TECHNICAL MANUAL
ON
ESTIMATION METHOD FOR YIELD PREDICTION AND INCREMENT IN NATURAL FOREST AND MAN-MADE FORESTS

**Technical Manual Series on
the Feasibility Study on the Forest Management Plan
in the Central Highland in Socialist Republic of Viet Nam**

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Con tents

Appendix 1 Feature of diagram and formula methods

Introduction

This book (hereinafter referred to as "the Manual") comprises one of seven (7) volumes produced by "The Feasibility Study on the Forest Management Plan in the Central Highland in Socialist Republic of Viet Nam" (hereinafter referred to as "the Study").   The Manual and the other six (6) volumes were prepared in compliance with provisions of the Inception Report and Annex1 in the Interim Report for the Study.

The Manual consists of two parts: (i) Method for measuring the increment of natural forest using fixed plot, and (ii) Method for preparing the yield table of man-made forest. The Manual was prepared for readers who, now or in the future, will have significant roles in the implementation of field activities on examination of increment and yield prediction in natural forest and man-made forest.

Hopefully, the Manual will be widely distributed and utilized.   Among others, the authors hope that readers will find it worthwhile to refer to and learn from the Manual when examining increment and/or yield prediction in other natural and man-made forest area, in addition to the Study Area (Kon Plong District in Kon Tum Province).   The Manual does not claim to be perfect.   Like most other manuals, it should be revised and updated from time-to-time as new knowledge is gained and improved techniques or methods are developed. This indeed is one of the intentions in further implementation of the Study.

1. Method for measuring the increment of natural forests using fixed plots

Although various methods can be considered for the measurement of the increment of natural forests, a method for the measurement of the increment of natural forests using fixed plots, which is considered to be effective for the measurement of tropical forests of which annual rings are unclear, will be described here. This is a method for measuring increment by establishing a certain number of fixed plots of a certain size, and measuring difference in stand volume between several time points.

1.1 Object of the survey

The object of the present survey is to obtain basic data for the establishment of future forest management plans, and for the operation methods of natural forests, through understanding the actual state of the stand volume, increment, and mortality of stands in natural forests, by establishing fixed sample plots in natural forests, and continuously surveying the fixed sample plots.

1.2 Definition of increment

The term " increment" used here means volume increment in a stand. The increment can be known as the difference in the total stand volumes of forest trees composing forest stand between two different time points. The size of each forest tree is naturally different if the time point of measurement differs. In addition, the constituting trees of forest stand differ in different time points. Therefore, when the increment is grasped, change in constituting trees must be considered in addition to change in the size of each of the trees. The change in constituting trees and the change in the size of each tree cause change in stand structure. Therefore, the increment is correctly known only through the process for pursuing this structural change.

In consideration of absolute structural change of forest stand, the conceptual volumes to know the increment are defined as follows:

(1)   Gross increment
        Total volume produced from all the trees of a stand in a certain period of time.

(2)   Mortality volume
        Volume of forest trees that became unusable in a year or a certain period of time due to forest fire, insect damage, tree disease, and climatic factors such as rainstorm and frost.

(3)   Net increment
        Net volume after deducting mortality volume from gross increment in a certain period of

time.

(4)   Yield

Volume of forest trees cut in a year or a certain period of time, regardless of whether or not they are removed from forests.

(5)   Net increase

Net volume after deducting dead volume and yield from gross increment in a certain period of time. Therefore net increase equals net increment, less yield.

(6)   Ingrowth volume

Volume of trees reaching a measurable size in a given period of time.

The increment generally known as the increment of stand volume is equivalent to the above-described net increment. That is, net increase is obtained as difference in forest stands at two time points, and net increment is obtained as the net increase plus the cut volume in the same period of time. In this manual, the volume of each tree is expressed by its stem volume.

1.3   Selection of fixed plot sites

One fixed plot will be established in every approx. 500 ha of a natural forest. The selection of fixed plots will be performed using the stratified sub-sampling method. For example, stratification will be performed in the order of 1) presence of selective cutting, 2) forest type, and 3) stand volume per ha or crown density. Specifically, stratification as shown in Fig. 1.1 can be considered; however, suitable determination can be made for each forest management unit. The forest management unit should be determined considering natural conditions, such as topology, climate, altitude, and vegetation; and socio-economic conditions, such as area, management, administration, physical distribution, and jurisdiction of forest enterprise. For example, in Kon Tum Province, a district unit is considered to be reasonable as a forest management unit. The value obtained by dividing the total area of natural forests in this forest management unit by 500 ha is the number of fixed plots.

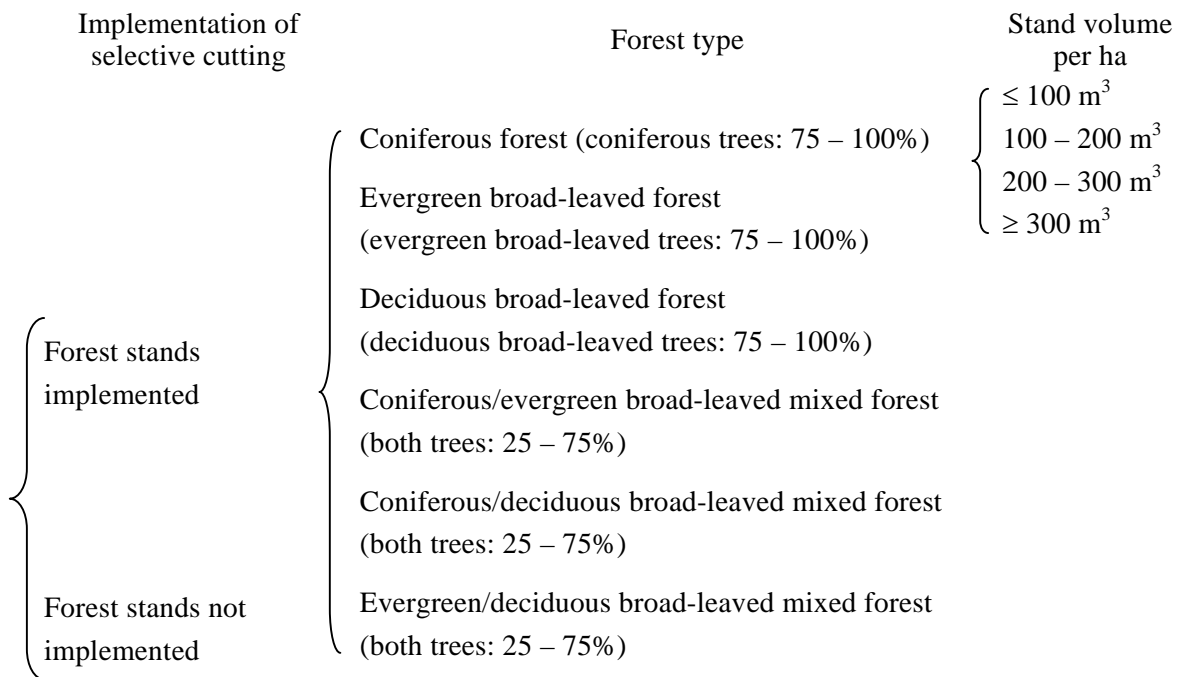| Implementation of selective cutting	Forest type	Stand volume per ha
Forest stands implemented Forest stands not implemented	Coniferous forest (coniferous trees: 75 – 100%) Evergreen broad-leaved forest (evergreen broad-leaved trees: 75 – 100%) Deciduous broad-leaved forest (deciduous broad-leaved trees: 75 – 100%) Coniferous/evergreen broad-leaved mixed forest (both trees: 25 – 75%) Coniferous/deciduous broad-leaved mixed forest (both trees: 25 – 75%) Evergreen/deciduous broad-leaved mixed forest (both trees: 25 – 75%)	$\leq 100 \text{ m}^3$ $100 – 200 \text{ m}^3$ $200 – 300 \text{ m}^3$ $\geq 300 \text{ m}^3$

Fig. 1.1 Example of stratification

Based on determined stratification, the places of fixed plots are decided using aerial photographs, forest-type maps, and field surveys. For the determination of the places for the fixed plots, the following method can be considered: First, the entire forest area in a forest management unit area is classified according to the stratification determined as much as possible. Next, plots are extracted from the populations of each forest type classified by the stratification by means of simple random sampling using dice and a random number table. This method contains statistically important points. However, if the random sampling method is used, places that are difficult for human beings to enter may be selected, and the continuous surveys may not be conducted. This suggests the possibility of lowering the accuracy of practical surveys because the statistical accuracy of the methodology is regarded important. Therefore, it is practical to select the places of the plots considering accessibility.

However, since crowns in forest edges, such as roads, tend to spread more than in forests, and affect the increment of trees, places like forest edges are avoided, and the plots are selected in the forest at least a linear distance of 100 m apart from the forest edges. The plots are selected also considering minimization of the deviation in the number of fixed plots in each forest type stratified, and are selected from the places that do not have a plan of clear cutting for harvesting or forest-road construction at least for five years from the establishment of fixed plots. Furthermore, considering the analysis of the results, the plots are selected so that a plot has an azimuth, and a plot has no complex topography that belongs to two or more topographic types. In addition, deviation in

azimuths or altitudes in all selected plots is also avoided.

1.4   Timing of the survey

This survey will be repeated every five years. As a rule, the time of the survey will be within two weeks before or after the day five years after the previous survey. If the time of the survey falls in the rest period of trees, the survey may be conducted within the rest period.

1.5   Procedures of the survey

1.5.1 Preparation of survey materials and tools

For field survey, the following survey materials and tools will be prepared.

(1)   Aerial photographs focused on the survey points

(2)   Forest type maps and forest management plan maps focused on the survey points

(3)   Previous field sheets (field sheets for site and forest conditions, tree measurement field sheets) (not required in case of the first survey)

(4)   Present field sheets (field sheets for site and forest conditions, tree measurement field sheets). Numbers, tree species and DBH etc. are copied from the previous tree measurement field sheets (not required in case of the first survey).

