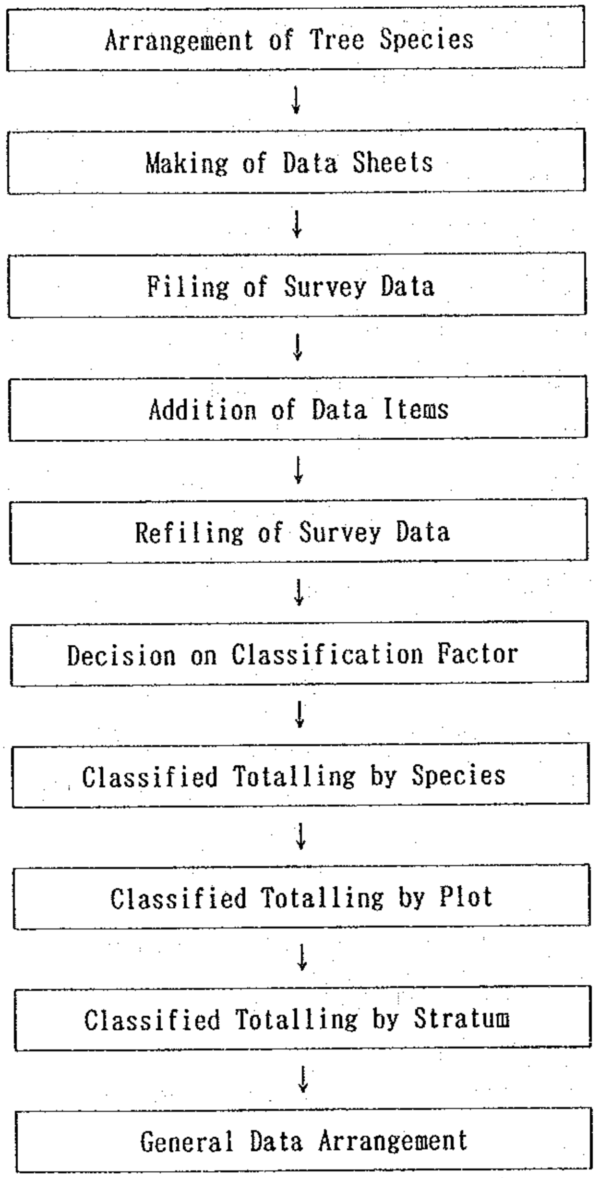


Figure-14 Flow-chart of data arrangement

namely, plot number, block number, stand tree number, vernacular name, upper or lower storey, diameter breast height, clear length and crown diameter (upper-storey trees only), were input to the computer.

c. Addition of data items

The following items were added to the field survey items mentioned above and were filed in the computer:

1) Stratum

This survey used the stratified double sampling method. Similar forest types were grouped in strata. As shown in Table-14, one stratum corresponded to one forest type, in order to select sample plots for each forest type. The following twelve strata were allocated to the sample plots: 2.1(1), 2.2(1), 3.1(1), 3.1(1,EX), 3.1(2), 3.2(2), 3.3(3), 3.5(1), 5(2), 5(2,EX), 5(4) and 8.

Table-14 Stratified standard

Stratum			Forest type	Plot No.
2	Freshwater swamp forest	2.1(1)	Levee alluvium	4,5
		2.2(1)	Lower level alluvium	21,35
3	Peat swamp forest (PSF)	3.1(1)	Mixed swamp forest (MSF) Dense even, small crowns	1,18'
		3.1(2)	Mixed swamp forest (MSF) Dense uneven, medium crowns	2,3,7,32
		3.2(2)	Mixed swamp forest (MSF) Dense uneven, large emergents	15,17,24,25 36
		3.3(3)	Alan bunga forest	6,22,23,26
		3.5(1)	Padang alan forest	16,38
5	Mixed dipterocarp forest (MDF)	5(2)	Dense uneven, medium or large emergents	8,9,10,12 13',14',19' 20,27,28,34'
		5(3)	Dense even, medium crowns	
		5(4)	Dense uneven, medium and large crowns	11,29,30,31
8	Secondary forest	8	Generally over 25 years old	33,37
9		9	Forest plantations	
10		10	Cultivation, cleared land & village	
11		11	Unstocked land & landslide	

' : Exploited forest

2) Genus name and family name

Based on the identification work mentioned above, genus and family names corresponding to vernacular names were input.

3) Tree species group

The identified tree species were classified into the groups as follows:

(Group A) Commercial species

(Group B) Available species

(Group C) Other

Included in Group A were the species listed in article 13, (Forest produce to be liable to royalty) of the Forest Act of Brunei Darussalam, as species whose royalty is higher than $15 per sawn timber ton. A total of 41 tree species were classified as commercial species taking into consideration characteristics such as application, durability and processability. Reference was made to "Wood Quality and Processability of Southsea Timber" by Takuzo Tsutsumoto, Tatsuo Nakano and Hitoshi Karasawa (1975), "Principal Timber Produced in Indonesia", abridged translation by Takuzo Tsutsumoto and Yukio Hiwatashi and others.

A total of 28 species were selected for Group B using the reference information mentioned above. Included in Group C were 34 species not listed in Group A or Group B whose sawn timber utilisation was not known yet.

App. Tables-5 to 7 list the species in the Groups A, B and C.

4) Dipterocarp family

The species in the Dipterocarp family are shown "D" (Dipterocarp trees) and species other than the Dipterocarp family are shown "N" (Non-Dipterocarp trees). All species in the Dipterocap family belong to Group A.

5) Volume

Using the volume formula mentioned in paragraph 3.2.2 "Preparation of stand volume tables", volumes (available volume outside bark) were calculated for single trees, based on diameter breast heights and clear lengths.

