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Preparing a Tree Plating Zone Map for Landscaping in Hokkaido

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Abstract

Geographical planting distributions of 125 tree species for landscaping in Hokkaido were surveyed by means of questionnaires, and the temperature parameters which were most closely related to their distributions were examined. The most suitable parameters related to the distributions seemed to be the average annual minimum temperature or January mean temperature. By using the isogram of average annual minimum temperatures partially revised with a 'Index of Warmth' isoline, a tree planting zone map for Hokkaido was prepared.

Key Words: Tree planting distributions, Tree planting zone map, Temperature factors, Isogram of average annual minimum temperatures, Index of Warmth, Landscaping, Hokkaido.

1. Introduction

In tree introduction programs in urban areas for landscaping, selection of adaptable species must firstly be made. The most important and the least readily controlled factor of the major environmental factors governing the geographical adaptability of trees is temperature. Selection of trees, therefore, should be made with due account to the temperature factors in each area. However, in practice, tree introduction is apt to be made by trial and error, resulting in occational failure in establishing certain species.

A few reports are available which deal with preparing a tree planting zone map on a nationwide scale; the 'Planting distribution group' map prepared based on the geographical distribution surveys by Iijima[5], Planting zone map using climatic zones by Ohyama[11] and 'Growth area' map based on winter mean temperature by Nakamura[28].

In selecting trees for practical purposes in a certain area, however, it is desirable to have a more detailed zone map on a regional basis. This study was undertaken 1) to survey the geographical planting distribution patterns of trees for landscaping in Hokkaido, 2) to analyze the temperature factors governing their distributions and, on the basis of these factors, 3) to prepare a tree planting zone map for Hokkaido.

2. Data

Of the tree species cultivated for landscaping in urban areas in Hokkaido, 125 important native and introduced species, including deciduous trees and evergreens, were selected for the present study[3,4,5,8,26]. A survey of their geographical distribution ranges was made by means of questionnaires. Questionnaires including a list of trees to be surveyed were sent to the sections in charge of lanfscape management in the city offices and the respondents were asked to indicate the occurrences, growth state, etc. of the entries within their cities. Answers were collected from a total of 110 cities.

As possible temperature parameters most closely related to the planting distribution of trees, the following were used in this study : January average temperature (JAT), average annual minimum temperature (AAMT), extreme minimum temperature (EMT), annual average temperature (AAT), 'Index of warmth' above 0°C (IW)*, 'Index of coolness' below 0°C (IC)* and length of frost-free period (FFP)[5,6,7,22]. The data for average annual minimum temperature were provided by the Sapporo Meteorological Observatory and the others were from "The Climate of Hokkaido, 1982"[27] published by the Meteorological Agency. Extreme minimum temperature is of extreme minima recorded since the establishment of each weather station until 1980. Average annual minimum temperature is based on a 30 year period from 1951 through to 1980, and the others are on a 27 year period from 1951 through to 1977. (Only the averages based on more than eight years were used when data were incomplete.)

The program SPSS was used for statistical analysis of the data.

3. Methods and Results

Temperature parameters closely related to the geographical distributions

In order to examine what temperature parameters are most closely related to the planting distributions of trees, the relationship between each parameter and planting distributions were analyzed in 90 cities which had climatic data by the following method.

In judging the occurrence of a certain tree species in a city, the cities which had well-growing specimens were referred to as present and those having no and low-growing specimens were referred to as absent, to meet the convenience in utilizing the resulting zone map. Cities were arranged according to their values (high to low) for each parameter and were replaced by the responses to tree occurrence (Table 1). In carrying this out, such cities were very likely as not to have certain trees only because they were not urbanized, but not due to a climatic cause, or because of certain local specific climatic situation. For this reason three neighbouring cities were treated as a unit (=a city group) to exclude the confusing effect of such cities. The range within which the responses to occurrence of

* Calculated by suming the normal monthly mean temperatures of all months with a mean temperature above or below 0°C.

