was probably the reason why the warm temperate evergreen montane oak forest was existing around the foothills of Mt Kinabalu, instead of the tall trees of Dipterocarpaceae which generally form tropical rain forests. I did not find a single *Nothofagus solandri*, an evergreen tree of the Southern Hemisphere belonging to Fagaceae, so many of which I had seen in Papua New Guinea. After this montane oak forest, we passed by groves of bamboo and thick clusters of ferns in the moss-covered forest (cloud forest), where the tree trunks were covered with mosses, ferns and orchids, and climbed to about 2700m. There, the vegetation changed abruptly. We entered a serpentinite area with a yellowish brown soil. The conifer *Dacrydium* and flowers of *Leptospermum* of Myrtaceae, which are common in the Southern Hemisphere, became more predominant. Here and there we noticed flowers of the tropical (*Rhododendron bireya*) and orchids. Gradually, from around a height of 2900m, we could see the summit of Mt Kinabalu towering above the forest. At even higher altitudes, beyond 3000m, we entered an area of huge exposed granite rocks and *sedimented Ice Age rocks*. Gradually, it became harder to breath. The area had well-developed rock vegetation, with trees a few meters in height. Soon, we could see the beautiful Pana Laban rest house (3350m) which sits at the tree line. We had started climbing
at 8 in the morning. It took 6 hours and a half to finally reach our destination, at 2:30PM. From the rest house we could get a panoramic view of summit made up of exposed granitic rocks shining white. The rock surface was shining because it was covered with thin ice (Fig 74).

From here, towards the summit of the mountain, in cracks in the rock, mud in depressions and other places where water might accumulate, some boreal plants, *Deschampia*, *Gentiana scabra* Var. Buergeri, *Ranunculus*, *Potentilla*, *Eleocharis congesta* and dwarf forms of *Leptospermum* of the Southern Hemisphere were growing in clusters. I was particularly interested to know how much of freezing the dwarf and cushion plants I saw near the summit could withstand on clear nights when the temperature would dip below zero. According to the weather data measured regularly at 3780m\(^*50\), in March, the mean temperature (in the Stevenson screen) is 10.3°C and the average daily minimum temperature is 3.3°C. This mean temperature of 10.3°C is close to that recorded in July near the Hakuu hut (2000m) in Daisetsuzan, Hokkaido. I therefore guessed that the plants growing in the altitude range 3780m to 4100m (top of the mountain) could probably withstand -7 to -10°C, like alpine plants of Daisetsuzan in summer. If the plants in the dormant state are acclimated to low temperature of 0 to -3°C for one week, they would probably withstand -15 to -20°C. This was likely to be the maximum frost hardiness of these plants growing in this alpine region of the tropics.

After returning to Sapporo, I learned from Professor Seigo Higashi of Hokkaido University that no ants lived at a height above Pana Laban on that mountain. No bees were found in a survey\(^*59\) of insect pollinators of alpine plants in the high ranges of Mt Kinabalu. The low temperature is probably restricting the movement of bees. This area seems to have no summer season, with the maximum day temperature being only 7 to 10°C. Small insects of the order *Diptera*, like flies, drone flies (*Eristalis tenax*), *Yuriska*, etc play the role of pollinators in this region.
ii El Niño and large scale drying up of plants near the tree line on Mt Kinabalu

Around Christmas in 1997, the sea surface temperature offshore of Peru in South America rose and the local fishermen exclaimed that “El Nino” had arrived. The sea water around the equator that gets warmed and becomes lighter is usually carried westward along the Equator by the trade winds and builds up in the Western Pacific, around Indonesia, Borneo and New Guinea. Because of this, the sea level in that area rises by a few tens of centimeters compared to the South American coast. The sea water temperature also rises. Ascending air flow develops over this warm sea surface, which brings rains to the Malay Peninsula, Indonesia, Borneo, New Guinea, etc. even in the winter, allowing the tropical rain forests to thrive. However, if the trade winds become weak for some reason, they
cannot confine the warm water to the Western Pacific and the bulk of the warm water spreads eastwards creating El Nino. The ascending air flow that develops over the warm sea surface brings rain shifts from the Western Pacific to its central part. One of the effects of this El Nino was the very much reduced precipitation in Indonesia, New Guinea and the northern part of Australia, creating drought. Particularly in New Guinea, almost no rain fell from February 1997. A drought, which they had not seen for the last 100 years, prevailed. Kalimantan, which is under Indonesian control, in the Borneo Island, and Sumatra had many forest fires one after another, creating a major environmental problem in Southeast Asia. We heard that many plants that we had seen along the tree line near Pana Laban on Mt Kinabalu dried up and died in large numbers because of an abnormal drought that persisted for 4 months from December 1997. I was very surprised that even the vegetation above the tree line in this tropical zone was affected in a significant way by the abnormal weather caused by El Niño.

### A canopy walkway

The Poring hot spring (altitude 500m) is located east of Kinabalu National Park. It had been developed by the Japanese army during World War II. Near this hot spring, there is a hanging bridge (Fig 75) that is about 200m long and is anchored at a height of about 40m to almost 70m tall Dipterocarpaceae trees. Thus, one can walk through the forest canopy. This walkway is used by tourists. While walking on it, one can observe the animals and insects that live in the canopy. It is at such a height that if you look down, you may become weak-kneed with fear. Earlier, visitors could not see the flowers in the tree crowns from close up. But this walkway has made it possible to study at close hand the status of flowering, the insects and animals that help in pollination, attractants released by the opening flowers, ascending and descending air flows in the forest, the microclimate, and the behavior of birds, insects and animals. I understand that very interesting discoveries are being made one after another. Presently, observations and research on tree canopies are being actively carried out not only in the tropics but also in temperate forests (for instance, at the Tomakomai Experimental Forest of Hokkaido University).
Fig 75  The canopy walkway near Poring hot spring (Photographed by the author).