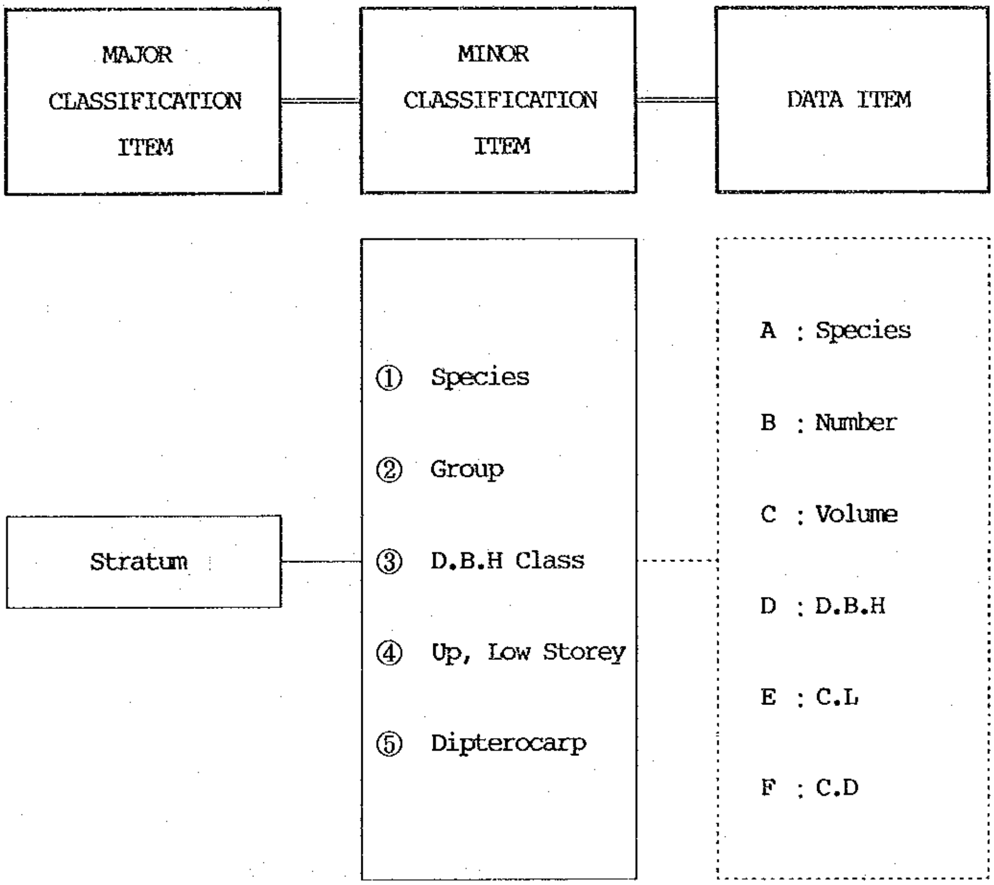
d. Decision on classification factors

In this survey, understanding the ecological characteristics of tropical forests inside the model plantation area, by analyzing the forest descriptions by forest type, was an important task. For this reason, the "stratum" was used as a major classification item of the sample point data. Five factors, namely,"tree species", "group", "diameter class", "upper or lower storey", and "Dipterocarp family" were taken up as minor classification items.

e. Classification, totalling and summation

"Tree species", "number of trees", "volume", "diameter breast height", "clear length", "crown diameter" and other factors were considered as data to be consolidated. As a result, for example, classification tabulation was made by defining "volume by stratified group" and "number of trees by stratified diameter class."

The data was consolidated by including a division between each of two diameter classes (more than 18cm, but less than 40cm and more than 40cm).



(Note) D.B.H : Diameter Breast Height
C.L : Clear Length
C.D : Crown Diameter

Figure-15 Classification system of data

(2) Sample plots

App. Table-8 lists the number of trees, diameter breast height, clear length, crown diameter and volume (available outside bark volume) for each sample plot, arranged by diameter class.

(3) Strata

The 38 sample plots could be classified into 12 strata as shown in Table-14.

App. Table-9 is a stratified list of the results of the complete enumeration (numbers of trees, diameter breast heights, clear lengths, crown diameters and volumes) in the sample plots.

a. Tree species

App. Table-10 shows the number of species that were found in each stratum. Even though the numbers of sample plots for individual stratum vary, the following clear trends emerged from this data.

(i) The number of tree species was large in the following order:
Mixed Dipterocarp forests (Stratum 5) ---> peat swamp forests (Stratum 3) ---> freshwater swamp forests (Stratum 2)
Dispersions of 10 to 25 species were found within the sample plots.

(ii) Stratum 5 had overwhelmingly more Dipterocarp species than the other strata.

(iii) The proportion of the Group A species (commercial species) was large in Stratum 5.

(iv) The number of tree species whose diameter breast heights were smaller than 40cm was larger than those whose diameter breast heights were larger than 40cm.

b. Number of trees

Stratum 3.1(1) had the largest number of trees (18cm or more in diameter breast height) per ha, i.e., 473 trees. Stratum 5(2,EX) had the smallest number of trees, i.e., 191 trees. Variations were prominent from one stratum to another. Trees smaller than 40cm in diameter breast height varied from 137 to 408 trees per ha. Trees 40cm and above in diameter breast height varied from 17 to 131 trees per ha. This showed that the variances in the numbers of trees for the strata were due to small-diameter trees less than 40cm in diameter breast height.

1) By species

App. Table-11 shows the numbers of tree species found in each individual stratum. The relationship between the species found and the various strata showed the following trends.

(1) Species prominent in freshwater swamp forests (Stratum 2)
Ubah, Nyatoh, Resak and Keruntum

(2) Species prominent in mixed swamp forests (Strata 3.1 and 3.2)

Ubah, Kapur group, Ramin, Resak, Sepetir, Kayu malam, Medang tabak and Kedondong.

(3) Species prominent in Alan forests (Strata 3.3 and 3.5)

Alan, Keruntum, Mengilas, Ramin and Nyatoh

(4) Species prominent in mixed Dipterocarp forests (Stratum 5)

Meranti group, Kedondong and Perah

(5) Species prominent in secondary forests (Stratum 8)

Ubah, Kapur group, Resak group and Kedondong

2) By group

App. Table-12 shows the numbers of trees per ha for the individual tree species groups. The commercial species group A could be found prominently in Stratum 2.2(1), but less prominently in Stratum 5(2). Both Group A and Group B, which included available species, were found prominently in Stratum 3.1(1).

As far as the trees in Group A which were 40cm and above in diameter breast height were concerned, a commercial value could be found in 74 of 229 trees per ha in Stratum 3.3(3), or about one third of trees, followed by Strata 3.5(1) and 5(4).

3) By Diameter breast height class

App. Table-13 shows the numbers of trees per ha by diameter breast height class. The table shows that the proportion of small-diameter trees less than 30cm in diameter was large for each stratum. Giant trees larger than 100cm in diameter were found in Alan forests (Stratum 3.3(3)) and mixed Dipterocarp forests (Stratum 5).

App. Figure-1 is the graph showing this observation. The diagram indicates that trees 20 to 30cm in diameter were largest in number showing an "L" distribution, but that this trend differed slightly in accordance with the stratum.

4) By upper or lower storey and by family

App. Table-14 classifies the number of trees per ha into whether trees were upper or lower-storey trees and whether trees were Dipterocarp family or other species. The table indicates that many upper-storey trees were found in freshwater swamp forests (Stratum 2) and peat swamp forests (Stratum 3.1). Many lower-storey trees were found in Alan forests (Strata 3.3 and 3.5) and mixed Dipterocarp forests (Stratum 5) as a trend.

In the composition ratios of the Dipterocarp species, Strata 3.5(1) and 5(4) were high, 40%, while Stratum 3.1(2) was lowest, 14%.

c. Volume

In volume per ha for the individual strata shown in App. Table-9, the secondary forests (Stratum 8) had the smallest volume, 205m3. The Alan forests (Strata 3.3 and 3.5) had the largest volume, 528 to 585m3. No difference between the peat swamp forests (Strata 3.1 and 3.2) and mixed Dipterocarp forests Stratum 5) could be found. Except for exploited forests, the volumes of the peat swamp and mixed Dipterocarp forests were 331 to 448m3 and were the next largest after Alan forests. The freshwater swamp forests (Stratum 2) were recorded with 230 to 278m3 and had small volumes after the secondary forests.