(5)   Survey tools
    1)   Diameter tape
    2)   Compass survey apparatus
    3)   Azimuth compass
    4)   Meter rope
    5)   Poles
    6)   Hypsometer
    7)   Slope distance conversion table
    8)   Protractor
    9)   GPS instrument
    10)   Origin indication board (Durable material that resists storage for years, such as aluminum)
    11)   Direction indication boards (Durable material that resists storage for years, such as aluminum)

12) Number tags (Durable material that resists storage for years, such as aluminum)

13) Wire

14) Nails

15) Hammer

16) Chalk

17) Felt pens

18) Writing instruments

19) Paint

1.5.2 Route to the survey point

The location of selected fixed plots is confirmed, and the route to the survey point is secured.

(1)   Preliminaries

1)   First survey

In the first survey, the place selected in Section 1.3 is confirmed using aerial photographs and topographic maps, and the route is roughly decided based on information of forest roads etc. In addition, a latitude and longitude of the survey points should be measured on the topographic map.

2)   Second and following surveys

The location of the plot is confirmed from the map recorded in the field sheets of the previous survey (see Fig. 1.3). Next, the location is marked on the aerial photograph, the forest management plan map, and the forest type map to make sure of the direction and distance to the plot.

The schedule is decided also referring to time consumed for the previous survey.
If there is a more convenient route than the previous route, because of the construction of forest roads after the previous survey, the new route can be used.

(2)   Route to the site

1)   First survey

When preparation is complete, the schedule is decided, and the field survey is started. The staff will follow the preliminarily investigated route to the plot. In the first survey,

direction indication boards are installed on the big target trees to indicate the route to the plot on the way going back after implementation of every survey.

A direction indication board is a board indicating the azimuth and distance from the board-installed tree to the next board-installed tree, or in the case of the board nearest to the origin indication board, from the board-installed tree to the origin indication board. Point A and Point B of Fig 1.2 show examples of the direction indication board. The board of the Point A shows the Point B, and the board of the Point B shows the Origin.

When the staff reaches the location of the fixed plot extremely, they should measured the latitude and longitude of the location by the GPS instrument to confirm whether the latitude and longitude are almost same as the latitude and longitude measured on the topographic map in the preliminaries stage. Then they can decide an origin and they install the origin indication board on a large tree nearest to the origin. The content of an origin indication board is similar to the contents of direction indication boards, and indicates the distance and azimuth from the origin indication board to the origin. Origin of Fig 1.2 shows an example of an origin indication board.

These direction indication boards and origin indication boards are installed, and the latitude and longitude of the location is measured with GPS instrument.

Point A	Point B	Origin

Forest Resources Survey
Direction indication board A
Fixed Plot No. 10
Azimuth   310°
Distance   250 m
Oct. 5, 2002
     Mang La FE
	Forest Resources Survey
	Direction indication board B
	Fixed Plot No. 10
	Azimuth 40°
	Distance 50 m
	Oct. 5, 2002
	     Mang La FE
		Forest Resources Survey
		Origin Indication board
		Fixed Plot No. 10
		Azimuth 36°
		Distance 1 m
		Oct. 5, 2002
		     Mang La FE

Fig. 1.2 Examples of direction indication board and origin indication board

The location map to summarize the route to the site, as shown in Fig. 1.3, should be prepared. The location map is a topographic map to which the boundaries of block, compartments and sub-compartment and these numbers, basic information on river stream and roads, the locations of the routes, the location of the direction indication boards and origin indication boards, the latitudes and longitudes of such locations of the boards measured with GPS instrument, information on trees such as tree species and DBH on which the boards are installed, and board marks are written.
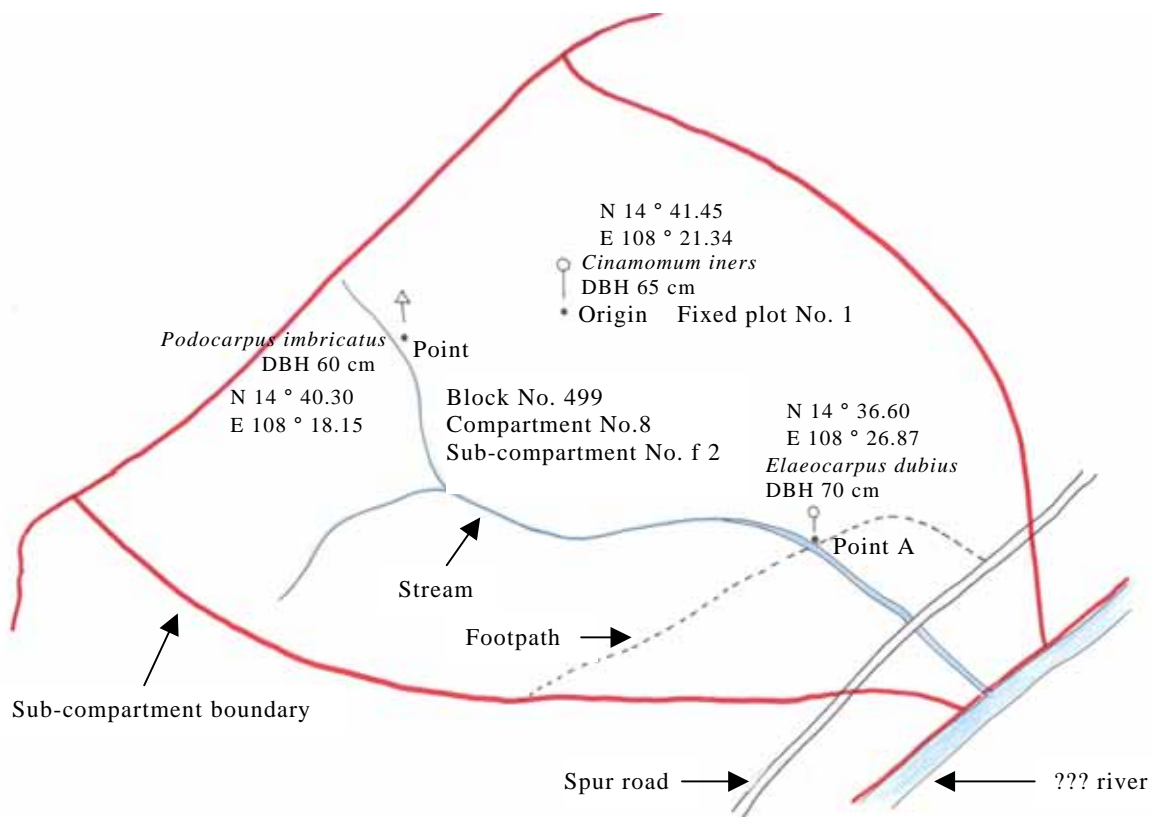
Fig. 1.3 Location map of s fixed plot

2) Second and following surveys

The preliminarily investigated route is followed, and the origin is confirmed. On the way, the direction indication boards indicated in the location map are confirmed, and if there is unclear information, the direction indication board is replaced. When the origin is confirmed, shrubs and vegetation outside the plot are cut to maintain the origin indication board.

If new forest roads have been constructed, or the route to the plot has been changed, new direction indication boards should be installed in the same manner as in the first survey. In this case, the location map must be corrected. Correction is made in the same way as the preparation of the location map in the first survey.

1.5.3 Establishment of fixed plots

When the staff reach the site of the fixed plot, they establish the fixed plot.
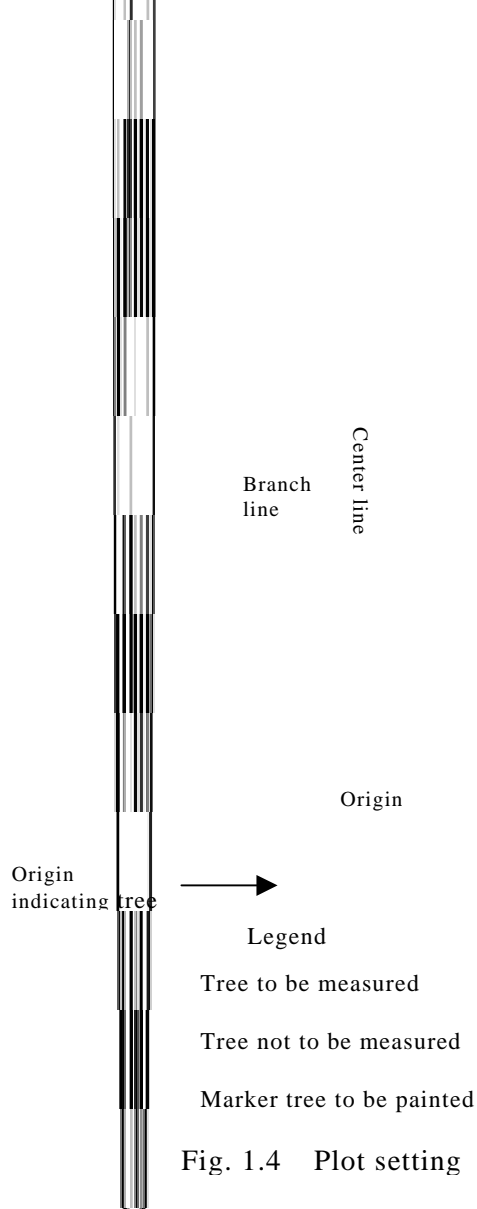
The plot is a rectangular plot of an area of 0.1 ha, a width of 20 m, and a length of 50 m, extending to north and south as shown in Fig. 1.4. First, the centerline of a horizontal distance of 50 m is measured from the origin to the north. Next, branch lines of a horizontal distance of each 10 m from the centerline to the east and the west are measured. The branch lines are measured at the point of about every 10 m of the centerline. Then, the plot boundary can be decided by the process that end points of the every line are connected.

Then, paint is applied to nearby trees surrounding the plot to indicate the area of the plot roughly.

Center line

Branch line

Origin

Origin indicating tree

Legend

Tree to be measured

Tree not to be measured

Marker tree to be painted

Fig. 1.4   Plot setting

2)   Second and following surveys

Since the plot has already been established, when the origin is confirmed, the surroundings are confirmed. Since the surrounding trees have been painted to indicate roughly the plot area, they are confirmed, and if there is unclearness, measurement is re-performed to eliminate unclearness. Faded painting is repaired.

1.5.4 Details of the survey

When the area of the fixed plot has been confirmed, the survey is started. The survey consists of tree measurement and the survey of forest and site conditions.