(4) Sundaland

The Sundaland Sea of Southeast Asia (Fig 73) is about 100m deep. Sundaland, which includes the current Indonesian Peninsula, Malay Peninsula, Sumatra, Java, and a part of the Philippines, had formed many times during the ice ages because of lowering of the sea level (by about 180m during the last Ice Age). Around the end of the Tertiary period, most of New Guinea Island came up above the sea level due to regression and further the Arafura Sea (see A in Fig 73) between New Guinea and Australia became land during the Ice Age. Moreover, the area connecting to the southern part of New Guinea via the Malay Peninsula, Sumatra, Java, and the Greater Sunda and Lesser Sunda islands became a highland providing a route of exchange between Indo-Malaysian and Australian floras. The plants of the Northern Hemisphere spread southward through these passages. For example, the Rhododendron moved south from the Yunnan Province of China and got differentiated to produce Rhododendron bireya, which spread to New
Guinea and even up to the Fiji islands. The evergreen oak forests (broad-leaved forests) found widely in the warm temperate zone of Asia are also widespread in the Malay Peninsula and New Guinea, forming tropical montane oak forests there. At the same time, the needle-leaved trees of the Southern Hemisphere, from Australia and New Guinea also moved along this passage to the Malay Peninsula and Thailand. Sundaland also played a major role in the migration and spread of the Mongoloid race.

The Wallace's line (see L in Fig 73), which is famous in biogeography, is a borderline that separates the Indo-Malaysian flora and fauna from the Australian ones. This line goes northward through the narrow but deep strait between the Bali Island and Lombok Island.

*Translator’s notes:*
1. Words added by the translator for clarity are given in [square brackets]
2. Kindly check parts marked in orange. Their translation is uncertain.

Dr. Sakai’s revisions:
Chapter 5
p.188. kinpouge Ranunculus; kijimushiro, Potentilla, komesusuki: deschampsia:
Dacrydium, conifer; leptospermum; Akou Ficus Wightiana matebashii
Pasania:
shii Castanopsis, konarazoku Quercus, oak
Willows that grow naturally in the tropics but still remember the cold

(1) Characteristics of willows as pioneer species

Willows have developed nearly 400 species through polyploidy (up to pentaploid) and repeated crossing. They have spread over a wide area ranging from the temperate zone to the subarctic zone of the Northern Hemisphere, as a pioneer species mainly associated with rivers. The name Salix of the genus comes from Celtic language in which “Sa” means near and “Lis” means water. Moreover, willows have differentiated into more than 100 dwarf species that creep on the ground and extended their range to the tundra of the far north and alpine areas. A surprising fact about willows is that a group of willows having traits that are believed to be ancestral have crossed the high barrier to distribution and reached tropical areas with high temperatures and little seasonal change. They have established themselves in the tropical regions of Asia that have a dry season, Africa, and even South America. Few people in Japan know that willows grow fairly widely in the tropics also. These willows have survived in the tropical or subtropical lowlands for several thousand to tens of thousand years but still latently retain the frost hardiness that they had acquired thousands of years ago. They show a fairly high level of frost hardiness when exposed to low temperatures.

Willows are the first trees to flower, in early spring. The seeds set early, a large number of the light seeds get dispersed widely and colonize newly created bare land. Moreover, willows have a high capacity for rooting and regeneration. For example, a broken twig can regenerate a new tree at a spot on the river bank to which it has drifted. Willows can also establish well on mud-covered land left after flooding. They have insect-pollinated flowers with nectar glands, unlike many other pioneer deciduous broad-leaved trees such as white birch and poplar, which are wind-pollinated. The willows have spread not only in the Northern Hemisphere but also in the tropics and in the Southern Hemisphere, in close association with rivers, while maintaining their unique style.

(2) How I came to study willows

Around 1960, I could confirm that the temperate willows growing naturally in
Japan, including Yamayanagi (Salix sieboldiana), which grows in Kyushu, could all withstand -70ºC if exposed to cold and could survive liquid nitrogen temperature (-196ºC) if cooled first to -30ºC. I then had a strong desire to find out how much freezing the willows growing naturally in the tropical and subtropical regions could withstand. To obtain the winter shoots of these willows, I sent out about 50 letters to acquaintances and botanical gardens abroad. This was in 1965. The first to arrive was Bonapland willow (Salix bonplandiana) from the late Dr. Eiji Matsuda, who was a close friend of mine and a renowned botanist working in Mexico. He wrote that this willow was distributed from Mexico to Argentina in South America. After that, Salix tetrasperma samples arrived one after the other from forest research stations of India and Pakistan. I came to know from scientific papers of India that only this species of willow was widely distributed in the tropical and subtropical lowlands (up to 1000m above sea level) of Pakistan, India, Myanmar and Thailand, along the rivers. I also came to know that the high altitude areas (above 1000m) and the northern temperate zones of India and Pakistan had many temperate willows found widely in Europe, Russia and West Asia. Another willow species, Salix safsaf, arrived from the African countries, Egypt, Sudan, Angola, and South Africa (Pretonia). Presently, we can see this willow growing along rivers in Iran and warm parts of southern Iraq. It had probably moved south along the rivers in the huge gorges of Africa and spread to the southern end of Africa and to Angola in western Africa while differentiating into new species. Willows are believed to have originated in the Northern Hemisphere, as can be seen from the fact that no willow species are found in New Zealand or Australia. Nevertheless, I came to know that some special willows that are different from the temperate willows of the Northern Hemisphere are growing in the tropical and subtropical regions of Asia, Africa and South America.