The differences among the various strata became more prominent as far as volumes of trees 40cm or more in diameter were concerned. Stratum 3.3(3) was recorded as 516m3, which was by far the largest, followed by Strata 3.5(1) and 5(4).

1) By species

App. Tables-15 to 26 list tree species found in order of volume for trees 40cm or more in diameter. The species with the highest such volumes are listed below.

Stratum	2.1	Ubah and Bintangor
	2.2	Keruntum and Kapur paya
	3.1	Kapur paya and Ramin
	3.2	Kapur paya and Kedondong
	3.3	Alan
	3.5	Alan
	5(2)	Meranti and Kedondong
	5(4)	Kapur bukit and Meranti

2) By group

App. Table-27 shows volumes per ha in accordance with the species group classification. The occupancy rate of Group A, which consists of commercial trees, was high in many strata. This trend was prominent especially in Stratum 3.3(3), registering a very prominent occupancy rate of

85%.

As far as species in Group A 40cm or more in diameter breast height and high in commercial value were concerned, Stratum 3.3(3) forming pure forests of Alan trees had an occupancy ratio of about 81% and was dominant among the tree species. Stratum 3.3(3) was followed by Strata 3.5(1) and 5(4) while Stratum 2.1(1) had the lowest occupancy ratio, 5%.

3) By upper or lower storey and by family

App. Table-28 classifies volumes per ha by stratification whether trees were upper- or lower-storey trees and whether they were Dipterocarp species or not. According to this data, volumes of upper-storey trees were large in each stratum.

Alan forests (Strata 3.3(3) and 3.5(1)) were highest in the volume occupancy ratio of Dipterocarp species, i.e., 72 to 77%, followed by Stratum 5(4) for mixed Dipterocarp forests of 65%. Stratum 2.1(1) of freshwater swamp forests had the lowest occupancy ratio at 15%.

d. Diameter breast height, clear length and crown diameter

App. Tables-29 to 31 show the average, maximum and minimum values of the diameter breast height, clear length and crown diameter of each stratum. As far as average values were concerned, Stratum 3.3(3) showed a large value in diameter breast height. Strata 5(2) and 5(4) showed large values in clear length and crown diameter, respectively. Depending on the strata, large variations were found such as 20.4 to 47.7cm in diameter breast height, 10.6 to 17.9m in clear length and 5.9 to 10.6m in crown diameter.

The maximum diameter breast height was 130cm, found in Strata 3.3(3), 5(2) and 5(4). The maximum clear length was 35m found in Strata 3.3(3) and 5(4).

3.2.4. Analysis of results of sample plot survey

The complete enumeration data gathered in the small sample plot survey was classified and totalled by stratum (forest type) to analyse the characteristics of the forest description of each stratum. The data was analysed by placing emphasis mainly on the commercial value of stand trees. The characteristic factors of each stratum are described below.

(1) Stratum 2.1(1) (Freshwater swamp forest)

The dominant species were Ubah, Bintangor, Medang, Resak, Rengas and others. Only Resak and Merbau were commercial species with diameter breast heights of 40cm or more belonging to the Group A. The volume proportion of those was 5%. Forest stands of this type mainly had small-diameter trees and were low in commercial value.

The average volume per ha of this stratum was 230m^3.

(2) Stratum 2.2(1) (Freshwater swamp forest)

The dominant species were Keruntum, Kapur paya, Nyatoh, Meranti paya, Medang tabak and others. The species which belonged to the Group A with diameter breast heights of 40cm or more were Kapur paya, Nyatoh, Meranti paya, Ramin and others, and accounted for 16% in volume proportion. This stratum also consisted of forest stands low in commercial value after Stratum 2.1(1).

The average volume per ha of this stratum was 278m^3.

(3) Stratum 3.1(1) (Peat swamp forest)

The dominant species were Keruntum, Ramin, Kapur paya, Bangkoh, Medang and others. In some places, variations of mixed species were large. The species which belonged to the Group A with diameter breast heights of 40cm or more were Ramin, Kapur paya and Nyatoh which accounted for 14% in volume proportion, which was low. Medium and small diameter trees smaller than 40cm in diameter breast height were dominant in these forest stands.

The average volume per ha of this stratum was 448m^3.

(4) Stratum 3.1(1EX) Peat swamp forest

This was the forest stand in which part of Stratum 3.1(1) had been felled in the past and was stratified as one of the forest types. The dominant species were Ramin, Kapur paya, Ubah, Medang and others. The species which belonged to the Group A with diameter breast heights of 40cm or more were Ramin and Kapur paya. These species accounted for 34% of the volume.

The average volume per ha of this stratum was 260m^3.

(5) Stratum 3.1(2) Peat swamp forest

The dominant species of this stratum were Kapur paya, Ramin, Sepetir, Ubah, Nyatoh and others. Kapur paya, Ramin, Nyatoh and the Meranti group belonged to the Group A with diameter breast height of 40cm or more. This group accounted for 39% of the volume.

The average volume per ha of this stratum was 393m³.

(6) Stratum 3.2(2) Peat swamp forest

The dominant species were Kapur paya, Kedondong, Rengas, Keruntum, Ubah and others. Kapur paya, Nyatoh, Ramin and the Meranti group belonged to the Group A which had diameter breast heights of 40cm or more. This group accounted for 30% of the volume.

The average volume per ha of this stratum was 331m³. Except for the site characteristics, this stratum had many similarities to Stratum 3.1(2).

(7) Stratum 3.3(3) Alan bunga forest

Alan was the only dominant species, forming pure uniform looking forests. The volume proportion of this species was 76%, accounting for 86% in trees 40cm or more in diameter breast height. It accounted for 66% in terms of the number of trees. The average volume per ha of this stratum was 585m³, the largest both in total volume and commercial species volume.

Ramin, Ubah, Jelutong, Sepatir, Nyatoh and other species were found growing as lower-storey trees.

(8) Stratum 3.5(1) Padang alan forest

As in Alan bunga forests of Stratum 3.3(3), Alan was dominant. Trees 40cm or more in diameter breast height accounted for 87% in volume and 82% in number of trees.

The average volume per ha of this stratum was 528m³.

The differences between this stratum and Alan bunga forests were that it formed pure uniform Alan forests of medium-diameter trees, and that it contained small-diameter trees of Alan in the intermediate storey. This was not found in Alan bunga forests.

(9) Stratum 5(2) Mixed Dipterocarp forest

The dominant species were the Meranti group, Kedondong, Ubah, Medang, Keranji, Keruing and others. The species which belonged to the Group A with 40cm or more in diameter breast height were the Meranti group, Keruing, Kapur group and other Dipterocarp species. The volume proportion of this group was 26%.

The average volume per ha of this stratum was 375m^3 and the number of trees in it was the smallest among the various strata. The merchantable volume per tree of the species belonging to the commercial species group A was about 5m^3. This stratum contained the second largest number of large-diameter trees after Alan bunga forests in Stratum 3.3(3).