Table 1. The responses to tree occurrence for each temperature parameter (Example: *Tamarix chinensis*)

Temp. parameter	City group* number																														'Segregation index'
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
JAT**	○	○	○	○	○	○	○	○	×	○	○	×	○	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	2
AAMT	○	○	○	○	○	○	○	○	×	○	○	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	1
EMT	○	○	○	○	○	○	×	×	○	×	○	×	×	×	○	×	○	×	×	×	×	×	×	×	×	×	×	×	×	×	4
AAT	○	○	○	○	○	○	○	○	×	×	○	○	×	×	×	×	○	×	×	×	×	×	×	×	×	×	×	×	×	×	3
IW	○	○	○	○	×	○	○	×	×	×	○	×	○	×	×	○	×	×	×	×	○	×	×	×	×	×	×	×	×	×	6
IC	○	○	○	○	○	○	○	×	○	×	○	×	×	×	○	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	3
FFP	○	○	○	×	○	×	○	○	×	○	×	×	○	×	×	×	×	×	×	×	×	×	×	×							(5)***

Transitional range

○ : Present, × : Absent.

* Arranged according to their values (high to low) for each parameter.

** See text for the abbreviations.

*** For 24 city groups which have the climatic data.

trees were not orderly was designated as a transitional range, and the smaller number** of the two kinds of responses, present or absent, within the range was counted as 'segregation index' which indicated the goodness of segregation of the distribution by the parameter. In the case of Table 1, the average annual minimum temperature shows the segregation index =1, indicating that the distribution of this species was most clearly segregated by this parameter. In the same way, segregation indexes by each parameter were obtained for 47 tree species which appeared to have their distribution boundaries among these city groups, and were averaged to obtain a mean segregation index (Table 2). The numbers of species in which the distributions are most clearly segregated by each parameter are shown in the right column of the Table 2. Although statistically significant differences are not necessarily evident because all of the parameters are highly inter-correlated, it may be recognized from the table that more tree species tend to be clearly segregated by the average annual minimum temperature or January average temperature. This result indicates that it is reasonable to use average annual minimum temperature as a temperature parameter on the basis of which a tree planting zone map is prepared.

Table 2. The mean segregation indexes of 47 tree species and the number of species in which the distributions are most clearly segregated by each temperature parameter: for 30 (24 for FFP) city groups

Temp. parameter	Mean segregation index±SD	No. of species most clearly segregated
JAT*	4.0±3.0[a]**	21
AAMT	3.8±2.6[a]	21
EMT	5.1±3.1[a b]	7
AAT	5.5±3.8[b]	11
IW	4.9±3.1[a b]	12
IC	4.8±3.4[a b]	13
FFP	(4.3±2.8[a b])	(15)

* See text for the abbreviations.
** Means followed by different letters are significantly different ($P<.05$).

Preparing a tree planting zone map

Drawing an isogram of average annual minimum temperature was attempted by plotting 264 observed temperatures on a map, supplemented by estimated temperatures at each intersecting point of latitude and longitude of 20' intervals. The method of estimating average annual minimum temperature at each point is as follows[9,10,30].

As the major geographical factors which affect temperature, latitude φ(°),

** By this method, the influence of the spontaneously isolated responses of present or absent can be become smaller.

altitude h(100 m) and distance from the sea l(km) are assumed. The temperature at point $i(=t_i)$ is expressed by the following formula:

$$t_i = t_0 + \frac{\partial t}{\partial \varphi} \Delta\varphi_i + \frac{\partial t}{\partial h} \Delta h_i + \frac{\partial t}{\partial l} \Delta l_i + \Delta t_i$$

where, t_0=temperature at the datum point

$\Delta\varphi_i = \varphi_i - \varphi_0$, $\Delta h_i = h_i - h_0$, $\Delta l_i = l_i - l_0$,

Δt_i=deviation by other factors of limited geographical areas such as topographical features, ground surface conditions, etc.