(1)   Tree measurement

1)   First survey

All the trees above DBH 5 cm existing in the fixed plot are measured. Dead trees are excluded from the subject of measurement. Survey items are tree species, DBH, and tree

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height. For trees on the boundary, trees on the south and west boundaries of the plot are surveyed, and trees on the north and east boundaries of the plot are not surveyed (see Fig. 1.4). The location of each tree, in the plot, on the boundary, or outside the plot, is determined by the location of the base of the tree.

The DBH is measured using a diameter tape and rounded off at 1 cm. It is measured from the mountain side at a height of 1.3 m from the ground. A number tag is firmly attached with a nail at the position of the DBH (see Fig. 1.5).
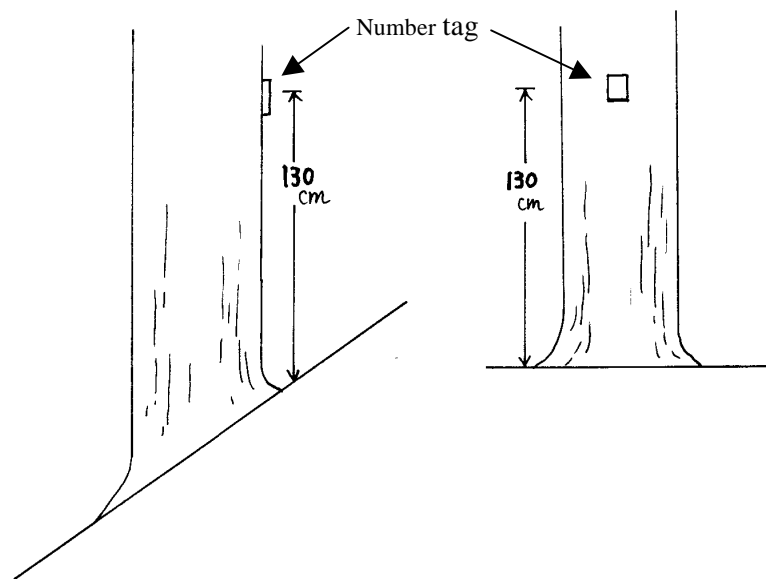
Fig. 1.5 Measurement point of DBH

The tree height is calculated from the height-diameter curve. Although the tree height is normally measured using a hypsometer, or by ocular estimation, these methods have their advantages and disadvantages. If the tree height is measured using ocular estimation, efficiency of the survey is high, but variation due to personal differences will occur, and even if the same person measures, variation between trees is unavoidable. On the other hand, if a hypsometer is used for tree height measurement, certain reliability can be obtained, but the survey efficiency will be significantly lower. Taking these considerations into account, the estimation of the tree height using a height-diameter curve is considered to be the most efficient.

However, the height-diameter curve is normally not available. Therefore, the object of the tree height measurement in the first survey is to prepare the height-diameter curve, and based on the DBH and tree height data obtained in the first survey of the fixed plot, the height-diameter curves are prepared for each forest management unit, and if necessary, for each group of tree species.

Therefore, for the measurement of the tree heights, basically a hypsometer is used in the first instance for a number of trees to give the surveyor a sense for tree heights, and then the tree heights for remaining trees are measured using ocular estimation. During the survey, the tree heights are also frequently measured using a hypsometer to fine-tune the sense of the surveyor in order to raise the accuracy of measurement.

Methods for preparing a height-diameter curve include 1) a free-hand method; 2) a method using mean values; and 3) a method using a height-diameter curve equation. Since 1) requires skill, the use of 2) or 3) is safer. For reference, some height-diameter curve equations will be shown below.

Inverse number equation: $h = a + d/(b + c*d)$

  where a is the height of normal breast height, and b and c are constants.

Henrickson's equation: $h = a + b \log d$

  where a and b are constants.

Naslund's equation: $h = a + d^2/(b + c*d)^2$

  where a is the breast height; b and c are constants.

Stoffels' equation; $h = a + b*d^c$

  where a is the breast height, and b and c are constants.

In all of the above equations, h is the tree height, and d is the DBH.

It must be kept in mind that all of these equations have little theoretical basis, and are empirically given; therefore, the suitability differs from time to time. The parameters of each height-diameter curve equation are determined by the least square method. For the least square method, refer to the reference books of statistics.

Thus, the height-diameter curve is prepared, and the tree heights measured by the height-diameter curve, not actual measured values, will be used even in the first survey.

2) Second and following surveys

In second and following surveys, the methods are basically the same as in the first survey. However, cut trees and dead trees following the previous survey are confirmed, and trees of ingrowth of which DBHs have become 5 cm or more are newly measured.

The DBH is measured at the location of the number tag, which is the location of measurement in the previous survey. Measurement is conducted confirming the DBH measured in the previous survey. In cases where the measured value in the previous survey is obviously erroneous by the erroneous location of the number tag, the number

tag is moved to the correct location; and two DBHs, at the location in the previous survey and at the correct location are measured (see Fig. 1.6).

Although the tree height measurement is not required because the height-diameter curves are used, only one tree height is measured for the following each diameter class by each kind of height-diameter curve (record them in the remarks column of the field sheets), to confirm the compatibility to the height-diameter curves. The diameter classes are determined as less than 10 cm, 10 – 19 cm, 20 – 29 cm, 30 – 39 cm, 40 – 49 cm, and 50 – 59 cm. For 60 cm or more, the diameter classes are determined in the same manner.

(2)   Survey of site and forest conditions

The survey of site and forest conditions is conducted in the same manner whether it is the first survey or second and following surveys, using field sheets of a form different from those for tree measurement (see Fig. 1.7). Specifically, the survey includes every item of site conditions, such as altitude, azimuth, topography, and slope, and forest conditions, such as crown density and mean crown diameter, referring to field survey, aerial photographs, topographic maps, forest inventory book, etc.

If trees were cut in the past 5 years in the plot or surrounding areas, the date and other information of cutting is recorded in the Reference column. Other findings, such as forest stand, are recorded in as much detail as possible.

Altitude		Crown density	
Slope		Mean crown diameter	
Azimuth		Understory vegetation	
Topography			
Soil texture			
Soil type			
Reference on site and forest conditions			

Fig. 1.7   Field sheet for site and forest conditions.

1.5.5 Method for filling in tree measurement field sheets

(1)   First survey

As described above, since tree species, DBHs, and tree heights are measured, tree

measurement field sheets of the form shown in Fig. 1.8 are used.

Fixed plot No. _____   Date of survey _____

Name of forest enterprise _____

Block No. _____   Compartment No. _____   Sub-compartment No. _____

Tree No.	Tree species	DBH (cm)	Tree height (m)	Remarks
1				
2				
3				
4				
5				
...				

Fig. 1.8   Tree measurement filed sheet for first survey

(2)   Second and following surveys

Tree measurement field sheets of the form shown in Fig. 1.9 are used.

Fixed plot No. _____   Date of survey _____

Name of forest enterprise _____

Block No. _____   Compartment No. _____   Sub-compartment No. _____

Tree No.	Tree species	Previous data		Current data		Use of data	Remarks
		Lost tree type	DBH	Lost tree type	DBH		
1							
2							
3							
4							
5							
. . .							

Fig. 1.9   Tree measurement filed sheet for second and following surveys

1)   Before going to the site, Plot No., tree No., Tree species, and data recorded in the "Current data" column such as Lost tree type and DBH, completed in the previous tree measurement field sheet are copied in the "Fixed plot No." column, the "Tree No." column, "Tree species" column, and the "Previous data" column in the tree measurement field sheet for the current survey. At this time, if two DBH values, with and without

parentheses, are recorded in the "DBH" column of the previous tree measurement field sheet, the value without parentheses is copied. These are necessary for confirming the tree No., and tree species, and comparing with measured values.

2) Among trees surveyed in the previous survey, if there are dead trees or cut trees at the time of the present survey, they are recorded in the "Lost tree type" column as "1" or "2", respectively (See Table 1.1). No survey is required for trees which, at the time of the previous survey, were dead trees or cut trees in the "Lost tree type" column, and all columns for the trees are kept blank and the trees numbers are skipped.
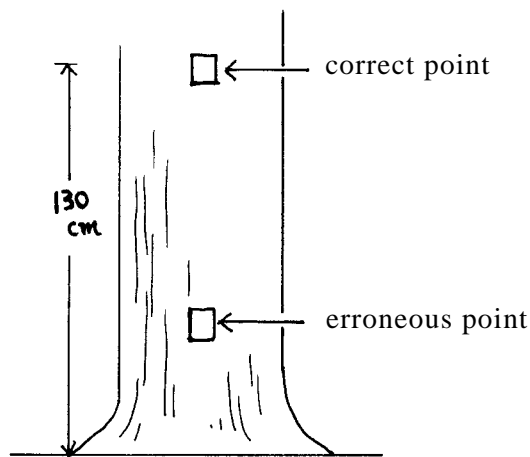
3) If the location of measuring the DBH in the previous survey was obviously erroneous (see Fig. 1.6), the diameter at the location of the previous measurement is recorded in parentheses, the DBH measured at the correct point in the present survey is recorded without parentheses above the data in the parentheses, and "1" is entered in "Use of data" column.

Fig. 1.6 Change of measurement point of DBH from erroneous point to correct point

4) If the measured value of the DBH in the present survey is smaller than that in the previous survey, "2" is entered in "Use of data" column.

5) Unidentified tree(s) are recorded as follows:
   A   Unidentified tree(s) in the present survey
        "3" is entered in the "Lost tree type" column under the "Current data" column.
   B   Unidentified tree(s) in both present and previous surveys
        The "Current data" column is kept blank and the tree number will be skipped in the next survey.
   C   Unidentified tree(s) in the previous survey, but identified in the present survey
        The "DBH" column under the "previous data" column is kept blank, the measured value is recorded in the "Current data" column, and "2" is entered in the "Use of data" column.

Table 1.1   Code table for lost tree type

Lost tree type	Code
Dead trees	1
Cut trees	2
Unidentified trees	3

The codes for lost tree type are shown in Table 1.1. If there are possibilities that the unidentified tree(s) has been cut or become an tree(s) damaged by logging activities in the plot or surrounding forest stand, it is recorded in the "Remarks" column.