(10) Stratum 5 (2.EX) Mixed Dipterocarp forest

In the past, trees in this forest stand were cut in some parts of Stratum 5(2) and variances in the forest description were large according to the differences in the method, intensity of development, and the number of years since their development. As average values of plots, the order of dominant species was Kedondong, Keruing, Belian, Ubah and Perah. The species which belonged to the Group A were Keruing, Belian, Resak and Meranti. The volume proportion of these species 40cm or more in diameter breast height was 34%.

The average volume per ha of this stratum was 237m^3, which was the lowest value after Strata 2.1 and 2.2 in freshwater swamp forests. It was noteworthy that the above commercial species was a succeeding growth of medium- and lower-storey trees.

(11) Stratum 5(4) Mixed Dipterocarp forest

The dominant species were mostly Dipterocarp species such as Kapur bukit, the Meranti group, Keruing, Resak and other Dipterocarp species. The volume proportion of the species belonging to the Group A 40cm or more in diameter breast height was 60% and the quality of forests of this type was high. A succeeding growth consisting of trees of the Dipterocarp family could be found in the medium storey.

The average volume per ha of this stratum was 440m^3.

(12) Stratum 8 Secondary forest

Nearly all secondary forests were distributed in peat swamp forest belts. The dominant species were Ramin, Kapur paya, Ubah, Pulai, Sindok sindok and others. All sun plants such as Pulai and Sindok sindok may become extinct in these forests, which will then revert to peat swamp forests in which Ramin, Kapur paya, Ubah, Resak and other species are dominant. In the future, Kedondong would become dominant in areas where drainage is good.

The average volume per ha of this stratum was 205m^3. The number of trees per ha naturally was large, 663.

Table-15 presents the number of trees and volume per ha for each stratum.

Table-15 Commercial value by stratum

Stratum	N Number/ha			Volume/ha			Volume per Tree	
	Group A & 40 ≦D	All trees	Ratio %	Group A & 40≦D m³	All tees m³	Ratio %	Group A & 40≦D m³	All tees m³
2.1(1)	5	310	1.6	11.592	229.969	5.0	2.318	0.742
2.2(1)	21	413	5.1	44.190	277.907	15.9	2.104	0.673
3.1(1)	28	473	5.9	63.023	448.380	14.1	2.251	0.948
3.1(1.EX)	33	355	9.3	89.633	260.465	34.4	2.716	0.734
3.1(2)	39	252	15.5	151.463	393.082	38.5	3.884	1.560
3.2(2)	25	268	9.3	98.181	331.004	29.7	3.927	1.235
3.3(3)	74	229	32.3	472.215	584.673	80.8	6.381	2.553
3.5(1)	110	383	28.7	336.541	528.278	63.7	3.059	1.379
5(2)	17	219	7.8	99.056	374.546	26.4	5.827	1.710
5(2.EX)	13	191	6.8	52.966	236.853	22.4	4.074	1.240
5(4)	51	243	21.0	261.594	334.768	78.1	5.129	1.378
8	8	663	1.2	23.127	205.010	11.3	2.891	0.309
Total	44	324	13.6	198.958	391.028	50.9	4.522	1.207

3.3. Estimation of Stand Volume

3.3.1. Preparation of standard interpretation cards

Standard interpretation cards are also called photo-stereograms. When interpreting a forest type in a forest stand, the desired forest type can be decided by selecting a card which matches one of the stereograms when they are collated, assuming stereograms of various forest types have already been prepared. Similarly, the numbers and volumes of trees of forest stand composition factors written on cards, as well as main species of dominant trees, can be used as values estimated by interpretation of the forest stand. The entire survey area was comparatively interpreted using these stereograms when final vegetation maps (forest type classification and land utilisation classification) were prepared to determine forest type.

Standard interpretation cards were prepared by the following three steps:

a) Maps of small sample plots (field survey sites) were enlarged by 2 and were cut to required sizes after marking the sample plots on the aerial photographs. The maps were oriented on the standard interpretation cards and were pasted on them to allow correct stereoscopic vision.

b) Paragraph 3.2.4 Analysis of results of sample plot surveycontains data consolidated to show quality characteristics of forest type at a glance by analysing data obtained in complete enumeration. The forest stand composition elements from this data needed as stereograms were selected and transferred onto the cards.

c) The photo interpretation values and photo specifications of the forest stand composition factors were shown. The photo specifications were the values needed when forests were measured using a parallax bar on pasted stereo model photos. Table-16 shows the format of the standard interpretation card.

The items shown inside the frame in upper left of the sheet enclosed by thick lines are the analytical data of all the trees in the forests.

In the species composition column, the five top species in the order of the number of upper-storey trees are described. Mean values of clear lengths and diameter breast heights are shown as numerators, and their ranges as denominators.

The values inside the frame the in middle enclosed by thick lines are only those for upper-storey trees. The values inside the frame in the bottom enclosed by thick lines are only the number of trees other than upper-storey trees.

The values inside the frame in upper right enclosed by thick lines are photo interpretation values. The first column is the mean crown diameter obtained by averaging the measured crown diameter of all upper-storey trees in the small sample plots.

The column for the canopy shows the characteristics of the canopy form. The tones were shown by interpreting the tones of the canopy in the photographs as follows:

(a) Dark gray

(b) Gray

Table-16 Standard interpretation card

FOREST TYPE

Forest Description

Volume/ha	m^3
Species Composition	
Clear Length	m
D.B.H	cm
Crown Density	
Number/ha	
(Upper-story Tree)	
Clear Length	m
D.B.H	cm
Crown Diameter	m
Number/ha	
(Middle-story Tree)	
Number/ha	

PLOT NO.

FOREST TYPE MAP

COURSE.PHOTO NO.(Left) (Right)

Characteristic of Photo-interpretation	
Mean Crown Diameter	m
Canopy	
Tone	
Data List for Photography	
Date of Photo.	
Focus Length	mm
Flying Height Above Ground	m
Scale of Photo.	
Absolute Parallax	mm
Land Description	
Altitude	m
Micro-topography	
Geology	
Soil	
Date of Field Survey	

Ground Photo.

(c) Light gray

The values shown inside the frame in the middle right enclosed by thick lines are the specifications of the photo. "Absolute parallax" at the end is a factor needed when measuring tree height using a parallax bar.

The frame in the bottom enclosed by thick lines shows land descriptions; i.e., altitude, micro-topography, geology, soil type and lastly the date of field survey.

The forest type map located in the center of the stereogram shows the forest types near a small sample plot intended to make the confirmation of the survey area at the site easy. The photo in the lower centre is a terrestrial photo of a forest stand.

3.3.2. Preparation of stand aerial volume formulae

As mentioned earlier, volumes by stratum (by forest type) and by overall stand volume were estimated by the stratified double sampling method (stratified combined regression estimation). Therefore, volumes of the large sample plots were estimated by the linear regression formula of measured volumes (Y) of the small sample plots and by photograph interpretation values (product of mean crown diameter X_1 and crown density X_2).

(1) Photo interpretation of small sample plots

Forest-stand mean crown diameters and crown densities of the small sample plots were measured using the aerial photos.