I decided to prepare cuttings from these willow twigs that I was gifted and grow them into saplings for use in experiments. I visited Professor Alika Kimura of Tohoku University, an international expert on willows, taking some of these willow shoots with me. Professor Kimura was very happy to see these willow samples. He commented that the scales on the buds of these willows would not be fused but free and overlapped like a roof tile, on the adaxial side, the side facing the shoot. Professor Kimura had reviewed the classification of willows in 1928 from the standpoint that once the scales got fused they would not become the free
type again. According to his classification, willows with free scales (Fig 76) belonged to the polysteminous subgenus Protitea having primitive characteristics and those with the fused scales were the new true willows of the subgenus Eutitea (Euitae?), which were widely distributed in the temperate zone. After hearing this, I checked the bud scales of the willows that I received from India, Africa and South America. All were primitive willows with free scales. Many of these willows had the basic chromosome number of 2n=38.

I grew these willows that I had gathered from different parts of Asia and Africa, along with temperate willows, for 3 years in a greenhouse (minimum temperature maintained at 10°C, natural daylength of Sapporo). The temperate willows all stopped growing and entered dormancy when the days became short in autumn, shed leaves, and remained leafless for 3-4 months. Contrary to this, the tropical willows did not shed their leaves at the higher than 10°C temperatures under the natural daylength, and continued to grow. Only once a year, in the winter, they stopped growing for 1-2 weeks. They shed their old leaves after opening new buds and then continued to grow. In other words, these willows were not the type that entered dormancy or shed their leaves, depending on the temperature or daylength.

These willows were planted outdoors in Sapporo. Their mature shoots were tested for frost hardiness after the plants were well-exposed to the cold climate in autumn. The willows from subtropical areas of India and Africa where the winter temperature never went below 10°C had a freezing tolerance of about -20°C. But I could not verify before my retirement in 1983 whether these willows growing naturally near the Equator could actually withstand subzero temperatures.

Before my retirement, I gifted these potted saplings of primitive willows from Asia and Africa to the Tohoku University Botanical Garden through Professor Kimura. He was very happy to have them. He said that it was the only live collection in Japan of willows with primitive characteristics. The willow Salix mucronata found in the southernmost part of South Africa was in this collection. This willow had a special significance for Professor Kimura. This was the willow that he had identified, in his younger days, to have primitive characteristics, from dried samples that he received from a friend in USA. That had led him to classify willows into two subgenera in 1928, one primitive and the other the true willow. “I am
seeing a living sample of this willow for the first time!”, he exclaimed when I took a living plant of this willow to him. Professor Kimura passed away in 1996 at the ripe age of 96. I had heard that he continued to collect willows up to his 90th year.

![Diagram of bud scales](image)

**图 76** 原始的な形質をもつヤナギ（A）と現性のヤナギ（B）の芽の腹部りん片。A：りん片がD の部位で重ね合わさり、癒着していない、B：りん片が癒着して袋状になっている

**Fig 76** Bud scales of willows with primitive traits (A) and of true willows (B). A: The scale is free and overlapped at the adaxial side. B: The scale is fused to form a bag-like structure.

### (3) An encounter with willows in the Bogor Botanical Garden

In early October, 1995, I had a chance to give a seminar on liquid nitrogen storage of genetic resources, at the Research Center for Biotechnology, Indonesian Institute of Sciences. The first thing I did after reaching Bogor was to visit the Bogor Botanical Garden to see if there were any tropical willows there. This Botanical Garden was established in 1860 by the Dutch. It is internationally known for its collection of tropical plants from all over the world.

The list of plants indeed had *Salix tetrasperma*. This is the same species as the willow distributed widely in India and Thailand. Following a map of this botanical garden, I finally stood in front of two giant trees. They were undoubtedly *Salix tetrasperma* and the label (Fig 77) said that they had been
brought from Sumatra. Each tree was about 40m tall with a chest height diameter of about 1m. Many new shoots were coming out from the base of the trunk. There was a pond very close to these trees, which probably supported these willows for many years, because willows planted at two other locations [in the garden] did not exist anymore. After seeing these giant willows, I felt a kind of excitement that I had not felt for some time and happily spent almost 3 hours sitting beside them. If these trees had been planted at the time when the botanical garden was established, they must have been about 180 years old. After seeing these giant willows, I once again fell under their spell.

In 1996, the following year, I collected shoots of *Salix tetrasperma* (Fig 78) growing naturally along rivers in the ancient cities of Ayudhya and Chiang Mai north of Bangkok. I found that in these locations, the willows shed their leaves at the end of December in the dry season (November to April) and unfold new leaves in the middle of January. When I visited the Bogor Botanical Garden again, I obtained special permission from the Director to collect several shoots with buds, growing on the trunk near the ground.