Multiple regression analysis was made between average annual minimum temperature and latitude, altitude and distance from the sea of 195 points, using the data appearing in the literature[10] and those read from a map, resulting in a formula of theoretical temperature by the three factors:

$$t_i = 102.17 - \overset{**}{2.77}\varphi_i + \overset{*}{0.57}\, h_i - \overset{**}{2.50} \log_e l_i$$

* significant at P<.05

** significant at P<.01

Moving the datum point to the latitude of 40°N, the following formula is obtained.

$$t_i = -8.46 - 2.77(\varphi_i - 40°) + 0.57\, h_i - 2.50 \log_e l_i \qquad (1)$$

Multiple correlation coefficient between average annual minimum temperature and the three factors is 0.839 and the coefficient of determination R^2 is 0.704, indicating

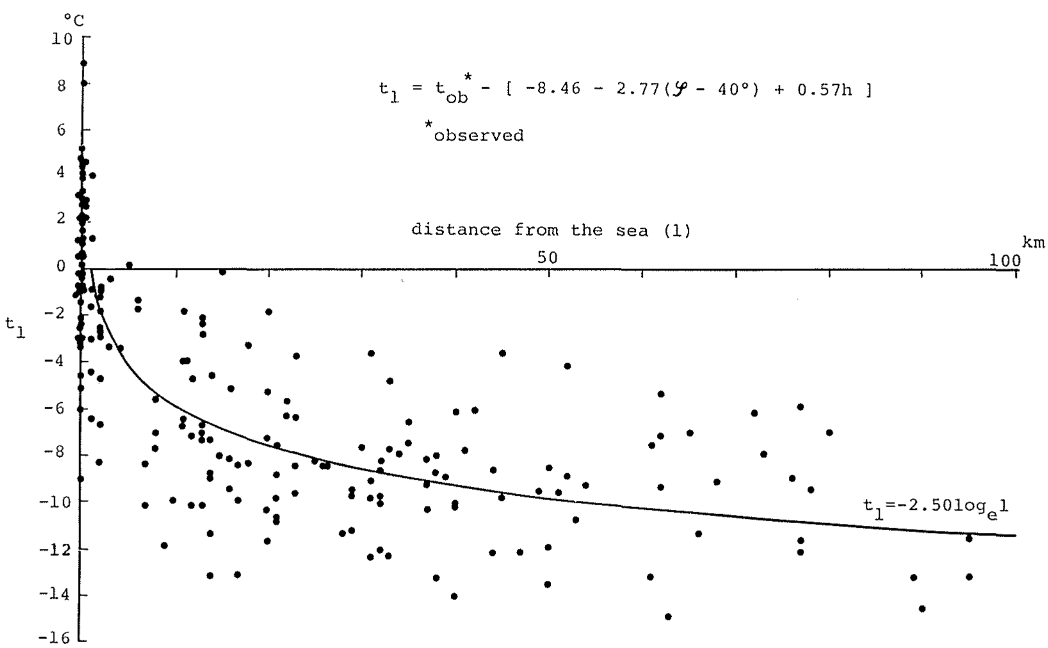

Figure 1. The effect of the distance from the sea on the average annual minimum temperature (t_1).

that approximately 70% of the temperature deviation is explained by these three factors. By comparing the absolute values of each standard partial regression coefficient, it is indicated that, of the three factors, distance from the sea (logarithmic value) has the strongest effect on the average annual minimum temperature, followed in order by the latitude and altitude, insofar as the region was studied. Partial regression coefficient of altitude is positive indicating the theoretically positive effect on average annual minimum temperature of increasing elevation. Figure 1 shows the effect of the distance from the sea on the average annual minimum temperature when excluding the influences by the two other factors. This figure indicates that the winter minimum temperatures are strongly influenced by the sea up to some 20 km from the coast, and are fairly raised[9].

After calculating the theoretical temperatures at each weather station by using the formula (1), the deviations between actually observed and theoretical values were yielded. By plotting the resulting Δt values on a map, an isogram of Δt was prepared (Figure 2). Estimated temperatures at each intersecting point of latitude and longitude of 20' intervals were produced by adding the Δt values read from Figure 2 to the theoretical values calculated using formula (1). An isogram of

Figure 2. The isogram of Δt between observed and theoretical average annual minimum temperatures (°C).