Mean crown diameters (X_1) were measured by measuring crown diameters of ten trees in each small sample plot marked on an aerial photo, and by calculating averages. A crown diameter scale was used in measuring the crown diameters. Mean crown diameters of those forest stands which had very small and uniform crowns were calculated by selecting by eye measurement those trees which had average crowns, and by measuring theei rcrown diameters.

Table-17 Crown diameter classification

Crown diameter classification	Interpreted mean crown diameter
1	Below 7 m
2	7.1m～ 9.9m
3	Over 10m

Crown densities of upper-storey trees in the small sample plots were measured using a crown density scale. Crown density percentages, "high", "medium" and "sparse", in the stand type classification obtained in the preliminary photo interpretation were further segmented into the following five classes:

Table-18 Crown density classification

Aerial stand volume fomula		Crown density classification
5	Over 90%	High density
4	70%～89%	Medium density
3	50%～69%	
2	30%～49%	Sparse density
1	Below 30%	

App. Table-32 shows the photo interpretation values of mean crown diameters (X_1) and crown densities (X_2) of the small sample plots.

(2) Preparation and application of stand aerial volume formula

Assuming the total stand volume to be a dependent variable (y) and crown diameter and crown density to be independent variables (x_1) and (x_2), the volume estimation precision by three combinations of linear and multiple regression formulae was studied. As a result, the three formulae did not produce significant variances in the estimation precision. The following linear regression formula was used for ease of photo interpretation work and because of the simplicity of the volume estimation formula:

$y = a + bx$ .... Eq. (1)

where y: volume per ha

x: product of mean crown diameter percentage (X_1) and crown density percentage (X_2)

Statistical calculations are made using the values y and x in App. Table-32

Σx_i=294 Σy_i=14,026.57 Σx_i^2=2,676

Σx_i=5,928,139.754 $\Sigma y_i \cdot x_i$=123,711.42

x=7.74 y=369.12 n=38

Using them, constants a and b are calculated as follows:

$Sx^2=\Sigma(x_i-x)^2=\Sigma x_i^2-(\Sigma x_i)^2/n=401.3684$

$Sy^2=\Sigma(y_i-y)^2=\Sigma y_i-(\Sigma y_i)^2/n=750,648.5444$

$Sxy=\Sigma(x_i-x) \cdot (y_i-y)=\Sigma x_i \cdot y_i-(\Sigma x_i) \cdot (y_i)/n=15,190.06263$

$b=Sxy/Sx^2=15,169.06263/401.3684=37.8457$

$a=y-bx=369.12-37.8457 \times 7.74=76.194$

Therefore, the following linear regression formula will be obtained to calculate mean volumes per ha for the various strata by substituting mean photo interpretation values (Xh) for each strata:

$y = 76.194 + 37.8457Xh$ .... Eq. (2)

where Xh: mean value of photo interpretation values (Xh) by stratum

h: Strata 1 to L

3.3.3. Aerial Photo interpretation

Errors in interpreting the aerial photos were corrected by collating the prepared standard interpretation cards and forest type classification in the photos sub-divided according to the preliminary interpretation work. The final forest type classification was then decided.

Next, the forest type classification on the aerial photos was transferred onto a topographic map 1/20,000 in scale to prepare a forest type map.

Discrimination between freshwater swamp forests and Stratum 3.1(1) of peat swamp forests was slightly difficult due to a problem in interpreting the aerial photographs in some areas. Discrimination between Strata 3.1(2) and

3.2(2) was also slightly difficult.

Large areas of non-cultivation land and land abandoned for cultivation became secondary forests. The future land utilisation mode for this land was not known and all these areas were included in the classification as farm land. The interpretation of boundaries between land that became secondary forests after cultivation on it was abandoned, and secondary forests was very difficult. These areas were classified in accordance with the conditions of the areas around them.

A total of 167 large sample plots were randomly set on the above forest type map for each stratum, taking stratum areas and forest types (descriptions) into consideration.

The large sample plots on the map were transferred on to the aerial photographs. Mean crown diameters and crown densities were measured and the product of both X'_h was calculated by the same operation as that used in photo measurement of the small samples. App. Table-33 shows the mean interpretation values X'_h for the individual strata.

3.3.4. Estimation of area by forest type

Measurement of the areas by forest type was necessary to estimate stand volumes for the strata, and for the entire forest stands, to prepare the forest inventory book. The forest type sectional lines plotted on contact photos of the survey area (scale 1/26,880) were transferred onto a topographic map 1/20,000 in scale to measure areas by forest type on the topographic map. The results of area measurement are shown in Table-19.

3.3.5. Estimation of mean volume and overall stand volume by forest type

As stated in paragraph 3.3.2., the volume for each forest type and the overall stand volume were estimated by the stratified double sampling method, by combined regression estimation. The linear regression formula presented in subparagraph 3.3.2. Eq.(2) is as follows:

$$y = 76.194 + 37.8457\overline{X}_h$$

This formula was obtained based on the measured volumes of the small

Table-19 Area by forest type

Forest type		Area (ha)		
		Forest land	Left-over area	T o t a l
Freshwater swamp forest	2.1(1)	1,107.93	11.65	1,119.58
	2.2(1)	3,780.18	2.63	3,782.81
	2.2(1.EX)	99.05		99.05
	2.2(1.S)	67.88		67.88
Peat swamp forest	3.1(1)	67.54		67.54
	3.1(1.EX)	360.49	0.46	360.95
	3.1(2)	2,033.69		2,033.69
	3.1(2.EX)	831.44		831.44
	3.2(2)	567.89	1.88	569.77
	3.2(2.EX)	606.54		606.54
	3.2(2.S)	28.67		28.67
	3.3(3)	583.51		583.51
	3.3(3.EX)	364.19		364.19
	3.5(1)	391.34		391.34
Mixed dipterocarp forest	5(2)	13,087.36	28.52	13,115.88
	5(2.EX)	8,770.35	8.10	8,778.45
	5(3)	358.70		358.70
	5(4)	1,848.89		1,848.89
	5(4.EX)	14.97		14.97
Secondary forest	8	1,057.31		1,057.31
	8(S)	67.49		67.49
Plantations	9	116.19		116.19
Cultivation, cleared land & village	10		14,752.55	14,752.55
Unstocked land & land slide	11		119.36	119.36
Sungai Belait			92.25	92.25
Total		36,211.60	15,017.40	51,229.00

samples and photo interpretation values X_h [product of mean crown diameter percentage Table- 17 and crown density percentage Table-18]. Assuming $\overline{X}_h$ to be the product 1 of the mean crown diameter percentage and lowest crown density percentage, the estimated volume would be 114.04m³. The formula was not used with the heterogeneous strata of volume that did not reach 114.04m³ per ha. Of the 21 strata comprising forest stands, the stratified double sampling method could not be used with three stratum, i.e., Strata 2.2(1.S), 3.2(2.S) and 8(S) and volumes of these strata were obtained by interpreting the aerial photos. The mean volumes per stratified ha, total mean volume and overall stand volume of the remaining 18 strata were estimated by the stratified double sampling method using the above formula.