I requested Mr. Toshikazu Matsumoto of the Shimane Agricultural Experiment Station at Izumo to plant these willow cuttings in a greenhouse, move them outdoors, make observations, and conduct tests on frost hardiness. At Izumo, the temperate willows growing outdoors shed their leaves in December. But the tropical willows retained their green leaves even up to the end of December and continued growing. But the tips of the shoots died off because of strong frosting in January. This suggested that tropical willows did not shed their leaves or enter dormancy when the days became short and the temperature low in autumn. I then requested Mr. Matsumoto to freeze some samples after exposing the overwintering shoots to 0°C for two weeks at the end of January. The willow from Ayudhya (N Latitude about 12° and mean temperature in January 26°C) of Thailand withstood -7 to -10°C and opened its buds and continued growth afterwards. Similarly, the willows from Chiang Mai (N Latitude about 18°, altitude 313m, mean January temperature 21°C and daily average minimum temperature 13°C) withstood freezing up to -15°C. The willows from Bogor (originally from Sumatra) showed poor growth and had weak shoots but tolerated freezing to -5°C. We may interpret these results as follows: Although these tropical willows had been growing for many generations close to the Equator, they
have retained the frost resistance that they had acquired when they were growing in warm temperate areas a long time ago. When exposed to near-zero temperatures, they express this capacity to some extent. Contrary to this, deciduous Dipterocarpaceae trees, which are representative of tropical rain forests, could not withstand freezing at all when their shoots were tested in the leaf shedding season. When the shoots of *Ficus whightiana*, another tree that had moved north from the tropical zone to Okinawa, were exposed to cold and then frozen, after the leaves had been shed in the winter, they died of freezing at -5°C.

From the findings of these experiments, I had speculated as follows about the primitive *Salix tetrasperma* trees presently found widely distributed in the tropical lowlands of East Asia. Compared to the high vitality of willows of the temperate zone, these primitive willows did not have sufficient competitiveness to be able to spread to the temperate zone of the Northern Hemisphere, and remained limited to warm temperate areas of subtropical Asia, as relics. They probably moved further south during the Ice Age, lost their capacity to enter dormancy, and spread along the rivers in tropical areas that had a dry season. Most probably, many other willow species that had also moved south during the Ice Age, moved back to the temperate zone or high altitudes in search of suitable temperatures when it became warmer once again. Only this species (*Salix tetrasperma*) of willow remained in the tropical regions with a dry season and the subtropical regions of East Asia where it spread along the rivers. In Southwest Asia, *Salix safsaf* having primitive traits and growing in Iran and southern parts of Iraq spread south from West Asia to Africa passing through the huge gorges of Africa. *Salix safsaf* gave rise to many species and spread along the rivers up to the southern tip of Africa and Angola, in southwestern Africa. Interestingly, *Salix acmophylla*, which has traits intermediate between the willow of India and the willows of West Asia and Africa, grow in the area (in southern Afghanistan and West Asia) about midway between these two regions. *Salix bonplandiana* that grows in Mexico in the North American continent has moved down to South America.

*Salix chaenomeloides* is the only primitive willow species that grows naturally in Japan. The northern limit of its distribution is the northern part of the Miyagi Prefecture. Two or three types of willows with primitive traits are known to grow naturally in Taiwan. *Chosenia bracteosa* Nakai and *Toinus urbaniana* Kimura are ancestral willows belonging to Salicaceae, but they do not belong to the genus...
Salix. These ancient willows have lost their nectar glands and have wind-pollinated flowers. They are distributed in central Honshu, Hokkaido and cool parts of East Asia. As in the tropical willows, these willows have the free bud scales that are not fused on the adaxial side and have the basic chromosome number of 2n=38.

A few years back, Dr Azuma Takayuki (currently at the Botanical Garden of the Hokkaido University), then working at Professor Ohashi’s Laboratory at the Biological Institute, Graduate School of Science, Tohoku University, obtained results after DNA analysis that suggested that willows with primitive characteristics and the basic number of chromosomes that were distributed in the early tropics (earlier in the tropics?) had differentiated as species relatively more recently (about 0.36 million years ago onwards, around the middle of the Ice Age) than assumed. The differentiation of spin-off traits did not occur during the creation of these species, but it is interesting to speculate that this differentiation created an opportunity for willows to lose their cold-induced or short day-induced dormancy, and spread to new areas along the rivers of tropical lowlands, escaping from the cold.

In any case, willows now occur in environments with different temperature conditions on earth, including the temperate zone, polar regions, alpine areas and the tropical zone, mainly along rivers. It is indeed a superstar among woody plants. Weeping willows (Salix babylonica), which are very vigorous trees of the Northern Hemisphere, had been planted in various parts of South Africa for controlling soil erosion along rivers. According to a recent news item, small branches of this willow that drifted downstream have taken root, threatening the survival of indigenous willows, which have less vitality.
Fig 77  *Salix tetrasperma* trees (from Sumatra) growing in the Bogor Botanical Garden, Indonesia. Their height is about 40 m and chest height diameter about 1 m (Photographed by the author).
Fig 78  *Salix tetrasperma* growing naturally in Ayudhya about 8km north of Bangkok. These willows are basically tall trees but remain shrub-like because they are trimmed once or twice a year to provide feed for cattle (Photographed by the author).

*Translator’s notes:*
1. Words added by thetranslator for clarity are given in [square brackets]
2. Parts of the source text that are ambiguous and require some modification are marked in pink and alternatives are sometimes given in parenthesis.
3. Kindly check parts marked in orange. Their translation is uncertain.

Chapter 6
Dr Sakai’s suggestions
marubayanagi: *Salix chaenomeloides* Kimura; keshowyanagi: Chosenia bracteosa Nakai; oobayanagi: Toisusu Urbaniana Kimura
Please add part II-Chapter 6,
Africa (refers: Sakai and Larcher 1987, fig.7.40, page 233)

Weeping willows (Salix babylonica) thank you very much, Sakai
7 Changing rules of nature

Although individual trees are fixed to the ground and do not move, forest vegetation has seen migrations, successions, and rise and fall with the changing environment and climate. The changes with time in forest colonies, i.e., forest successions, are changes in forest flora on a time scale of several hundred years or a few thousand to a few hundred thousand years at the most. Contrary to this, there are geohistorical changes that take place over a much longer timescale. In a broader sense, succession means change in the dominant species. The history of evolution of living things over a period of 3000 million years on the stage of this earth is, in a way, a story of large-scale changes of the dominant species.