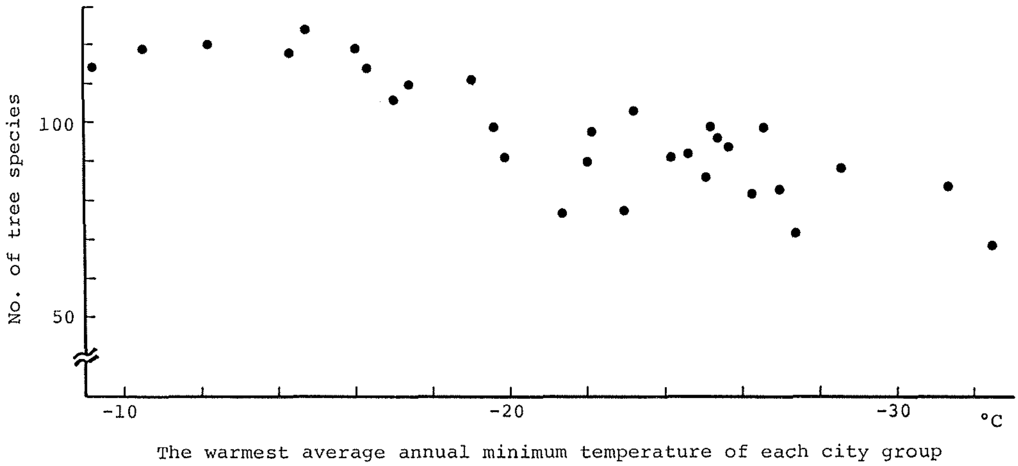

Figure 3. The relationship between average annual minimum temperature and number of tree species of each city group.

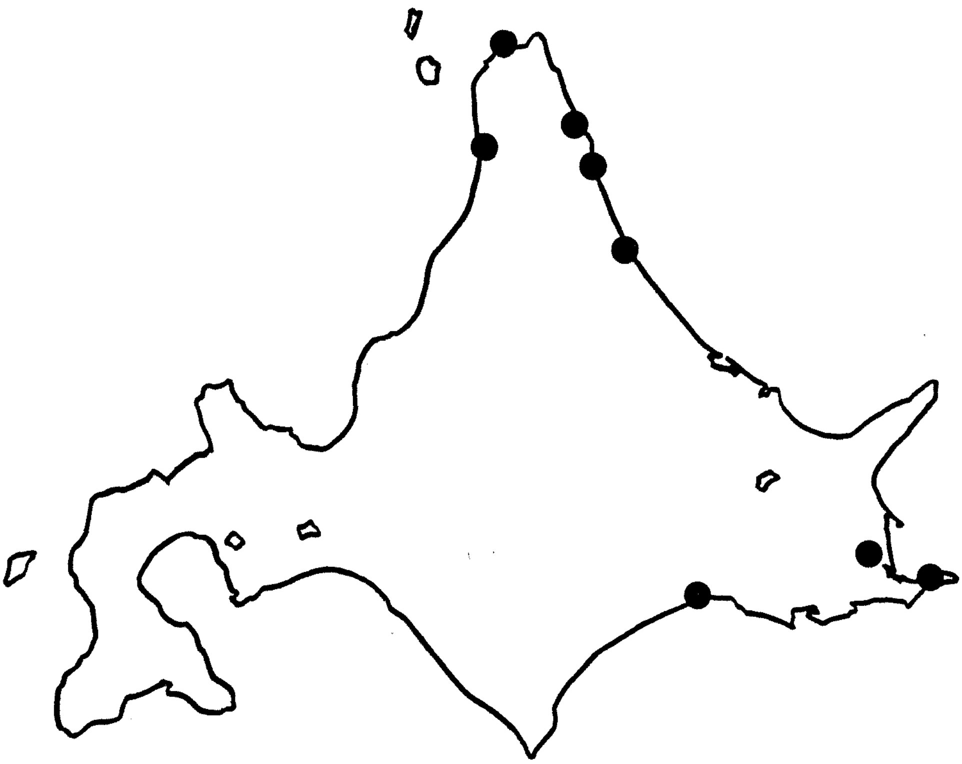

Figure 4. The distribution of the cities in which the ratios of the numbers of actually occurring tree species to those expected from the temperature distributions are below about 40%.

average annual minimum temperatures was prepared following the above procedures.