The mean volumes per ha for each stratum were calculated by fitting the mean photo interpretation values ($\overline{X}_h$) contained in App. Table-33 to Eq. (2). By eye measurement, mean volumes per ha of 2.0, 15.0 and 4.0m³ were calculated for Strata 2.2(1.S), 3.2(2.S) and 8(S).

Standard errors of mean volumes of the strata were calculated based on the ranges of the measured volumes of the small samples in the strata, as the number of small samples allocated to each stratum was not sufficient. The standard error of the distribution in Range R could be obtained by the following formula.

$E[R] = d_2\ \sigma$

By this, the unbiased estimate of can be calculated based on R/d_2. The coefficient d_2 could also be decided by the distribution type and n as shown in Table-20. The standard error for each stratum by R is shown in Table-21.

The forest types and volumes of Strata 2.1(1) and 2.2(1) and in Strata 3.1(1) and 3.1(2) were similar and calculations were made by combining both. The number of small sample plots for Stratum 3.1(1.EX) was only one, and this stratum was disregarded as calculations were not possible.

Table-22 shows estimated values of mean volumes ($\bar{y}_h$) and standard errors ($s\bar{y}_h$) per ha of the individual strata.

The forest type which had the largest volume per ha was Alan bunga forests of Stratum 3.3(3) and the volume of it per ha was 580m³. The error was 7.79% and this stratum had the smallest volume dispersions. Stratum 5(4) of the mixed Dipterocarp forests was the forest type which had the next largest volume, followed by Stratum 5(3) of the same type and by Stratum 3.5(1) of Padang alan forests. The forest stands around the model plantation area being developed at present were Stratum 5(2.EX). The volume per ha of them was 254.189±2 x 18.93 = 216 to 292 and the volume per ha was estimated to be within the range of 216 to 292m³.

The mean volume per ha of the entire area of the stratified double sampling method, i.e., estimated value of the mean value $\overline{Y}$ of the population

Table-20 Coefficients(d_2) used for standard deviation calculation (Formal distribution)

n	D_2	Remarks
2	1.128	
3	1.693	
4	2.059	
5	2.326	
6	2.534	
7	2.700 ………	Approximate quantity

y_{lr} could be calculated by the following formula:

$\bar{y}_{1r}=\bar{y}+b(\bar{x}'-\bar{x})$ ………………………………Eq.(3)

y, x and b could be calculated based on the small samples using the following formulae, respectively:

$\bar{y}=\Sigma y_i/n$ $\bar{x}=\Sigma x_i/n$ $b=Sxy/Sx^2$

x' was an estimated value of the population mean X of x_i from the large samples.

$\bar{x}'=\Sigma N_h \cdot x_h/N=\Sigma W_h \cdot \bar{x}_h$

where N_h: area of Stratum h (h = 1 to L)

N_n: total of area per stratum

$\bar{x}_h$: mean interpreted value of Stratum h

The following approximation formula was used with the population variance of y_{1r} if 1/n could be neglected.

$$\sigma^2 \bar{y}_{1r} \fallingdotseq \sigma^2 y\,(1-\rho^2)/n+\rho^2\,\sigma^2 y/n'$$

In the above formula, $\sigma^2 y$ was a population variance of y_i. ρ was a population correlation coefficient of x_i and y_i.

The unbiased estimator of this variance from the samples could be calculated from the following formula:

$$s^2 \bar{y}_{1r}=s^2 y\cdot x/n+(s y^2 - s^2 y\cdot x)/n' \quad \text{------------------ Eq.(4)}$$

$s^2y.x$ in Eq. (4) was a residual variance and s^2y was a sample variance of

Table-21 Estimation of the standard error in mean stand volume

Stratum	Range of stand volume	Number of small sample plots(n)	d_2	sy_h (R/d_2)	$\bar{s}y_h$ $(sy_h/\sqrt{n})$
2.1(1) 2.2(1)	132.82	4	2.059	64.507	32.254
3.1(1) 3.2(1)	272.29	5	2.326	117.064	52.353
3.2(2)	389.61	5	2.326	167.502	74.909
3.3(3)	185.95	4	2.059	90.311	45.156
3.5(1)	78.48	2	1.128	69.574	49.196
5(2)	243.95	7	2.700	90.352	34.150
5(2.EX)	198.12	4	2.059	96.222	48.111
5(4)	214.78	4	2.059	104.313	52.157
8	90.68	2	1.128	80.390	56.844
Total		37			

Table-22 Average stand volume by stratum

Forest type	Forest land		$\bar{x}'_h$	$\bar{y}_h$ (m³/ha)	$W_h\ \bar{y}_h$	$W_h\ \bar{x}'_h$	Standard deviation	Standard error	Rates of error
	N_h (Area)	$W_h=(N_h/N)$					(sy_h)	($s\bar{y}_h$)	$s\bar{y}_h/\bar{y}_h \times 100$(%)
2.1(1)	1,107.93	0.0308	3.9	223.912	6.896	0.120	64.507	32.254	14.40
2.2(1)	3,780.18	0.1052	4.3	239.051	25.148	0.452	64.507	32.254	13.49
2.2(1.EX)	99.05	0.0028	2.0	152.006	0.426	0.006	—	—	—
3.1(1)	67.54	0.0019	6.0	303.388	0.576	0.011	117.064	52.353	17.26
3.1(1.EX)	360.49	0.0100	2.8	182.282	1.823	0.028	—	—	—
3.1(2)	2,033.69	0.0566	8.0	379.080	21.456	0.453	117.064	52.353	13.81
3.1(2.EX)	831.44	0.0232	3.4	204.990	4.756	0.079	—	—	—
3.2(2)	567.89	0.0158	6.4	318.527	5.033	0.101	167.502	74.909	23.52
3.2(2.EX)	606.54	0.0169	3.6	212.559	3.592	0.061	—	—	—
3.3(3)	583.51	0.0162	13.3	579.662	9.390	0.215	90.311	45.156	7.79
3.3(3.EX)	364.19	0.0101	3.9	223.912	2.261	0.039	—	—	—
3.5(1)	391.34	0.0109	9.0	416.925	4.544	0.098	69.574	49.196	11.80
5(2)	13,087.36	0.3642	7.9	375.295	136.682	2.877	90.352	34.150	9.10
5(2.EX)	8,770.35	0.2441	4.7	254.189	62.048	1.147	96.222	48.111	18.93
5(3)	358.70	0.0100	9.0	416.925	4.169	0.090	—	—	—
5(4)	1,848.89	0.0515	10.4	469.909	24.200	0.536	104.313	52.157	11.10
5(4.EX)	14.97	0.0004	4.0	227.697	0.091	0.002	—	—	—
8	1,057.31	0.0294	2.4	167.144	4.914	0.071	80.390	56.844	34.01
Total(18)	35,931.37	1.0000			318.005	6.386			
2.2(1.S)	67.88			2.00					
3.2(2.S)	28.67			15.00					
8(S)	67.49			4.00					
9(PL)	116.19								

yi. Both could be expressed as follows:

$$s^2\ y \cdot x = \frac{1}{n-2}\ (S\ y^2 - b\ S\ x \cdot y)$$

$$s^2\ y = S\ y^2\ /\ (n-1)$$

The number of small samples was small in the forest survey and 1/n could no longer be neglected. Therefore, the unbiased estimator of variances from the samples was calculated using the following formula:

$$s^2\ \bar{y}_{lr} = s^2\ y \cdot x\ \left\{ \frac{1}{n} + \frac{(\bar{x}' - \bar{x})}{S\ x^2} \right\} + \frac{(s^2\ y - s^2\ y \cdot x)}{n'} \text{ ---- Eq.(5)}$$