1.6   Maintenance of plots

Since the surveys of fixed plots are continued for a long period of time, and allowed to stand for at least 5 years, the plots must be maintained carefully. Specifically, as described in Section 1.5.1, number tags to be attached to survey trees must be made of a material that can withstand storage for years, such as aluminum, and be firmly attached to the trees using nails and so on. Also as described in Section 1.5.3, it is important that trees standing adjacent to the fixed plot are marked with paint to clearly indicate the location of the plot.

1.7   Continuity of plots

It is most important that the fixed plots are surveyed continuously. However, since the fixed plots do not receive special treatment such as the prohibition of cutting, there may be cases where continuous data cannot be collected because of the construction of forest roads or spur roads, or because of the execution of clear cutting. In such cases, new plots will be established for supplementation according to the following procedures.

(1)   The time of establishment will be the time of the survey of the original plot(s).
(2)   The survey plot(s) is selected according to "1.3 Selection of fixed plot sites".
(3)   The plot number(s) will be the second number(s) after the last number(s) used at present. Therefore the original plot number(s) will be skipped.

1.8   Analyses of survey results

The results of the survey will be analyzed using personal computers. First, the contents of the survey field sheets in which the results of the survey are recorded must be input into spreadsheet software, such as Microsoft Excel.

1.8.1 Calculation of volume and increment for each plot

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After the first survey, only volumes are calculated. For second and following surveys, volumes at the time of previous and present surveys are calculated to obtain net increment, gross increment, mortality volume, etc. For the volume calculation of a plot, the volume of a single tree must be calculated firstly. At this time, it is recommendable to prepare the column of tree heights estimated from a height-diameter curve and volumes of single trees, and input the calculation equation into every cell in both columns.

When the results of the survey are analyzed for the increment from the previous survey to the present survey, the DBH data in the parentheses are used for the trees which "1" is entered in the "Use of data" column of the tree measurement field sheets in the present survey. As described in Section 1.5.5, (2), 1), since the values without parentheses recorded in the upper column of the "DBH" column in the present survey will be copied to the "Previous data" column of the tree measurement field sheet for the next survey, the values without parentheses are used as the DBH values for analyzing increment between the present and next surveys.

In addition, for the analysis of increment, it is not used for data of the plot including tree which even one "2" is entered in the "Use of data" column of the tree measurement field sheet for second and following survey.

This rule is also applied to the analysis of increment in the analysis after 1.8.2.

1.8.2 Tabulation by tree species or species groups, and classes of DBH

When data for all the plots are tabulated, the number and volume of trees are tabulated according to tree species and classes of DBH or according to species groups and classes of DBH.

1.8.3 Statistical processing of volumes and so on

Statistical processing, such as calculating the mean values of volumes, increment, and the mortality volume is performed.

1.8.4 .Analysis of increment

The analysis of increment is the main analysis for the fixed plot. The analysis of increment means a multiple variate analysis using Group I quantification of multiple regression analysis making the following site and forest conditions items (explanatory variates), using the data of each fixed plot in the forest management unit, finally to prepare a increment score table. In this case, increment becomes the objective variate. Here, the determination of items will be described briefly. For details of multiple variate analysis, refer to a reference book of statistics.

On determining the items, as one of the criteria for selecting explanatory variates, those with small correlation between explanatory variates considering multi-collinearity should be selected. In the following example, the stand volume per hectare of A, the number of trees per hectare of B, and the crown density of D are considered to fall under multi-colinearity. In this case, one of these, which has a high correlation with the objective variate is selected as the explanatory variate.

Since the score table is utilized to calculate the increment of each sub-compartment, data obtained without going to the site, such as data in the forest inventory book, is used in practice for the items of the score table. Since the number of trees per hectare of B, or the soil type of H are not recorded in the forest inventory book prepared by the Study, these must be excluded if the calculation is performed based on the forest inventory book.

When multiple variate analysis is conducted, each item must be divided into several categories. The examples of categorization for each item will be shown below. In case that the target accuracy of the increment table is established to be a multiple correlation coefficient of 0.8 or more, and a ratio of error of 20% or less, in order to obtain the value within this range, multiple variate analyses are repeated changing the items and categories in the items, and lastly the items and categories are decide and the increment score table is prepared.

When the increment score table is prepared from the results of the third or following survey, although there is a method to correct the increment score table using the increment data for 5 years to compare the results of the previous survey, for lowering the error of the increment score table, there is also a method to prepare the increment score table using data for 10 years (in the case of the third survey), for 15 years (in the case of the fourth survey), and a longer period of time (on or after the fifth survey) to compare the data of the first survey. In these cases, data of a fixed plot including trees for which "1" or "2" is entered in the "Use of data" column of the tree measurement field sheet are not used. Therefore, although the error is lowered in the data to be used, number of the data of the plots that can be used must reduce if period of comparing data is longer.

As previously described in 1.8.1, although the data of a fixed plot can be used for processing the increment data when "1" is entered in the "Use of data" column of the tree measurement field sheet in the case of comparison for 5 years, it cannot be used in the case of 10 years or longer. In addition, the increment score table cannot be prepared by combining increment data for 5 years in different period, for instance increment data for 5 years obtained from the results of the first and second surveys, and increment data for 5 years obtained from the results of the second and third surveys, can no be combined.

Examples of items, and categories in each item

A   Stand volume per hectare (categorized by about every 25 m^3)

B   Number of trees per hectare (categorized by about every 100 trees)

C   Proportion of conifers (categorized by about every 10%)

D   Crown density (categorized by about every 10%, or by thin, medium, and dense)

E   Altitude (categorized by about every 100 m)

F   Azimuth (categorized by 8 divisions)

G   Slope (categorized by about every 5 degrees)

H   Soil type (categorized by every soil type)

I   Topography (categorized by every topographic type)

J   Cutting in 5 years (categorized by yes and no)

1.9   Use of the increment score table

Using the prepared increment score table, the annual increment per hectare is obtained for each sub-compartment of natural forest recorded in the forest inventory book.   The annual increment per hectare in each sub-compartment can be obtained by applying, values of site and forest conditions of each sub-compartment in the forest inventory book that correspond to each item of the increment score table, to the category of each item in the increment score table, and adding the scores of the applied category.

The annual increment in each sub-compartment can be calculated by multiplying the area by the obtained annual increment per hectare of each sub-compartment; and the total annual increment of natural forests in each forest enterprise can be calculated by adding the total annual increment in each sub-compartment.

The basis of selective cutting is to determine the annual cutting volume within a range not exceeding the total annual increment of the natural forest subjected to cutting.   Therefore, for determining the cutting volume, the annual increment of the cutting-prohibited natural forest must not be included in the cutting volume.   The actual annual cutting volume is decided taking into account the social and economic factors based on the total annual increment.

2. Method for preparing the yield table of man-made forests

In Chapter 2, a method for preparing the yield table of a man-made forest will be described in order to grasp the increment of the man-made forest and estimate the yield volume. The yield table of a man-made forest is prepared for each tree species, each region, and each site quality.

2.1 What is the yield table?

A yield table is a table that indicates standard values of factors, such as the number, volume, and increment per ha of dominant and co-dominant trees produced in an even-aged pure forest treated by the same management method for a certain tree species, by every constant forest age (normally 5 years), and is normally prepared for each site quality. This table also indicates the process of the growth of forest stands.

Dominant trees at a certain forest age are forest trees that remain after thinning suitable for the tree species and site quality; and co-dominant trees are forest trees to be cut for thinning.

A site quality means a grade that indicates the soil fertility of the land, and is typically divided into first, second, and third grades for each region.

The major uses of the yield table include (1) the estimation of the volume of a man-made forest, (2) the estimation of the increment of a man-made forest, (3) the determination of the site quality, (4) assessment of the results of management, (5) the estimation of future yield, (6) the guidance for management techniques or forest tending, and (7) materials for forest planning, and economic calculation. for the management.

2.2 Planning of the survey

2.2.1 Selection of region covered by a yield table

Since the growth of forest trees is affected by natural conditions, such as climate, geology, and soil, and the method for managing forests normally becomes different when the forest area is large, the region covered by a yield table should be selected from regions that have similarity in such natural and artificial conditions.

Also, since the method of managing forests differs depending on the industrial structure, geographic conditions, and historical tradition, such socio-economic conditions must be considered in establishing the regions covered by the yield table.

Therefore, although there is no standard for the area of the region covered by the prepared yield table, it is often selected according to the units, such as characteristic forestry regions, regions of common management, and the regions of similar natural conditions.   However, it is considered to be realistically reasonable to prepare it in the province unit.

2.2.2   Determination of the number of sample plots

Although the number of sample plots for preparing a yield table depends on difference in the site conditions of objective regions and accuracy required, and cannot be stated unconditionally, it is desirable to establish 30 sample plots or more for every site quality.

However, since this is limited by time and costs required for the survey, it is required to establish as many sample plots as possible within the allowable range, and to select the sample plots so as to distribute in different natural conditions and forest ages for the effective use.

2.2.3   Selection of sample plots

Since the yield table is prepared based on the results of the survey of sample plots, the selection of the sample plots is very important.   The sample plots should be selected considering the following items.

1)   Even-aged pure forests that belong to the same strain of stand composition, growing soundly without damage or other trouble.
2)   Forest stand in which crowns are not excessively dense or coarse.
3)   Forest stand in which the number of trees is not excessively large or small.
4)   Sample plots that contain stands with as much variety of forest ages as possible by each site quality.   The site quality is determined based on the mean tree height of dominant trees in the forest stands corresponding to forest ages.   The forest age is calculated so that the year of planting is the first year.

2.2.4   Design of survey field sheet

Although the form of the survey field sheet differs depending on the survey method of a sample plot, the form is normally designed to record the DBH, height, tree class, and the classification of dominant and co-dominant trees, as well as all the survey items in the Section 2.3.2 (see Fig. 2.1 for an example of field sheet for sample plot survey).   The tree classes are basically superior trees, semi-superior trees, intermediate trees, and suppressed trees.   The trees thinned at this time point are regarded to be co-dominant trees.