(1) Climate change and changes in forest vegetation

i Migration of forests in the ice ages

The period from about 1.6 million years ago to the present is known as the Quaternary Period. The Quaternary is divided into the Pleistocene (the ice ages) that lasted from 1.6 million years ago to about 11,000 years ago and the current Post-Glacial Age. During the Pleistocene, there were at least 4 ice ages with interglacial ages between them. The last Ice Age started about 70,000 years ago and ended 11,000 years ago. In the coldest period of the last Ice Age, the sea level is said to have been about 100m lower than now globally and temperature lower by about 7°C. A lowering of the annual temperature by 7°C would mean that the annual mean temperature of Tokyo, which is presently about 15°C, would become 7.8°C, which is the current mean temperature in Sapporo. Sapporo would have had an annual mean temperature of the present Western Siberia, about 0°C. The temperature changes by about 6°C for every 1000 m of altitude. Therefore, in the coldest period, the vegetation of mountainous regions must have moved down by more than 1000 m. It has been estimated that at that time, most of the interior of Hokkaido was a tundra with open forests here and there. It is believed that during the coldest part of the last Ice Age, warm temperate evergreen broad-leaved forests of Japan had disappeared from Honshu, except from some parts of the warm Pacific Coast. The interior parts of the Tohoku region and Chubu region were probably covered with subarctic needle-leaved forests. Fossils of northern needle-leaved trees like *Picea jezoensis*, *Abies mariessi* and *Larix leptolepis* have
been discovered from the soil stratum belonging to the last Ice Age, in Ekoda, Tokyo. In this sequence of repeated ice ages and interglacial ages, some plants survived by expanding their range northwards or southwards in search of suitable temperatures. But in places where mountain ranges run east-west, such as the Alps of Europe, their southward migration was blocked and many of the species became extinct.

After the end of the last Ice Age, the ambient temperature rose gradually while undergoing repeated fluctuations, and in the warmest post-glacial time (the hypsisamar (hypsithermal?) interval of about 6300 years ago) the temperature is said to have been about 3°C higher than now. In Japan, during the warming phase after the Ice Age, Japanese beech (Fagus crenata) trees rapidly spread towards the snow-covered areas of the north and reached the northern end of Honshu from the Wakasa Bay in about 3500 years. This type of shifting of forests in response to change in the ambient temperature is a very slow process. On the other hand, when a forest recedes because of a reduction in temperature, some areas with favorable conditions remain as refuges. Groups of plants that survive there during the harsh inhospitable period start multiplying when the temperature increases. They gradually expand their ranges through seed dispersal, and the refuges eventually get connected. The plants that survived can spread very rapidly in this manner, it is believed.

Trees are fixed to the ground and cannot move by themselves. But groups of trees that exist in forest communities disperse a very large number of seeds over a wide area. If we assume an average lifespan of 250 years for a tree, there will be 4 generations in 1000 years and 20 in 5000 years. The seeds become the progeny after being subjected to the natural selection pressure of climate change. Forests move considerable distances towards favorable temperatures in this manner over long periods of time.

ii Mountain vegetation that became extinct

Slopes of mountains of the Tohoku region facing the Japan Sea are all areas with heavy snow cover. The deepest snow cover is 3-4 m on the average in areas above 800 m. As we move higher, Japanese beech trees that constitute the upper storey of the forest become shorter and their frequency also becomes less.
time, ground-hugging shrubs such as *Fagus crenata*, *Miamana* (Quercus magnolica var. undulatifolia), *Alnus maximowiczii*, *Miamakaide*, *Sorbus sambucifolia* and *Sasa kurilensis* appear in the lower storey. There are no needle-leaved trees at all in this area at heights where one would expect to see them. Such areas are called the pseudoalpine zones. Until recently it was thought that needle-leaved trees did not exist here because their growth was inhibited by the snow pressure in these heavy snow cover areas.

In 1982, after studying the Japanese beeches on Mt. Naeba, Kaji confirmed that during the warm post-glacial age, the forest vegetation had extended to 200-400m higher than its present range and proposed the following hypothesis about the pseudoalpine zone: During the post-glacial warm period, the montane forest vegetation belt climbed up on the mountain in search of suitable temperatures. During this time, when the lower limit of the needle-leaved tree belt became higher than the height of a particular mountain, that vegetation disappeared. On such mountains, therefore, when the vegetation moved down during a cool period that followed the warm period it lacked the species that had been pushed out. However, if the mountain was sufficiently tall, it did not lack the upper part of the vegetation and the vegetation sequence of the warm period descended almost intact. Kaji assumed that *Abies mariessi* was the species that the pseudoalpine zone of this area was lacking, studied its distribution in great detail from the flora of that area and the literature, etc and proved the above hypothesis. He thought that forests of bushy trees created by reduction in the height of trees had expanded their range during the post-glacial warm phase to the spaces thus created. He also clarified that such pseudoalpine zones were not limited to heavy snow cover areas but were also found on the Appalachian Mountains in Eastern USA.