The following was obtained as calculations of the mean volume per ha ($\bar{y}_{lr}$) and its variance is ($s^2\bar{y}_{lr}$) when data of the small and large samples were fitted to Eqs. (3) and (5):

$$\bar{y}_{lr} = y + b\ (\bar{x}' - \bar{x})$$

$$= 369.12 + 37.8457\ (6.386 - 7.74)$$

$$= 317.877$$

$$s^2\ y = S\ y^2\ /\ (n-1) = 750,648.5444 \div 37 = 20,287.7985$$

$$s^2\ y \cdot x = (S\ y^2 - b\ S\ x\ y)\ /\ (n-2)$$

$$= (750,648.5444 - 37.8457 \times 15,190.06263)\ /\ (38-2)$$

$$= 4,882.4998$$

$$s^2\ \bar{y}_{lr} = s^2\ y \cdot x\ \left\{ \frac{1}{n} + \frac{(\bar{x}' - \bar{x})^2}{S\ x^2} \right\} + \frac{(s^2\ y - s^2\ y \cdot x)}{n'}$$

$$= 4,482.4998\ \left\{ \frac{1}{38} + \frac{(6.386 - 7.74)^2}{401.3684} \right\} + \frac{20,287.7985 - 4,882.4998}{167}$$

$$= 243.03575$$

$s\ \bar{y}_{lr} = \sqrt{s^2\ y_{lr}} = 15.5896$: Standard error

The value in table of t distribution for the degrees of freedom of (n-2) = 36 and of the confidence level of 95% was 2.029. The confidence limit of the mean volume per ha could be expressed as follows:

The error rate was 9.95% (31.63 x 100/317.88 = 9.95%).

Therefore, the mean volume per ha was estimated to be within the range 286 to 350m^3, with an error rate of about 10%.

The total stand volume of the entire area could be calculated by the following formula:

$$35,931.37\text{ha} \times (317.88 \pm 31.632)\text{m}^3 = 11,421,863.90\text{m}^3 \pm 1,136,509.23\text{m}^3$$

(Error rate 9.95%)

The following could be obtained if the three strata estimated by eye measurement were added:

Table-23 Area and stand volume by stratum

Forest type	Stratum	Area ha	Stand volume m^3
Freshwater swamp forest	2.1(1)	1,107.93	248,078.82
	2.2(1)	3,780.18	903,655.81
	2.2(1.EX)	99.05	15,056.19
Peat swamp forest	3.1(1)	67.54	20,490.83
	3.1(1.EX)	360.49	65,710.84
	3.1(2)	2,033.69	770,931.21
	3.1(2.EX)	831.44	170,436.89
	3.2(2)	567.89	180,888.30
	3.2(2.EX)	606.54	128,925.54
	3.3(3)	583.51	338,238.57
	3.3(3.EX)	364.19	81,546.51
	3.5(1)	391.34	163,159.43
Mixed dipterocarp forest	5(2)	13,087.36	4,911,620.77
	5(2.EX)	8,770.35	2,229,326.50
	5(3)	358.70	149,551.00
	5(4)	1,848.89	868,810.05
	5(4.EX)	14.97	3,408.62
Secondary forest	8	1,057.31	176,723.02
2.2(1.S)	2.2(1.S)	67.88	135.76
3.2(2.S)	3.2(2.S)	28.67	430.05
8(S)	8(S)	67.49	269.96
Total	Total	36,095.41	11,427,394.67

'Notes' EX : Exploited forest
S : Sparse density

2.2(1.S)	67.88 x 2.00 = 135.76
3.2(2.S)	28.67 x 15.00 = 430.05
8(S)	67.49 x 4.00 = 269.96
Total	835.77

Combining both, the total stand volume calculated was 11,422,700m^3. Table-23 presents the areas and stand volumes by stratum.

The total stand volume shown in Table-23 produced a variance of about 4,700m^3, or about 0.04%, compared with the value calculated using the estimation formula for total stand volume. The variance was produced due to a difference in the calculation procedures used.

3.4. Considerations of Results of the Forest Survey

Thanks to the forest type classification by aerial interpretation, selection of small sample plots, random sampling and photo interpretation of large sample plots and other work, which was conducted satisfactorily, results surpassing the initially-anticipated precision could be obtained. The goals for the estimation precisions of the mean volume and total stand volume per ha were set at 80% for the confidence limit, and 20% for the error rate during the survey design stage. The net result was that a confidence limit of 95% and error rate of 10% could be accomplished as the stand volume estimation precision.

This accomplishment was possible mainly from the interpretation of the aerial photos, which were very clear due to a zero amount of cloud. It was also made possible by setting 38 small sample plots, more than originally planned, and 167 large sample plots. It can be said that results with a very high precision were achieved as a survey of stand volumes of tropical rain forests.

Next, the characteristics of the forest types analysed as a result of the field survey, and views of the consultants for the future practical application of scientific, economic and social principles to the administration and working of forest estate for specified objectives, are described below.

Freshwater swamp forests, particularly of Type 2.1(1), penetrated to valleys inside mixed Dipterocarp forests. The necessity of retaining these forest stands for conservation of banks is high. If mixed Dipterocarp forests in the outer edges of them are clear-cut, eroded soil will flow into these forest stands and will be deposited there. If the volume of deposition is large, the danger of trees withering is very high.

Variances within strata of forests, such as volume, are relatively large with Types 3.1 and 3.2 of peat swamp forests. On the other hand, these stratum types have many site conditions in common. Farmland and rubber plantations are sometimes distributed in areas having these site conditions with good drainage. These areas can become plantations for species which like swamps, such as Kapur paya.

Generally, secondary forests in Stratum 8 are found mostly in areas which were formerly mixed peat swamp forests. At present, trees in these forests are small-diameter trees less than 40cm in DBH. In some areas, however, many succeeding trees of commercial species are found. It is recommended that future forest operations will also include positive measures to raise these species.

Alan bunga forests in Type 3.3(3) form single-storey canopies of Alan only. Succeeding growths of Alan do not appear in the lower storey. Kapur paya and various other non-Alan species are grown as succeeding species in areas about 18 years after felling Alan bunga forests, suggesting difficulty in regenerating Alan bunga forests.

Unlike Alan bunga forests, small and medium succeeding trees of Alan grow in intermediate and lower strata of Padang alan forests in Type 3.5(1). Natural regeneration may become possible by appropriate forest operations such as selection felling.

Lowland mixed Dipterocarp forests in Type 5(2.EX) have large volume variances within strata, in accordance with the felling method, felling rate or years after felling. [See Table-22.] Some plots have a volume per ha of only about $210m^3$. In many places commercial species are grown in the intermediate and lower storey. This forest type is suitable for plantation establishment, and consideration should also be given to preserving these commercial species.