Sample plot No. _____   Tree species _____   Date of survey _____

_____

Forest enterprise _____   Block No. _____   Compartment No. _____   Sub-compartment No. _____
Altitude _____   Gradient _____   Azimuth _____   Topography _____

_____

Soil texture _____   Soil depth _____

Description of undergrowth _____

Remarks _____

No.	Tree class	Dominant or co-dominant	DBH (cm)	Tree height (m)	Remarks
1					
2					
3					
4					
5					

Fig. 2.1   Example of field sheet for sample plot survey

2.3   **Field survey**

2.3.1 Sample plots survey

When reaching the location of a sample plot, the sample plot is established on the ground.   The shape of the sample plot should be as simple as possible, such as rectangular, and the boundary should be established so as to pass between trees.   The area of a sample plot is typically approximately 0.2 ha, but a wider area may be applicable.   After completing the establishment, all the trees in sample plots are surveyed as follows.

1)   The trees are classified into dominant trees and co-dominant trees, and the DBH of each tree is measured. The DBH is measured using a measuring tape from the mountain side at a height of 1.3 m from the ground. Alternatively, the DBH may be measured using a caliper from the mountain side.   However, in the case of an elliptic tree of which diameter measured from the mountain side is more than 20% larger or smaller than the diameter in the diagonal direction, diameters in two directions, perpendicular and parallel to the slope direction are measured, and are averaged. The units of DBH measurement are centimeters.

    The definitions of dominant and co-dominant trees are as described before. Depending on the method of thinning normally practiced in the region, the trees remaining after actual thinning are made dominant trees, and thinned trees are made co-dominant trees.

2)   Although it is preferred to measure the height of every tree, the heights may be estimated from DBH using height-diameter curve prepared by randomly extracting an adequate number of sample trees (Please refer to the Section 1.5.4 (1) 1) for height-diameter curve). The units of tree height measurement are meters.

2.3.2 Survey of reference items

Before or at the time of the field survey of sample plots survey, the following items are studied to apply to the yield table, and to obtain other reference items.

1)   The altitude, gradient, azimuth, underlying rocks, soil texture, soil depth, and bed vegetation of the sample plot are checked.

2)   The number of thinning performed in the past, and the forest ages at thinning are checked, and the forest age at the next thinning is estimated.

3)   The average log scale (the ratio of the total log volume to the total stem volume when assuming cutting in the fiscal year) in the sample plot is estimated.

4)   The area, number of trees, and volume in the sub-compartment to which the sample plot belongs are confirmed form the forest inventory book, or measured or estimated in the field.

2.4   Editing and examination of materials

2.4.1 Editing of materials

The survey results of the sample plot and reference items are edited in the table of sample plot survey results (see Table 2.1) and the table of site and forest conditions etc. of the sample plot (see Table 2.2).

For the table of sample plot survey results, the required factors are calculated for dominant trees and co-dominant trees base on the results of the sample plot survey, and the sample plots are edited in the order of forest age from young forests. The calculation is performed using the following procedure.

1)   The mean DBH and the mean heights of dominant and co-dominant trees are obtained by arithmetically averaging the DBH and height of each tree, and rounding the values at the second decimal place.

2)   The stem volumes are calculated from the diameters and heights using the stem volume equation or obtained from volume tables. The units of stem volumes are cubic meters.

The mean stem volume is obtained by dividing the total stem volume by the number of trees for dominant and co-dominant trees, and rounding the values at the third decimal place.

Table 2.1   Example of table of sample plot survey results

No.	Place				Sample plot		Forest age (Yr)	Estimated seedling age (Yr)	Dominant trees						Co-dominant trees						Total of dominant and co-dominant trees					
									Mean			Per ha			Mean			Per ha			Mean			Per ha		
	Forest enterprise	Block	Compartment/	Sub-compartment	No.	Area (ha)			DBH (cm)	Tree height (m)	Stem volume (m^3)	Number of trees	Basal area (m^2)	Stem volume (m^3)	DBH (cm)	Tree height (m)	Stem volume (m^3)	Number of trees	Basal area (m^2)	Stem volume (m^3)	DBH (cm)	Tree height (m)	Stem volume (m^3)	Number of trees	Basal area (m^2)	Stem volume (m^3)

Table 2.2   Example of table of site and forest conditions etc. of sample spots

No.	Place				Sample plot No.	Altitude (m)	Slope	Azimuth	Topography	Soil texture	Soil depth	Overview of bed vegetation	Remarks
	Forest enterprise	Block	Compartment/	sub-compartment									

The stem volume per ha is obtained by dividing the total stem volume for dominant and co-dominant trees by the area of the sample plot, and rounding the values at the second decimal place.

3) The basal area is obtained by multiplying the sectional areas in each DBH class by the number of trees, and totaling the values of each basal area in each. DBH class for each of dominant and co-dominant trees.

The basal area per ha is obtained by dividing the total basal area by the area of the sample plot.

The units of the basal area are square meters, and the value is rounded at the fifth decimal place for each DBH class, and at the second decimal place for the basal area per ha.

2.4.2 Examination of materials

The survey results of each sample plot are examined to decide if the results are suitable as materials for preparing the yield table, and unsuitable results are excluded from the materials.   The excluded sample plots are not included in the future computations.

The materials are examined using the relationship between the following factors, or other suitable methods, and the results of sample plots significantly deviated from general tendency are excluded as the materials.

1)   Number of dominant trees per ha for each forest age

2)   Basal area of dominant trees per ha for each forest age

3)   Stem volume of dominant trees per ha for each forest age

4)   Mean DBH of dominant trees for each forest age

5)   Number of dominant trees per ha for each mean DBH of dominant trees

Fig. 2.2   Review of mean DBH of dominant trees versus forest age

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Examination is performed according to the following procedures (Specific methods will be described in 2.5.).

The frequency distribution diagram for the sample plot is prepared, and the centerline of distribution is drawn. Based on the centerline of distribution, the upper and lower boundary lines, which show general tendency, are determined, and data beyond the boundary lines are excluded (see Fig. 2.2 for mean DBH of dominant trees for each forest age). In case of Fig. 2.2, plot No. 15 and 38 are excluded.

2.5 Determination of site quality

Although volumes may be used as the criterion for the classification of site qualities in the yield table, the mean height of dominant trees is normally used.

Methods for the classification of site qualities include the diagram method and the formula method. In the diagram method, the relationship between forest ages and mean heights of dominant trees are illustrated, and curves considered suitable are drawn freehand. The formula method is a method for computation by applying the relationship between forest ages and mean heights of dominant trees to empirical formula. The features of the diagram method and the formula method will be summarized in the Appendix 1.

From here, the procedures of site quality determination will be described exemplifying the hinoki cypress (*Chamaecyparis obtuse*) stand of Japan.

1) Distribution diagram of the sample plot

The distribution diagram is drawn to indicate the values of each sample plot taking forest ages on the abscissa and mean heights of dominant trees on the ordinate.

2) Determination of centerline of the distribution
To draw upper and lower boundary lines, it is convenient
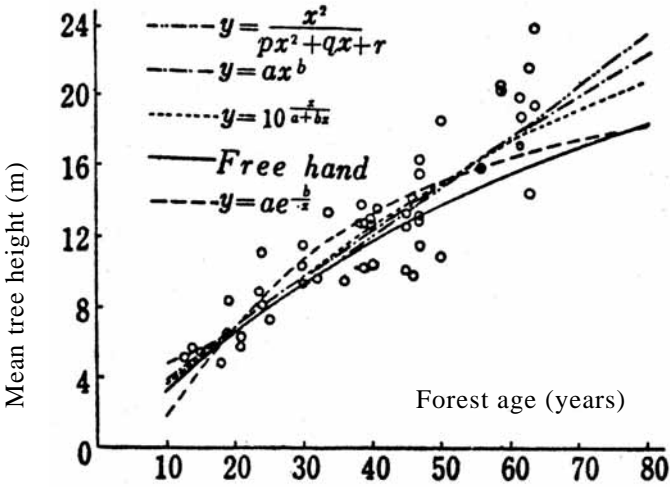
Fig. 2.3   Center line the distribution
(Mean height total growth curve)

The curves shown in the figure are:

$$y = \frac{x^2}{px^2+qx+r}$$
$$y = ax^b$$
$$y = 10^{\frac{x}{a+bx}}$$
Free hand
$$y = ae^{-\frac{b}{x}}$$

to determine the centerline of distribution, and to draw the boundary lines based on the centerline. Drawing of the centerline was described above using the diagram method or the formula method. In this example, four empirical formulas (see below) are computed, and a freehand curve is drawn as the centerline referring to these formulas (see Fig. 2.3).

The standard deviation (σ) and correlation ratio (ρ) of the freehand curve are as follows:

$\sigma = 2.29$

$\rho = 0.89$

The four empirical formulas used for computation are as follows:

$h = t^2/(-0.00505t^2 + 4.04107t - 18.36016)$	(Formula 2.1)
$\log h = t/(12.52256 + 0.60354t)$	(Formula 2.2)
$\log h = 1.40449 - 11.55006/t$	(Formula 2.3)
$\log h = -0.29500 + 0.86256 \log t$	(Formula 2.4)

where   t: forest age

h: mean height of dominant trees

Table 2.3 shows the standard deviations and correlation ratios of the above formulas.

Table 2.3   Standard deviations and correlation ratios of empirical formulas

	(Formula 2.1)	(Formula 2.2)	(Formula 2.3)	(Formula 2.4)
Standard deviation (σ)	2.03	2.13	2.40	2.06
Correlation ratio (ρ)	0.90	0.89	0.86	0.90

3)   Drawing of upper and lower boundary line of the distribution based on centerline

Drawing of upper and lower boundary lines will be described below.

i)   Difference between the measured value (y) and the estimated value (y^: the corresponding value on the centerline) of mean tree height in sample plots is obtained, this is divided by the estimated value (to calculate (y − y^)/y^), and the mean deviation ratio is obtained using the following formula.

$\delta' = \Sigma|Z'|/n$ (Formula 2.5)

where Z' = (y − y^)/y^.

ii)   From the value of the mean deviation ratio, the upper and lower boundary lines are determined using the following formula.

$$y' = y\char`^ \pm m\delta'y\char`^ = (1 \pm m\delta')y\char`^ \qquad \text{(Formula 2.6)}$$

where m is a multiple of the mean deviation ratio.

Here, the question is the value of m. Since it is statistically known that there is a relationship between the mean deviation δ and the standard deviation σ of δ = 0.79788σ, if m is 2.5, 2.5δ = 2σ. This includes 95.5% of distributed numbers, and 19 out of 20 pieces of data are included in this range.