(2) Succession in the Alaskan forest and formation of permafrost

Plant succession is one of the major concepts in ecology. It is the change in flora with time. For example, if we stop weeding in an upland field or a paddy field, miscellaneous plants would grow all over it in no time. In the following year, tall grasses that are often found on the sides of roads would become dominant. Within 4-5 years, graminaceous plants like *Miscanthicus sinensis* and *Imperata cylindrica* take over. Soon we will have a thicket of assorted trees. In short, one plant community is taken over by a group of other plants and eventually a stable climax
A colony of plants is established. It is difficult for higher plants to cope with fast changing environments by modifying their forms and functions. Instead, they change through succession of plant communities.

Fairbanks and its surroundings in interior Alaska are located in a transitional zone on the edge of the permafrost area. The southern slopes of hills and places close to rivers in that area have forests of 10-20 m tall (with chest height diameter about 20-30 cm) broad-leaved trees like white birch, poplar and white spruce (Picea glauca, a relative of Picea jezoensis). In those areas, the soil temperature is high, and the soil thaws to a considerable depth, is well-drained and fertile. Contrary to this, on the northern slopes of the hills and on the plains, permafrost table exists quite close to the ground surface. Therefore, the soil temperature is about 0ºC, the water drainage is poor and the ground surface is covered with sphagnum moss. These areas have wetland forests of bushy (2-3m tall) black spruce (Picea mariana) trees. Thus, by looking at the vegetation we can determine whether permafrost exists below.

In interior Alaska, the succession of forests, i.e., willows -> poplars -> the evergreen needle-leaved white spruce (climax forest) -> black spruce (a wetland climax forest) continues.

In the sandy soils of the flood plains created in the spring, firstly, willows, which are the earliest to flower and set seed, disperse a large number of seeds and occupy the virgin land (Fig 79). Soon, other trees like poplars make their entry. But willows are particularly hardy on the unstable land along the riverbanks. Even when the ground surface is covered many times with sand and mud, they easily extend their roots from their stems and continue to grow there.

After 10-15 years, the litter of willows accumulates, nutrients accumulate, and the land becomes stable. In about 20 years, poplars surpass the willows in height and it becomes a poplar forest. The willows, which have a shorter lifespan, disappear in this process. Shade tolerant conifers like white spruce that had a meager existence on the forest floor below the poplars start growing faster as the soil becomes enriched with large amounts of poplar litter. In about 100 years, when the white spruces become taller than the poplars, the poplars, which cannot grow in the shade, get reduced in number and gradually disappear, allowing the needle-leaved trees to dominate the forest. Thus, it takes about 250 years for a white spruce forest to get established naturally on virgin land. The ground thaws fast and to a
great depth on the southern slopes and riverbanks in summer, and the soils are warm, nutrient-rich and well drained. White spruce is dominant in such places. This is the climax of the succession (Fig 80).

On the plains, however, the situation on the ground changes altogether after the leaves of the conifers cover the surface. In fact, a thick layer of three kinds of mosses covers the ground. Once this happens, the heat above the ground is not easily transmitted to the underground parts and the soil frozen in the winter does not thaw even up to autumn. Soon, fresh freezing occurs from the ground surface downwards and the seasonally frozen soil connects to the already frozen soil and becomes part of the permafrost. When soil that never melts during the whole of the year is once formed near the ground surface, the drainage becomes poor and white spruce, which likes well-drained soils, declines. In its place, sphagnum moss and a wetland forest of short black spruce trees that can grow well on poorly drained soils (Fig 81) are established. Fig 82 is a diagram showing the succession of the vegetation. The black spruce forest is the climax community of succession in such poorly drained plains and northern slopes. In the permafrost zones of Alaska and Canada, this type of segregation of tree species occurs, depending on the depth of the seasonal melting layer.

Forest fires are frequent in interior Alaska, which is quite dry in the summer. When a wetland forest gets burnt in this manner, the surface vegetation burns and the melting layer becomes deeper. The inorganic nutrient content of the soil also increases which triggers a new succession. Black spruce opens its cones only when exposed to forest fires. It then disperses a large amount of seed. Flooding of the river banks and forest fires play important roles in renewing the succession of plants in the permafrost zones of Alaska and Canada.

In the forests of Alaska, the plants that thrive at a certain time create through their activities an environment that is not suitable for their own survival and always provide, instead, soil for other plants that would follow. Succession of plant communities occurs in this manner.
Fig 79  A cluster of willow seedlings on a flood plain along a riverbank.  (Photographed by the author, 1974).

Fig 80  A white spruce forest established near a large river.  (Photographed by the author).
Fig 81 A wetland forest of black spruce (On the outskirts of Inuvik, Canada).
A diagram of succession of forests in Alaska.*129.

**Key:**
*In the Fig, from left to right:* Permafrost; Wetland forest; Black spruce; White spruce; Balsam poplar; Willow; Water level of the river.

(3) **Geohistorical succession of dominant species**

Succession is, in a way, a change in the dominant species. The history of evolution of living organisms on this earth over a period of 3000 million years can be viewed as a history of grand successions of dominant species. At one time, fish were dominant. Then it was the turn of reptiles, then mammals, and now humans who are also mammals. There is no doubt indeed that continuous change is the true state of nature. The human race too would be no exception. All the activities being undertaken for promoting human prosperity would themselves create an environment unsuited for our survival. When a time comes when humans can no longer biologically adapt to a global environment that they themselves have
changed, they may have to give up their dominant position to another species that would then take the lead. It would be inexcusable if humans become aware of this reality only when it is already too late. We must understand how crucial the global environment is for the survival of humans. It is sad to note that chemical substances synthesized by humans lower the immunological potential and reproductive capacity of humans and their progeny. It is truly regrettable that environmental degradation is bringing a large number of species, which have evolved over millions of years, to the brink of extinction. It would of course take a lot of time to regenerate the natural environment already degraded by humans over a long period of time. But I sincerely feel that we all should do whatever we can for restoring the natural environment.