Figure 3 shows the relationship between average annual minimum temperature and number of tree species of each city group. From this figure it was judged that the decrease of numbers of tree species with temperature decline was gradual. Zone boundary lines, accordingly, were drawn mechanically with the same intervals (5.6°C (10°F)) according to the previous instance[1]. Determination of the coldest planting zone to where each tree species is adaptable was made by comparing the temperature of the point city group of the distribution to zone boundary temperatures; when the former largely corresponded to the latter, the same zone was taken, and the preceding zone was taken when not.

An attempt, however, to plot the distributions of each tree species on the prepared isogram made it apparent that tree species tended to be often absent in definite areas where they were expected to occur judging from the average annual minimum temperatures. Calculating the ratio of the numbers of actually occurring species to those expected from the temperature distributions in each city showed that the cities with fairly low ratios (below about 40%) were maldistributed (Figure 4), indicating certain common climatic factors other than minimum temperature limiting the tree distributions in the areas including those cities. This result was

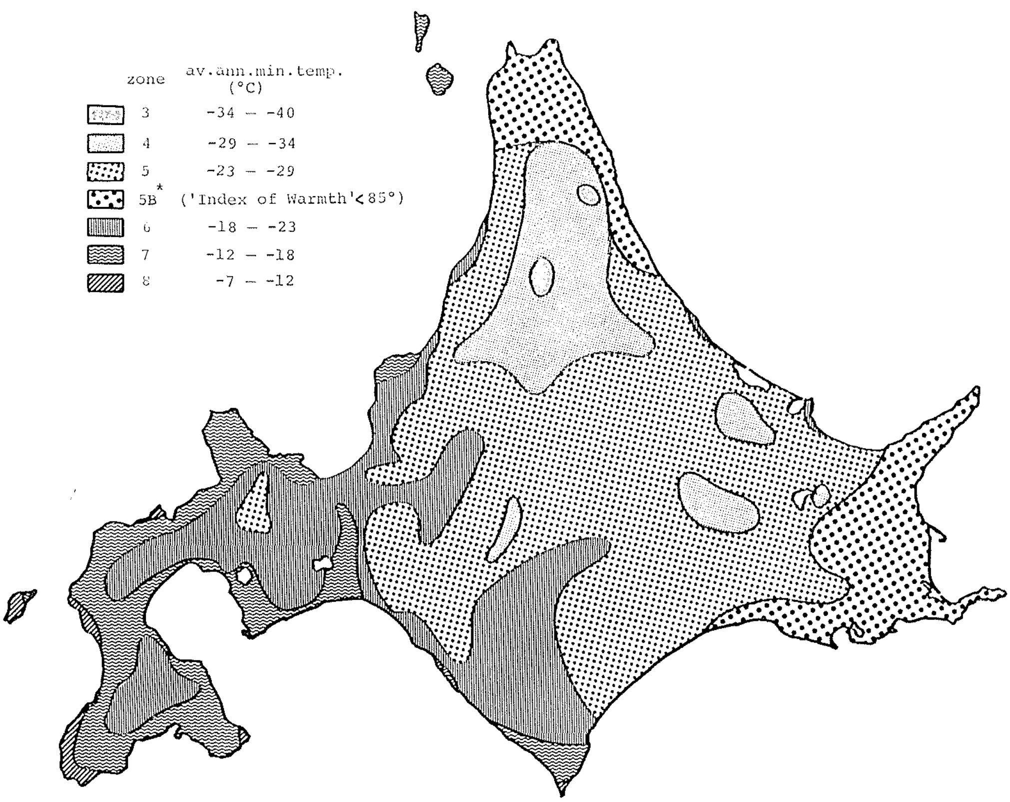

Figure 5. The tree planting zone map for Hokkaido.
* Boundary lines slightly simplified.

caused from the procedure in which a city group was used as unit area for which occurrence of each tree species was surveyed, neglecting definite cities which were often lacking in tree species due to the common climatic factors. This led to the need of partial revision including these areas of the average annual minimum temperature isogram to achieve an end product.