4) The space between the upper boundary line and centerline and between centerline and lower boundary lines is divided into three equal zones respectively, and the each two zones are named sequentially from the top as class 1, class 2, and class 3 sites.

In the Formula 2.6, since m = 2.5 is used for the upper and lower boundary lines, m of each site quality class is as follows:

Upper and lower boundary lines of the distribution   m = ±2.50000
Centerlines of site quality class 1 and class 3   m = ±1.66667
Boundary lines between class 1 and class 2, and class 2 and class 3 m = ±0.83333

When the mean deviation ratio of the mean height total growth curve calculated using the Formula 2.5 is δ' = 0.14206, each site quality differentiating line is as follows, from the Formula 2.6 (see Fig. 2.4).

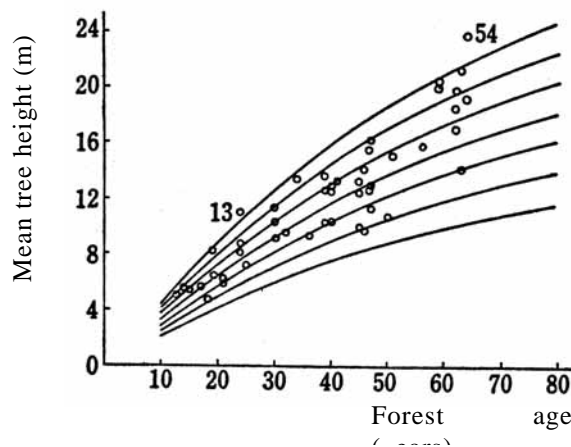Fig.   2.4   Site   quality

Upper boundary line of site quality class 1   h = 1.35515h^
Centerline site quality class 1   h = 1.23677h^
Boundary line between site qualities class 1 and class 2   h = 1.11838h^

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Centerline site quality class 2   h = 1.00000h^

Boundary line between site qualities class 2 and class 3   h = 0.88162h^

Centerline site quality class 3   h = 0.76323h^

Lower boundary line of site quality class 3   h = 0.64485h^

Table 2.4 shows the mean height of dominant trees on each site quality differentiating line calculated based on these figures.

Table 2.4   Mean height of dominant trees classified according to forest age and site quality boundary lines

(Units: m)

Forest age	Class 1 upper boundary	Class 1 center line	Class 1 / class 2 boundary	Class 2 center line	Class 2 / class 3 boundary	Class 3 center line	Class 3 lower boundary
5 years	1.8	1.6	1.5	1.3	1.1	1.0	0.8
10	4.3	4.0	3.6	3.2	2.8	2.4	2.1
15	6.6	6.1	5.5	4.9	4.3	3.7	3.2
20	8.8	8.0	7.3	6.5	5.7	5.0	4.2
25	10.7	9.8	8.8	7.9	7.0	6.0	5.1
30	12.5	11.4	10.3	9.2	8.1	7.0	5.9
35	14.1	12.9	11.6	10.4	9.2	7.9	6.7
40	15.7	14.3	13.0	11.6	10.2	8.9	7.5
45	17.2	15.7	14.2	12.7	11.2	9.7	8.2
50	18.6	16.9	15.3	13.7	12.1	10.5	8.8
55	19.8	18.1	16.3	14.6	12.9	11.1	9.4
60	21.0	19.2	17.3	15.5	13.7	11.8	10.0
65	22.1	20.2	18.2	16.3	14.4	12.4	10.5
70	23.0	21.0	19.0	17.0	15.0	13.0	11.0
75	24.0	21.9	19.8	17.7	15.6	13.5	11.4
80	24.8	22.6	20.5	18.3	16.1	14.0	11.8

5)   The centerline of each class is made the standard mean height of each site quality. When the diagram method is used, it can be read from the diagram; and when it is determined by calculation, the calculated value of the centerline of each site quality can be used.

6)   The sample plots beyond the upper and lower boundary lines are excluded, and the sample plots are classified according to site qualities (see Table 2.5 for sample plots classified according to site qualities).

Table 2.5　Sample plots classified according to site qualities

Site quality	Sample plot No.	Number	Percentage (%)
Class 1	1, 2, 7, 11, 19, 21, 26, 30, 40, 41, 42, 46, 47, 48, 49, 52, 53	17	32
Class 2	3, 4, 8, 10, 12, 14, 16, 19, 20, 23, 24, 25, 27, 28, 29, 32, 33, 35, 36, 39, 44, 45, 50, 51	24	44
Class 3	5, 9, 22, 31, 34, 37, 43	7	13
Exclusion	6, 13, 15, 17, 38, 54	6	11
Total		54	100

2.6　Determination of numerical values constituting the yield table

Values of factors required for the yield table are determined for each site quality in the following order.

1) The values of dominant trees are determined by previously assessing the values of constitutive factors for each forest age, and further correcting by the functional relationship between factors.

2) The values of co-dominant trees are assessed by the functional relationship with the values of dominant trees.

3) The total values of dominant and co-dominant trees are assessed by totaling the values of dominant and co-dominant trees for each factor.

4) Increments and increment rates are calculated.

2.6.1　Determination of numerical values for dominant trees
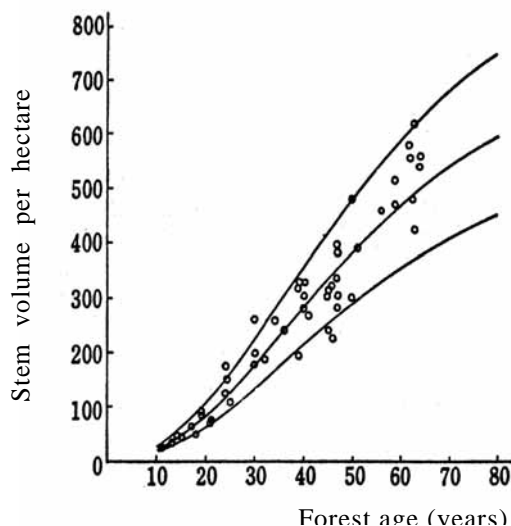
Fig.2.5　Dominant tree stem volume total growth curve (stem volume per hectare)
(Stem volume per hectare)

1) The values of constitutive factors are assessed for each forest age. The values are assessed for the following factors using suitable methods, such as the diagram method and the formula method, corresponding to the determination of site qualities.

i) Number of dominant trees per ha for each forest age

ii) Stem volume of dominant trees per ha for each forest age (see Fig. 2.5)

iii) Basal area of dominant trees per ha for each forest age

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iv)   Mean DBH of dominant trees for each forest age

2)   Values assessed in 1) are corrected based on the functional relationship between the factors.

Although the values of each factor of dominant trees listed in the yield table have been assessed in the process of 1), since there are the functional relationships between factors, such as the mean height, mean DBH, number of trees per ha, total basal area per ha, stem volume per ha, and mean stem volume, these relationships are compared and examined, corrections are repeatedly performed for each combination of these factors, and the constitutive values are determined so as not to cause improperness between any factors.   The values thus constituted are called the corrected values for each factor.   The major corrected values are as follows:

i)   Corrected mean DBH of dominant trees
Using the functional relationship between the mean height and mean DBH of dominant trees, the mean DBH of each sample plot is corrected to the value corresponding to the standard mean height.

ii)   Corrected stem volume per ha of dominant trees
Using the functional relationship between the mean height and the stem volume per ha, the stem volume per ha of each sample plot is corrected to the value corresponding to the standard mean height (see Fig. 2.6 and Table 2.6).

iii)   Corrected number of dominant trees
Using the functional relationship between the mean DBH and the number of dominant trees, the number of trees for the corrected mean DBH is determined.

iv)   Corrected total basal area of dominant trees
Using the functional relationship between a total basal area obtained by multiplied the mean basal area of dominant trees by the corrected number of dominant trees and the total basal area per ha, corrected total basal area of dominant trees is obtained. The mean basal area of dominant trees (g) is obtained from the mean DBH (d) using the following formula.

$$g = \pi d^2/4$$
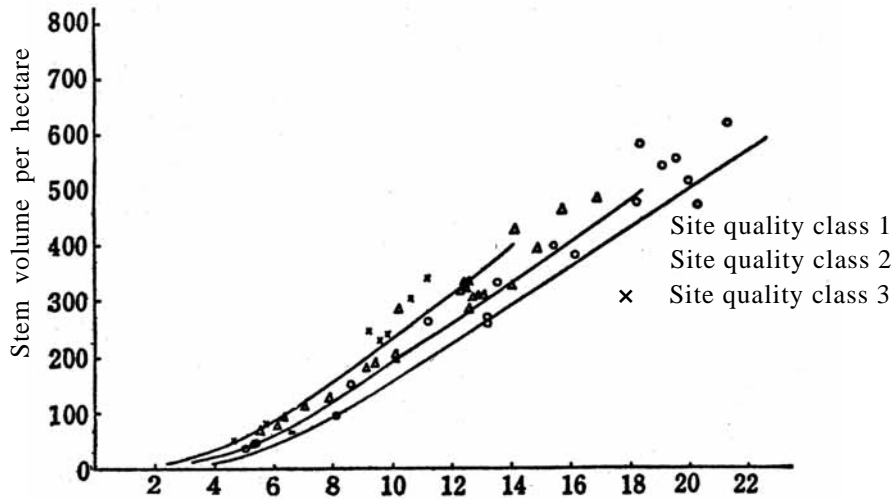
Fig. 2.6　Relationship between mean height of dominant
trees and stem volume per hectare

Table 2.6　　Stem volume per ha for mean height of dominant trees according to site qualities

(Units: m^3)

Height (m)	Class 1	Class 2	Class 3	Height (m)	Class 1	Class 2	Class 3
3			13.8	13	260.9	296.9	352.6
4	10.4	19.5	29.9	14	295.0	333.3	390.8
5	24.3	36.6	52.5	15	329.0	370.2	
6	41.9	59.0	84.3	16	362.8	406.8	
7	64.2	86.2	118.0	17	396.9	443.8	
8	92.2	117.9	154.3	18	431.3	481.2	
9	123.3	153.8	193.7	19	465.8		
10	156.7	190.5	235.0	20	499.5		
11	191.2	226.0	247.3	21	535.0		
12	225.9	261.0	313.0	22	572.1		

Fig. 2.7　Corrected stem volume total growth curve of
dominant tree

3)　The corrected stem volume of dominant trees is examined.