Translator’s notes:
1. Words added by the translator for clarity are given in [square brackets]
2. Kindly check parts marked in orange. Their translation is uncertain.
3. Parts where the source text needs some modification are shown in pink and alternatives given in parenthesis

Dr. Sakai’s suggestions

page 207: Chigaya Imperata ; susuki Miscanthus sinensis
8 Giant trees of the world that have lived for 2500 years

(1) The lifespan of plants and animals

A major difference between plants and animals is that plants cannot move around while animals can. This is closely related to how their bodies are made and their lifespan. Unlike plants, animals cannot synthesize the food they need. So, they have to move around and hunt other living things for food. Therefore, in higher mammals, nerve and muscle cells are particularly well developed so that they can execute complex movements efficiently. Moreover, their body temperature is maintained at a certain high level so that they can move fast. Their energy consumption is 30 times that of heterothermal animals. Apparently, mammals have opted for a shorter life and high expenditure of energy for fast movement of their bodies\textsuperscript{70}.

Plants, on the other hand, get established at a suitable place with sufficient water, light and inorganic nutrients, produce seed, and continue to produce progeny. Trees in particular make their bodies very large in search of sunlight and appear to have chosen the strategy of living longer. Plant cells are surrounded by hard strong cell walls. The cell walls are particularly well developed in trees. The cells, each surrounded by a hard cell wall, arrange themselves like laid bricks during the growth of the tree. The apical meristems of buds are involved in the elongation of shoots and trunk and another meristematic tissue called cambium located between the bark and the xylem takes part in the thickening of the trunk. In the trunks of trees, only the cells near these growing points are alive. This is very convenient for support because the energy requirement for respiration is very much reduced. The stems and shoots are made of not easily digestible macromolecular compounds like cellulose and lignin. Besides, they also contain substances like tannin, which protect trees from insect damage. Leaves also contain various substances like tannins and alkaloids that protect them from insects. Because of such protective measures, the proportion consumed by animals is not more than a small percentage of the net production of trees. Trees are thus a difficult to use food resource for animals. We may say that this is the reason why the earth still has a green cover.

Cells are similar in different parts of plants and they are totipotent. So, if we take
out a cell and culture it under suitable artificial conditions, we can regenerate a plant. In particular, we can produce genetically identical clones vegetatively in large numbers through aseptic culturing of the apical meristems (growing points). Thus, plants and animals are very different in the way their bodies are organized and also with regard to the concept of individual longevity.

Unlike animals, plants can continue to live for fairly long periods of time if they do not encounter natural calamities and if they are located in a favorable place. Besides, *Katsura* tree (*Cercidiphyllum japonicum*) and many other trees have the property that when the tree becomes old, many suckers grow from the base of the trunk, at the ground surface or near it, which grow taking nutrients from the trunk of the parent tree. These soon become independent trees growing near the parent tree. So, although many individual trees have lifespans, some appear to grow continuously and do not seem to have individual lifespans.

**Fig 83** Young *Katsura* trees (*Cercidiphyllum japonicum*) growing near the parent tree, utilizing nutrients from the old and decaying parent tree (Photographed by the author on Mt. Moiwa). N: Independent trees near the parent tree. O: Roots that absorb nutrients from the old decaying parent tree.
(1) Giant trees of the world and the Mediterranean climate

There are a number of giant trees in California believed to be 2000-3000 years old. Yakushima island in Japan has some giant *Sugi* cedars (*Cryptomeria japonica*) like the "Jomon Sugi" that are several thousand years old according to some reports. However, many of the giant cedars of Yakushima are partly broken by storms, etc, the upper parts of their trunks had been cut off earlier by people, and the remaining bases of the trunks are now becoming hollow. In any case, if they have lived for a few thousand years, they must have experienced a number of typhoons, lightning strikes, forest fires, land slides and other such natural disasters. It is certain that the area where these giant trees are growing had relatively few natural calamities, rich soil and plentiful water. Tropical rain forests that have high productivity and few typhoons have many giant trees. But it is difficult to determine their age because trees in tropical rain forests do not have distinct tree rings. However, because of the high temperature and humidity, energy consumption for respiration would be high and these giant trees are likely to be only about 100-300 years old. It seems that warm temperate coniferous forests of middle latitudes have many giant trees that are taller than those of tropical forests.

The western coast of USA has a Mediterranean climate, dry in summer with a lot of rain in the winter. Normally, the rainy season continues from mid-October to March, with very little rain from April to late October. During the summer, the dry season, the grass on the ground looks brown and almost dried up. Herbaceous plants germinate in late autumn after the start of the rainy season and the mountains and fields turn green all over and misty with rain. On this West Coast, from California in USA to Vancouver in Canada, from the coast to the hills, a temperate needle-leaved tree belt consisting mainly of Douglas firs (*Pseudotsuga menziesii* (Mirb) Franco exists. The winter here, which is the rainy season, is mild and there is no strong cooling. In the summer, when the climate is dry, mist provides the moisture and snow-melt water supports the forests.

Stands of 60-70 m tall giant Douglas firs can be seen in the states of Oregon and Washington, which are north of California but have mild winters, and on the Vancouver island of Canada (50° N Latitude), which is more northern than
Hokkaido. The forests of 70-100 m tall evergreen broad-leaved eucalyptus trees are also famous. Thus, if we exclude the tropical forests, giant trees are mostly found in areas with Mediterranean climate. In regions where the summers are dry and winters rainy, there are perhaps fewer tree diseases and less rotting of trunks than in areas with warm and moist monsoon climate. Apart from this the mild winter of Mediterranean climate and absence of strong cooling that might cause trunk freezing are also advantageous for trees. In places where strong cooling occurs in winter, trees have to stop growing early and prepare for the winter, sacrificing quite a bit of growth. I believe that these are the reasons for there being many giant trees in regions with Mediterranean climate.