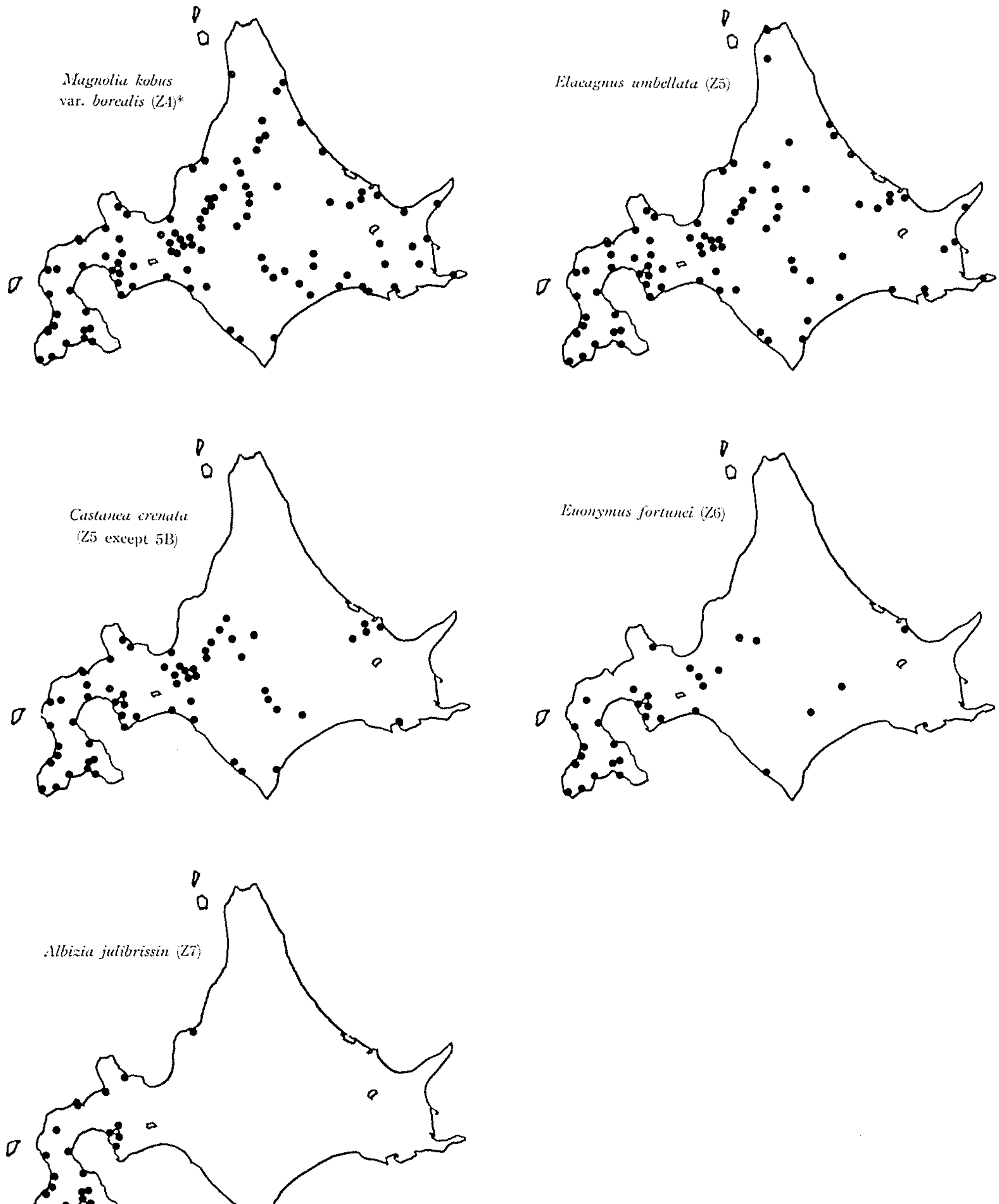

Figure 6. The planting distributions of some tree species.
* The coldest zone in which it grows.