Stem volumes per ha, which are the most important factor of values constituting the yield table, are reviewed and corrected again using the following relationships to ensure accuracy. Fig. 2.7 and Table 2.7 show the relationship between stem volumes per ha and forest ages.

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Table 2.7   Corrected dominant tree stem volume per ha for the each site quality
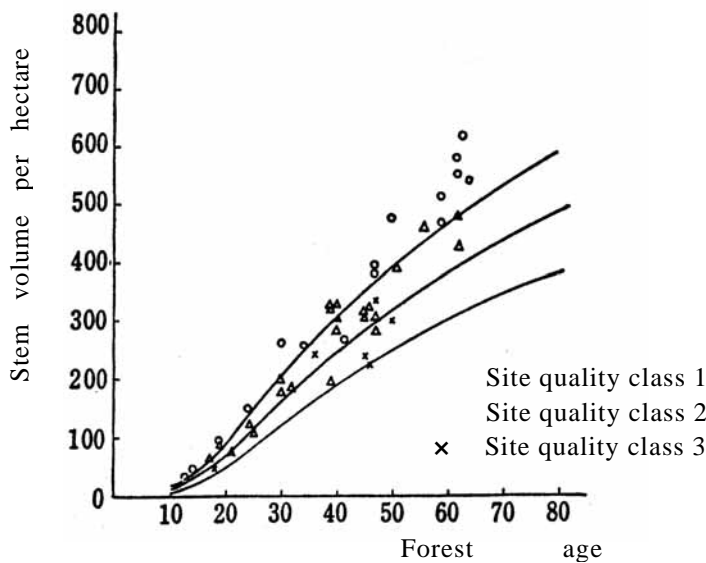
(Units: m^3)

Forest age (years)	Class 1	Class 2	Class 3	Forest age (years)	Class 1	Class 2	Class 3
10	10.4	8.7	7.0	50	393.0	321.8	253.1
15	42.6	34.0	25.0	55	432.1	355.7	281.6
20	93.9	72.2	52.0	60	468.8	387.3	307.8
25	150.0	115.5	83.8	65	503.2	416.6	331.8
30	206.0	160.7	118.3	70	535.4	443.7	353.6
35	258.5	204.7	153.7	75	565.5	468.7	373.3
40	306.5	246.4	188.7	80	593.7	491.8	390.8
45	351.2	285.4	222.1				

i)   Stem volumes per ha versus total basal areas per ha

Stem volumes for corrected total basal areas are obtained from the relationship between the total basal areas and the stem volumes per ha of dominant trees.

ii)   Mean stem volume versus stem volumes per ha
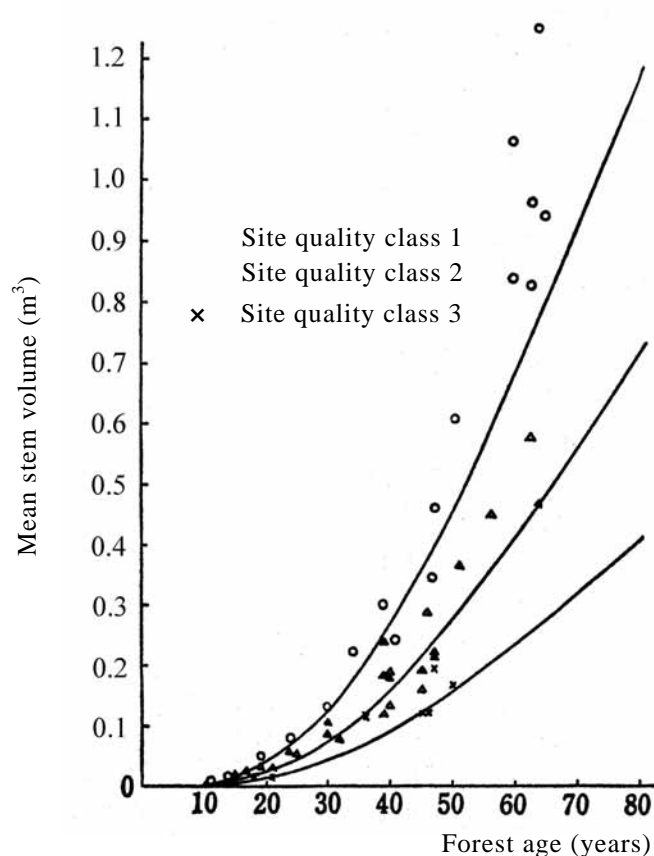
Relationship between mean stem volumes obtained from the volume table or the volume equation using the corrected mean DBH and standard mean heights for each age grade, and the mean stem volume calculated by dividing the corrected stem volume of dominant trees by the corrected number of dominant trees, is examined (see Fig. 2.8 and Table 2.8), and values are corrected so as not to cause the contradiction. Then, the corrected stem volume is examined by these factors corrected again.

Fig. 2.8   Corrected mean stem volume curve of dominant

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Table 2.8   Mean stem volume of dominant trees classified according to site qualities and forest ages   (Units: m^3)

Forest age (years)	Class 1	Class 2	Class 3	Forest age (years)	Class 1	Class 2	Class 3
10	0.003	0.002	0.001	50	0.465	0.218	0.161
15	0.015	0.009	0.005	55	0.577	0.348	0.199
20	0.039	0.024	0.013	60	0.695	0.420	0.239
25	0.076	0.047	0.026	65	0.817	0.495	0.281
30	0.128	0.078	0.044	70	0.940	0.571	0.323
35	0.198	0.117	0.067	75	1.062	0.648	0.366
40	0.271	0.164	0.094	80	1.184	0.725	0.409
45	0.362	0.219	0.126				

2.6.2 Determination of numerical values for co-dominant trees

Since the direct assessment of the values of factors for co-dominant trees from the measured value in the sample plot is generally difficult due to the state of thinning and so on, the values of factors of co-dominant trees are assessed using the functional relationship with the values of dominant trees.

1) Mean height of co-dominant trees, mean DBH of co-dominant trees, and mean stem volume of co-dominant trees are assessed deeming that they have a functional relationship with the corresponding factors of dominant trees. Fig. 2.9 and Table 2.9 show the relationship between the mean DBH of dominant trees and the mean DBH of co-dominant trees.   Table 2.10 shows the DBH of co-dominant trees for each forest age and each site quality.
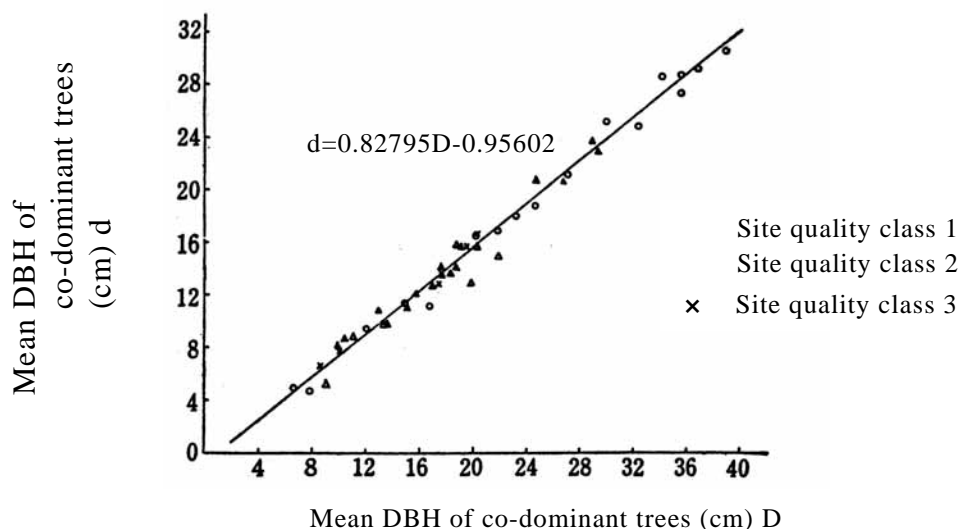

Fig. 2.9   Relationship between DBH of dominant and co-dominant trees

Table 2.9   Relationship between DBH of dominant and co-dominant trees

(Units: cm)

Dominant tree	Co-domi-nant tree	Dominant tree	Co-domi-nant tree	Dominant tree	Co-domi-nant tree	Dominant tree	Co-domi-nant tree
2.0	0.7	12.0	9.0	22.0	17.3	32.0	25.5
4.0	2.4	14.0	10.6	24.0	18.9	34.0	27.1
6.0	4.0	16.0	12.3	26.0	20.6	36.0	28.9
8.0	5.7	18.0	13.9	28.0	22.2	38.0	30.5
10.0	7.3	20.0	15.6	30.0	23.9	40.0	32.2

Table 2.10 Mean stem volume of co-dominant trees classified according to site qualities and forest ages

Forest age (years)	Class 1	Class 2	Class 3	Forest age (years)	Class 1	Class 2	Class 3
10	2.9	2.2	1.6	50	22.1	18.3	14.5
15	6.1	4.9	3.8	55	23.9	19.8	15.7
20	8.8	7.2	5.7	60	25.5	21.2	16.8
25	11.4	9.4	7.4	65	27.0	22.6	17.8
30	13.8	11.4	9.1	70	28.5	23.8	18.7
35	16.0	13.3	10.6	75	29.8	24.9	19.7
40	18.2	15.0	12.0	80	31.1	26.0	20.5
45	20.2	16.8	13.3				

2)   The number of co-dominant trees per ha is determined from the difference of the number of dominant trees per ha between age grades.

3)   The stem volume of co-dominant trees per ha is determined by multiplying the mean stem volume of co-dominant trees by the number of co-dominant trees per ha in each age grade.

2.6.3 Determination of total numerical values for dominant and co-dominant trees

The total values of the dominant and co-dominant trees are determined by totaling the values of each factor of dominant and co-dominant trees for each age grade.

2.6.4 Calculation of increment

Current annual increment and mean increment are obtained for the stem volume of dominant trees and the total of dominant and co-dominant trees.