In places like Hokkaido, where the summer temperatures are relatively low and the winters are severely cold, trees rarely become taller than 40 m. The oldest Mizunara tree (Quercus mangolica) recorded at the Hokkaido Experimental Forest of Tokyo University was 614 years old and the oldest Akaezomatsu spruce (Picea glehnii) tree recorded at the Teshio Experimental Forest of Hokkaido University was 625 years old. This tree was 40m tall and had a trunk diameter of 1m. Seattle on the western coast of USA, which has a mild winter, has an Olympic National Park (Latitude about 48ºN) which is at about the same latitude as the central and southern Sakhalin islands. The Sitka spruce trees in the temperate rain forest in this park are 90m tall with trunk diameter 4m and girth as much as 13m. We cannot find such giant trees anywhere in Hokkaido, which has severe winters.

(2) Giant trees of the world and the General Sherman tree

The Yosemite National Park is located about 200 km east of San Francisco. Some distance southeast of Yosemite, there is a Sequoia National Park. A giant sequoia tree in this park, named General Sherman, has a maximum trunk diameter at the ground level of 12.3 m, girth at ground level 32.8 m, height 82 m, estimated age 2500 years, and estimated weight of 1250 tons. This is the largest tree in the world (Fig 84). Unlike the aged cedars of Yakushima, these giant sequoias are alive up to the tips of their trunks and continue to grow even now. Because of the dry climate of the summer, there are no mosses, lichens and algae attached to the trunks of these trees, which are red in colour.
The giant sequoias do not have a tap root that goes deep into the ground. Nor do they have plank roots, which tropical trees use to support themselves. Instead, the trunk has many **round buttressing bulges** at the ground level that are connected to the roots spreading near the ground surface (Fig 85). Many of these giant sequoias are found on mountains, such as on the western slopes of the Sierra Nevada, which have a comparatively large annual precipitation (1500 mm). Almost all of this precipitation falls as snow in the winter (snow cover 3m) with almost no rainfall in the summer. The giant sequoias living in this region are on mild slopes of basins where the snow-melt water stored in the soil can be used even in summer. They are thus well-adapted to face the dry climate and forest fires. This area is subjected to forest fires caused by lightning at the rate of about once in 20 years. Sequoias have an approximately 60 cm thick inner bark inside the outer bark that peels off easily. This inner bark does not contain any easily combustible resins. So it remains more or less intact even when the outer bark is scorched by lightning. The inner bark and the regions inside it contain various chemicals like tannins that prevent insect damage and fungal rots.

Another interesting feature is that like in the pines and eucalyptus in dry areas, the cones are tightly sealed with resin and do not open unless they are heated in a fire. So, unless there is a forest fire, the cones remain attached to the branches unopened for almost 20 years. Even if the cones open and the seeds get dispersed, they cannot germinate unless the humus layer accumulated on the ground surface is burned by a fire and the seeds reach the ground and get covered with soil.

General Sherman, the largest tree in the world, has luckily survived for the past 25 centuries, withstanding repeated forest fires and avoiding insect damage and fungal attack. But this tree also will fall some day after losing its balance like many other giant trees. Factors that can disturb the balance include damage to the roots, forest fires, changes in the surrounding environments (paving of roads and people walking on the ground around the tree), strong winds, abnormal snow cover, earthquake and climate change, and also a combination of some of these factors.
Fig 84 General Sherman, a giant sequoia tree. Height: 82m, girth at ground level: 32.8m, estimated age: 2500 years. (Photographed by M.P.M. Nair, 2000).
(4) Giant trees and annual herbs

The strategy of surviving as a giant tree was beneficial when the climate was mild and stable, as in the period up to the early Tertiary. The large bodies of these trees confer another advantage; they provide the ability to survive environmental changes and to withstand natural disasters better. However, when major environmental changes that cannot be coped with occur, they become extinct or remain as relics in well-provided special environments, because they have fewer chances of producing progeny that can adapt to the new environment. The current giant sequoia stands of California cannot compete with the highly competitive needle-leaved trees of the genus *Abies* under natural conditions. So, they are protected and maintained in a National Park.

Changes in the natural environment over a long period of time constitute natural history. The long-lived giant trees are time capsules that have survived with a
record of such changes in their trunks. Thus, they are very precious monitors of natural history.

The annual herbs are a stark contrast to these giant trees. They have short lives and have spread their range to drylands and cold areas where trees cannot grow. Unlike trees, the annual herbs disperse a large number of seeds every year. While some giant trees complete one generation in 3000 years, the annuals have 3000 generations during the same period. By continuing to disperse large numbers of seeds with rich genetic variation every year, they can adapt rapidly to environmental change. The biggest strength of short-lived herbs is the swiftness with which they can adapt to environmental changes. This is even truer for microorganisms with generation times of hours or days.

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3. Parts where some modification appears to be necessary are shown in pink with alternatives in parenthesis

Dr Sakai’s suggestions for Chapter 8:
Chapter 8 Fig. 83, Cercidiphyllum japonicum
Douglas fir (Pseudotsuga Carr.)
Please correct Chapter 8, Line 3 (upper) Page 3: Pseudotsuga menziesii (Mirb) Franco, thank you, Sakai