Table 3. The list of tree species assigned according to the coldest zone in which they will normally grow

Zone	Name of tree species
3	*Populus maximowiczii, P. nigra, P. alba, Betula platyphylla* var. *japonica, Ulmus davidiana* var. *japonica, Cercidiphyllum japonicum, Malus baccata* var. *mandshurica, Sorbus commixta, Acer mono, A. negundo, Fraxinus mandshurica* var. *japonica, Syringa reticulata, S. vulgaris, Hydrangea paniculata, Rosa rugosa, Euonymus alatus, E. oxyphyllus, Rhododendron japonicum, R. dauricum, R. fauriae, Picea glehnii, Pic. abies, Pinus sylvestris, Pin. strobus, Pin. mugo, Thuja occidentalis, Juniperus chinensis* var. *sargentii, J. conferta*
4	*Larix leptolepis, Quercus dentata, Magnolia kobus* var. *borealis, M. obovata, Prunus sargentii, P. salicina* ↑, *Robinia pseudo-acacia, Tilia maximowicziana* ↑, *Cornus florida* ?, *Paeonia suffruticosa, Hydrangea macrophylla, Ribes grossularia* ↑, *R. rubrum* ↑, *Chaenomeles speciosa, Kerria japonica, Spiraea thunbergii, Lespedeza bicolor, Euonymus sieboldianus, Enkianthus perulatus, Rhododendron kaempferi* ↑, *Forsythia koreana, Liqustrum obtusifolium* ↑, *Weigela hortensis* ?, *Wisteria floribunda, Ilex crenata* ↑, *Taxus cuspidata, Abies sachalinensis, Pinus parviflora* var. *pentaphylla, Pin. banksiana* ↑ [*Ginkgo biloba, Populus euroamericana* ↑, *Platanus occidentalis, Aesculus turbinata* ↑]*
5	*Salix babylonica, S. matsudana* f. *tortuosa, Quercus rubra, Malus halliana, Prunus* × *yedoensis, Acer japonicum* 4 ?, *A. palmatum* var. *matsumurae* 4 ?, *Styrax obassia, Berberis thunbergii, Cytisus scoparius* ?, *Elaeagnus umbellata, Viburnum opulus* var. *calvescens, Parthenocissus tricuspidata, Cotoneaster horizontalis, Pinus densiflora* ?, *Juniperus chinensis* ? [*Castanea crenata, Magnolia denudata, M. stellata, M. liliflora, Prunus mume, Catalpa ovata* ?, *Philadelphus satsumanus, Corylopsis spicata* ?, *Rhodotypos scandens* ?, *Hibiscus syriacus, Rhododendron indicum, Chamaecyparis pisifera, Thujopsis dalabrata* var. *hondae* ?]*
6	*Juglans regia* var. *orientis* 5 [] ?, *Fagus crenata* 5 [] ?, *Zelkova serrata, Liriodendron tulipifera* ?, *Prunus persica, Ailanthus altissima* 5 [] ?, *Cornus kousa* ?, *Cercis chinensis, Buddleja davidii* ?, *Rhododendron mucronatum, Euonymus fortunei, Lonicera sempervirens, Pinus thunbergii* ?, *Sciadopitys verticillata* ↑, *Chamaecyparis obtusa, Thuja orientalis*
7	*Albizia julibrissin, Firmiana platanifolia, Stewartia pseudocamellia, Paulownia tomentosa, Tamarix chinensis, Mahonia japonica, Nandina domestica, Euonymus japonicus, Camellia japonica* 6 ?, *Fatsia japonica, Aucuba japonica, Kalmia latifolia* ?, *Pieris japonica, Osmanthus heterophyllus, Hedera helix, Cedrus deodara, Cryptomeria japonica*
8	*Poncirus trifoliata, Ligustrum japonicum*

↑ : Possible at least to the zone rated.
? : Estimated.
* The species enclosed in brackets may be impossible in the zone 5 B.

By overlapping isograms of other climatic parameters on Figure 4, it became apparent that an 85° isoline of 'Index of warmth' was largely suitable as a boundary line which separated the areas concerned. According to this, partial revision for the areas of the average annual minimum temperature isogram were made using this additional line, resulting in a final map displaying seven tree planting zones (Figure 5). Some examples of tree planting distributions are shown in Figure 6.