1)   Current annual increment is calculated using the following formulas

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i)   Dominant trees = (Stem volume of dominant trees in the latter term − Stem volume of dominant trees in the preceding term) / Number of years of the term

ii)   Total of dominant and co-dominant trees = (Total stem volume of dominant and co-dominant trees in the latter term − Total stem volume of dominant and co-dominant trees in the preceding term) / Number of years of the term

2)   Mean increment is calculated using the following formulas.

i)   Dominant trees = Stem volume of dominant trees in the age grade / Number of years in the age grade

ii)   Total of dominant and co-dominant trees = Total yield in the age grade / Number of years in the age grade

Total yield = Stem volume of dominant trees in the age grade + Total stem volume of co-dominant trees until the age grade

3)   The total stem volume of co-dominant trees up to the year is obtained for each age grade, and this is divided by the stem volume of dominant trees and total yield in the age grade to calculate each ratio.

4)   Relationship between the current annual increment for each age grade and mean increment are examined for each site quality to confirm that these are consistent to actual values.   If inconsistency is found, the correction is made retroactively to corrections of the values constituting each factor.

2.6.5 Calculation of increment rate

The increment rate is calculated from the total stem volume of dominant and co-dominant trees, using Pressler's formula or Leibnitz' formula.   In this case, the formula used is recorded.   Pressler's formula and Leibnitz' formula are as follows:

Pressler's formula
$$P(\%) = (M - m)/(M + m) \times 200/n$$
Leibnitz' formula
$$P(\%) = (\sqrt[n]{M}/m - 1) \times 100$$

where
P: increment rate
M: stand volume at the end of the term

m: stand volume at the start of the term

n: number of years from the start to the end of the term

2.7   Preparation of yield table and explanatory notes

1)   Preparation of yield table

When the constitutive values have been determined, they are edited in the form of Table 2.11 to prepare the yield table.   Values in Table 2.11 are those in the yield table for the site quality class 2 of the example used in and after the Section 2.5.   Here, when the cutting period is about 30 years or more, yield tables can be prepared every 5 years of the forest age, such as fifth, tenth, and fifteenth years.   However, when the cutting period is about 10 years, the yield tables must be prepared about every 2 years of the forest age.

2)   Preparation of explanatory note

An explanatory note should be attached to a yield table to clarify the process of preparation or the notices for applying the yield table.

i)   Bases of region determination
ii)   Items related to the selection of sample plots
iii) Table of sample plots survey results (Sample plots not used for the preparation of the yield table are also listed in the table, and the reason is described in the remarks column.)
iv)   Methods of computation, examination, and measurement used in the preparation of the yield table
v)   Notice on the use of the yield table
vi)   Date of preparation and the person in charge of preparation
vii) Other necessary items

2.8   Estimation of yield using the yield table

What should be noted for estimating the future stand volume or yield is that the values listed in the yield table do not usually agree with the values of actual forest stand, except when the subjected actual forest stand is in the normal state as the object of the yield table.   The actual forest stand normally exhibits values different from the values listed in the yield table of the same site quality and the same forest age due to difference in density control or other reasons.   Therefore, the values in the yield table must be corrected for the estimation of future stand volume or yield of actual forest stands.   The procedure for correcting the values

is as follows:

1) The mean height of dominant trees in the actual forest stand is obtained, and compared with the value for the same forest age in the yield table to decide the site quality of the yield table.   Since the growth of tree height is little affected by tree density, it can be used for the assessment of the site quality.

2) The coefficient of site quality is obtained.   The coefficient of site quality is the ratio of the mean height of dominant trees in the actual forest stand to the mean height of dominant trees listed in the yield table, and is stable regardless of the growth of the forest stand.

3) The stand density is obtained.   The stand density is the ratio of the total basal area per ha in the actual forest stands to the total basal area per ha listed in the yield table, and approaches 1 with the growth of the forest stand.

4) The stand volume in the actual forest stands is obtained.   The stand volume per ha in the actual forest stands is obtained by multiplying the stand density and the coefficient of site quality by the total stem volume of dominant and co-dominant trees listed in the yield table.

5) The future stand volume is estimated.   The future stand volume per ha is estimated by multiplying the stand density and the coefficient of site quality by the total stem volume of dominant and co-dominant trees listed in the yield table for the future forest age to be estimated.

Table 2.11   Example of form of yield table (values are for site quality class 2)

Forest age	Dominant trees								Co-dominant trees							Total of dominant and co-dominant trees						Increment rate
	Mean			Per ha					Mean DBH	Per ha						Per ha						
	DBH	Tree height	Range of tree heights	Number of trees	Basal area	Stem volume	Annual increment of stem volume	Mean increment of stem volume		Number of trees	Ratio of number of trees to number of total of dominant and co-dominant trees	Stem volume	Ratio of stem volume of total of dominant and co-dominant trees	Total of stem volumes	Ratio of total of stem volumes to stem volume of dominant trees	Number of trees	Stem volume	Annual increment of stem volume	Mean increment of stem volume	Total yield	Ratio of total of stem volumes of co-dominant trees to total yield	
Yr	cm	m	m		m²	m³	m³	m³	cm			m³		m³			m³	m³	m³	m³		
10	3.8	3.2	2.8-3.5	-	6.7	8.7	-	0.9	2.2	-	-	-	-	-	-	-	8.7	-	0.9	8.7	-	-
15	7.1	4.9	4.3-5.4	3,581	15.4	34.0	5.1	2.3	4.9	-	-	-	-	-	-	-	34.0	5.1	2.3	34.0	-	31.3
20	9.9	6.5	5.7-7.2	2,916	23.6	72.2	7.6	3.6	7.2	665	18.6	7.9	9.9	7.9	10.9	3,581	80.1	9.2	4.0	80.1	9.9	18.7
25	12.5	7.9	7.0-8.7	2,407	30.8	115.5	8.7	4.6	9.4	509	17.5	12.7	9.9	20.6	18.0	2,916	128.2	11.2	5.4	136.1	15.3	12.2
30	14.9	9.2	8.1-10.2	2,019	36.5	160.7	9.0	5.4	11.4	388	16.1	16.3	9.2	36.9	23.1	2,407	177.0	12.3	6.6	197.6	18.8	8.9
35	17.2	10.4	9.2-11.5	1,718	41.0	204.7	8.8	5.9	13.3	301	14.9	20.3	9.0	57.2	28.0	2,019	225.0	12.9	7.5	261.9	21.9	7.0
40	19.3	11.6	10.2-12.9	1,481	44.7	246.4	8.3	6.2	15.0	237	13.8	23.4	8.7	80.6	32.8	1,718	269.8	13.0	8.2	327.0	24.7	5.7
45	21.4	12.7	11.2-14.1	1,292	47.6	285.4	7.8	6.3	16.8	189	12.8	25.2	8.1	105.8	37.1	1,481	310.6	12.8	8.7	391.2	27.1	4.7
50	23.3	13.7	12.1-15.2	1,143	49.9	321.8	7.3	6.4	18.3	149-	11.5	25.7	7.4	131.5	40.9	1,292	347.5	12.4	9.1	453.3	29.0	4.0
55	25.1	14.6	12.9-16.2	1,024	51.7	355.7	6.8	6.5	19.8	119	10.4	25.3	6.6	156.8	44.1	1,143	381.0	11.8	9.3	512.5	30.6	3.4
60	26.8	15.5	13.7-17.2	927	53.2	387.3	6.3	6.5	21.2	97	9.5	24.5	5.9	181.3	46.9	1,024	411.8	11.2	9.5	568.6	31.9	3.0
65	28.4	16.3	14.4-18.1	848	54.4	416.6	5.9	6.4	22.6	79	8.5	23.8	5.4	205.1	49.3	927	440.4	10.6	9.6	621.7	33.0	2.6
70	29.9	17.0	15.0-18.9	782	55.5	443.7	5.4	6.3	23.8	66	7.1	22.9	4.9	228.0	51.4	848	466.6	10.0	9.6	671.7	34.0	2.3
75	31.2	17.7	15.6-19.7	727	56.5	468.7	5.0	6.3	24.9	55	7.0	21.9	4.5	249.9	53.4	782	490.6	9.4	9.6	718.6	34.8	2.0
80	32.5	18.3	16.1-20.4	680	57.5	491.8	4.6	6.2	26.0	47	6.5	20.9	4.1	270.8	55.1	727	512.7	8.8	9.5	762.6	35.5	1.8

Appendix 1 Features of diagram and formula methods

1 Diagram method

(1) Advantages

1) The process is simple and easy to understand.

2) It is flexible, not rigid like empirical formulas. Therefore, it is possible to draw a curve illustrating the fact in a straightforward manner.

(2) Disadvantages

1) Because the curve can be drawn freely, there is the risk of drawing the curve misunderstanding the facts through a subjective point of view.

2) It is not objective because it is impossible to process automatically.

3) It requires special skills and experience to draw correct curves. Even though it doesn't seem elaborate, it can be considered a very difficult method.

(3) Requirements when drawing a curve according to the diagram method.

The following three requirements should be satisfied as fully as possible.

1) The sum of plus and minus deviations should be algebraically zero comparing basic data with the data on the curve.

2) The arithmetic average of absolute value of deviations should be as small as possible. To be exact, the sum of the squares of deviations should be the smallest.

3) Curve shapes should be derived recursively from previous experience and comply with the acknowledged basic rules.

2 Formula method

(1) Advantages

1) It is objective. Everyone can obtain identical results every time by applying certain

empirical formulas for certain materials.

2) Difficult elaborations are required to find empirical formulas, but they are not necessary when using formulas found by previous workers.

3) Calculation requires many tasks, but the use of PCs and calculating tables can reduce these tasks because they calculate automatically.

4) It is possible to prove the range of errors and accuracy of a result mathematically.

5) Reliable curves are obtained even with a comparatively small number of samples, if the empirical formulas are good.

(2) Disadvantages

1) It is not easy to perform because deep learning and a wide range of knowledge are required to derive correct empirical formulas.

2) It is difficult to derive perfect empirical formulas.   Nevertheless, there is no way of correcting biases and defects of empirical formulas, because the empirical formulas do not offer flexibility.

3) Generally speaking, it is completely objective, free of the subjective point of view regarding the empirical formula.   This, however, is arguable since the individuals applying the formulas choose empirical formulas according to their subjective views, and in a sense the initially determined inflexible subjectivity eliminates entirely objectivity.   However, the case where various objective judgments are employed in choosing empirical formulas is another issue.