Table 3 lists tree species assigned according to the coldest zone in which they will normally grow.

4. Discussion

In Japan, temperature is the principal factor which determines tree planting distributions because there is little difference in precipitation throughout the lands. Furthermore, the distributions are exclusively limited in the north by low temperatures but not in the south by high temperatures[5].

As the temperature parameters which are most related to tree planting distributions, Iijima[5] referred to annual average temperature or January average temperature from his study on the geographical distribution patterns, while Sakai *et al.*[15,17,22] suggested that the average annual minimum temperature would be the determinant from their study on freezing resistance of trees. A plant hardiness zone map for the United States and adjacent Canada was prepared on the basis of average annual minimum temperatures[29]. The present study showed that the average annual minimum temperature or January average temperature might be the most suitable parameters related to tree planting distributions. Of the two parameters, the former was determined to be used in this study because of its possible direct influence on tree survival.

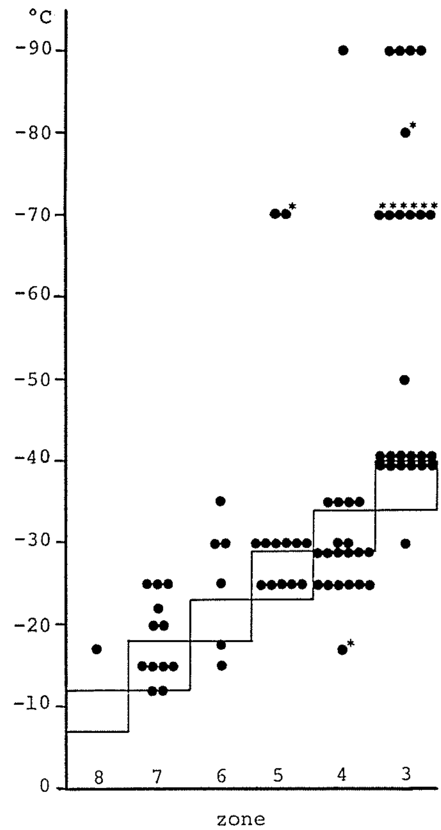

Figure 7. The relationship between the freezing resistance** of the trees and the corresponding zone temperatures; Only the species of which planting zones were determined were referred.

** By Sakai *et al.*[2,14,15,17–25]: the value of the least hardy part of bud, leaf and twig (stem). When the values were varied in the same species, that of the hardest specimen was used.

* Tissues were uninjured at the lowest test temperatures indicated.

Since even in the case where the segregation indexes of other parameters are smaller than that of the average annual minimum temperature, large differences are seldom found between them, it may be reasonable to use the average annual minimum temperature as a parameter which is generally related to tree planting distributions. However, the fact that partial revision by an 'Index of warmth' isoline was necessary for the average annual minimum temperature isogram indicates that summer heat is also another factor controlling tree distributions independent of winter coldness. An 85°-isoline of 'Index of warmth' is almost equal to a 55°-isoline calculated on 5°C basis which corresponds to a border line for some crop and fruit cultivations, indicating a critical line for heat requirement by plants during the growing seasons[7].

Figure 7 shows the freezing resistance of the trees by Sakai *et al.*[2,14,15,17~25] assigned to the corresponding zones rated here. It appears from the figure that in many cases freezing resistances of the trees roughly correspond to the temperatures of the zones to where they were assigned, indicating direct control of tree planting distributions by average annual minimum temperatures. The reason why trees do not need to be tolerant to the extreme minimum temperatures, and even to the average annual minimum temperatures according to species, of the cultivated areas may be by the fact that in urban areas trees are grown under artificial milder micro-climatic conditions. This tendency is pronounced especially in shrubs which are covered by protectors against the cold.

This tree planting zone map based on the average annual minimum temperature and partially on 'Index of warmth' should be appropriate for most general reference purposes in landscaping. It is necessary to consider other local climatic conditions than the above factors in determining whether a certain tree species will succeed in a given zone. For example, in the areas having strong wind and soil freezing in winter, trees are often damaged by desiccation[12,13,16].

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