Lowland mixed Dipterocarp forests in Types 5(2), 5(3) and 5(4) are the forest types that have high volumes after Alan bunga forests. The stand types are formed by three storeys; upper, intermediate and lower storeys. The Dipterocarp species are dominant in the upper storey. Commercial species including Dipterocarp species grow in the intermediate and lower streys also. Young growths appear in parts where upper-storey canopies are opened up. It is desirable that the forest composition including this forest type will be sustained by appropriate forest operations.

3.5. Vegetation Maps

The vegetation maps referred to in this report are the drawings which show the distribution of forest types, including the land utilisation status such as farmland. Five sheets of vegetation maps in the scale of 1/20,000 were prepared.

The entire forests in the survey area were divided into those in Daerah Tutong and Daerah Belait, and these areas were divided into the different forest types including farmland and other types. Some of the forest compartments were as large as several thousand hectares. It would have been appropriate to divide these forest compartments by natural terrains such as ridges. However, classification by terrains was not possible as the topography was generally low-relief, wavy topography. The minimum areas for the forest compartments were generally about 5ha. As a rule, the forest compartments were numbered sequentially clockwise. Each forest compartment was given a forest compartment number and forest type symbol. Forest compartment numbers on the 1000-level were assigned to Daerah Tutong and on the 2,000-level were assigned to Daerah Belait. The forest type symbols and descriptions are described in paragraph 3.2.4. Analysis of results of sample plot survey and are also shown in the vegetation maps as legends.

The compartments other than forests (left-over areas) are assigned with numbers on the 500-level. The river channel areas of the Belait River inside the survey area were divided, but were not assigned with compartment numbers. The other river channel areas and roads were treated as left-over areas. These areas are described in the forest inventory book.

4. Soil Survey

4.1. Field Survey

4.1.1. Selection of survey points

The access to the survey area was studied in advance by a field reconnaissance and aerial examination by helicopter. South of the central part of the model plantation area, only one road from Merangking in the centre to Buau in the south, which is under construction, is available for vehicle transportation. This road can be used during the dry season. If it rains, even a 4-wheel drive vehicle has difficulty passing through it. There are no other roads that are passable to vehicles. The southern part can be accessed only by boat using rivers, then on foot.

In Phase 2 (August and September, 1992), interpretation of detailed micro-topography, footpaths and other objects was attempted using the aerial photos. However, these objects were hidden in the forest type and there were many uncertain points. Therefore, detailed topographical classification was not possible. Nevertheless, by taking into consideration the survey schedule and access to the sites and by comparing the existing topographical maps in the scale 1/50,000 and Soil Maps (Brunei Agriculture and Forestry Development Study: Soil Survey, Inter-Riverine Zone, ULG, 1982) with the aerial photographs,survey points corresponding to typical soil types and topography were selected.

The plan was to cruise the Belait River following the western part of the survey area upstream, and to reach Rumah Buau, using the Sg. Buau tributary, so as to start the survey using Rumah Buau as a base. However, the water in Sg. Buau was low and the river could not be navigated upstream. Thus, a base near the confluence of the Belait River and Sg. Buau was established and six typical survey points were set between the lowland in the watershed of Sg. Buau and in hill land. Two points, in lowland (peat swamp) and in hill land near Kg. Apak-Apak located on the right bank in the downstream of the Belait River from the confluence of the Belait River and Sg. Buau, were selected as survey points.

During the second half of the survey in the second year, the Tutong River flowing on the eastern side of the survey area was cruised upstream. Four points were set as survey points in hill land near Supon Kechil in the west and in lowland near the headwaters of Sg. Supon, establishing a base in Kg. Belabau on the left bank upstream of the Tutong River. Finally, the road under construction (from Merangking to Buau and Apak-Apak) passing through the centre of the survey area southward was accessed. An additional five survey points were set on a ridge of hill land with high relief, in lowland in the areas of headwaters of small tributaries of the Belait River, and in other places.

The survey in Phase 3 (June and July, 1993) used detailed topographical maps, since the topographical maps of the model plantation area 1/20,000 in scale were completed. Survey points matching typical soil types and topography were selected taking the survey schedule and accessing into consideration, while comparing these topographical maps with aerial photographs.

The following survey points were selected. Six in an area in hill land with high relief in which trees were already cut, in the northwest part of the survey area. Six in hill land and lowland in the Bukit Sawat area, excluding the area on the west bank of the Belait River. Five in hill land with high relief and in low swamps surrounded by Sg. Bang Tajok and Sg. Malayan, located on the west bank of the Belait River. Six points in lowland along the Belait River, peat swamps and hill land near Apak-Apak, cruising the river by boat where the survey base was established during the previous survey.

During the second half of the survey, nine survey points were set in the Ukong area in Daerah Tutong, in hill land which had a relatively large altitude difference compared with other areas in the survey area. Two survey points were also set in the northern part of the Rambai area near Tasek Merimbun.

Except for the Apak-Apak area, the survey points in Phase 3 could be accessed by a car and wide areas could be surveyed.

It was decided to set survey points near the southern part of border between Daerah Belait and Daerah Tutong, which could not be surveyed during the supplementary survey in September, 1993, due to poor access conditions to the area. The water flow in the river had increased, and access to points near the area by boat was possible.

Sg. Buau, a tributary of the Belait River, was cruised upstream to reach Sg. Sagat, a tributary of Sg. Buau, and to survey the area by walking to near the border using Buau School as a base. Four survey points were set in remote hill land and lowland near the border. Two additional survey points were set in lowland near Buau.

As a supplementary survey, a bore survey was conducted on soil type variations in the hill land and lowland in the Ukong area in the northern part of the survey area, and on soil types in the lowland in the Bukit Sawat area.

Figure-16 shows the distribution of all the survey points.

4.1.2. Survey method

After reaching the survey points, places to be used as typical survey points were chosen based on the micro-topography, vegetation and other factors in the vicinities of the survey points. Pits for soil profile surveys were excavated. Vertical sections to observe soil were then set inside the pits.

Generally, standard profiles 1m wide and 1 to 1.5m deep are required as standard profiles for soil surveys. If a bedrock is found before excavating to 1 to 1.5m, pit excavation would stop there, and a stair of several steps for survey work would be provided on the opposite site of the soil profiles.

After roughly excavating the pits, the observation profiles would be smoothed by shaving the soil left by scooping, or by trimming of plant roots inside the profiles to be surveyed, using a soil survey trowel, pruning scissors and other tools.

A scale would be put on the left side of a profile after smoothing and adjusting the soil profile. A card written with the survey point name and date would be put on each profile, and the profiles photographed.

Next, the sketch of a profile, classification of horizon, soil colour, soil texture, hardness, distribution of gravel and roots, and other items are entered in a profile description sheet. A sample of this profile description sheet is shown in App. Figure-2.

The soil profile survey items and descriptions conform to the "Guidelines for soil profile description (2nd ed. 1977)", issued by the FAO. The survey items and descriptive symbols are contained in App. Table-34. The sheet also

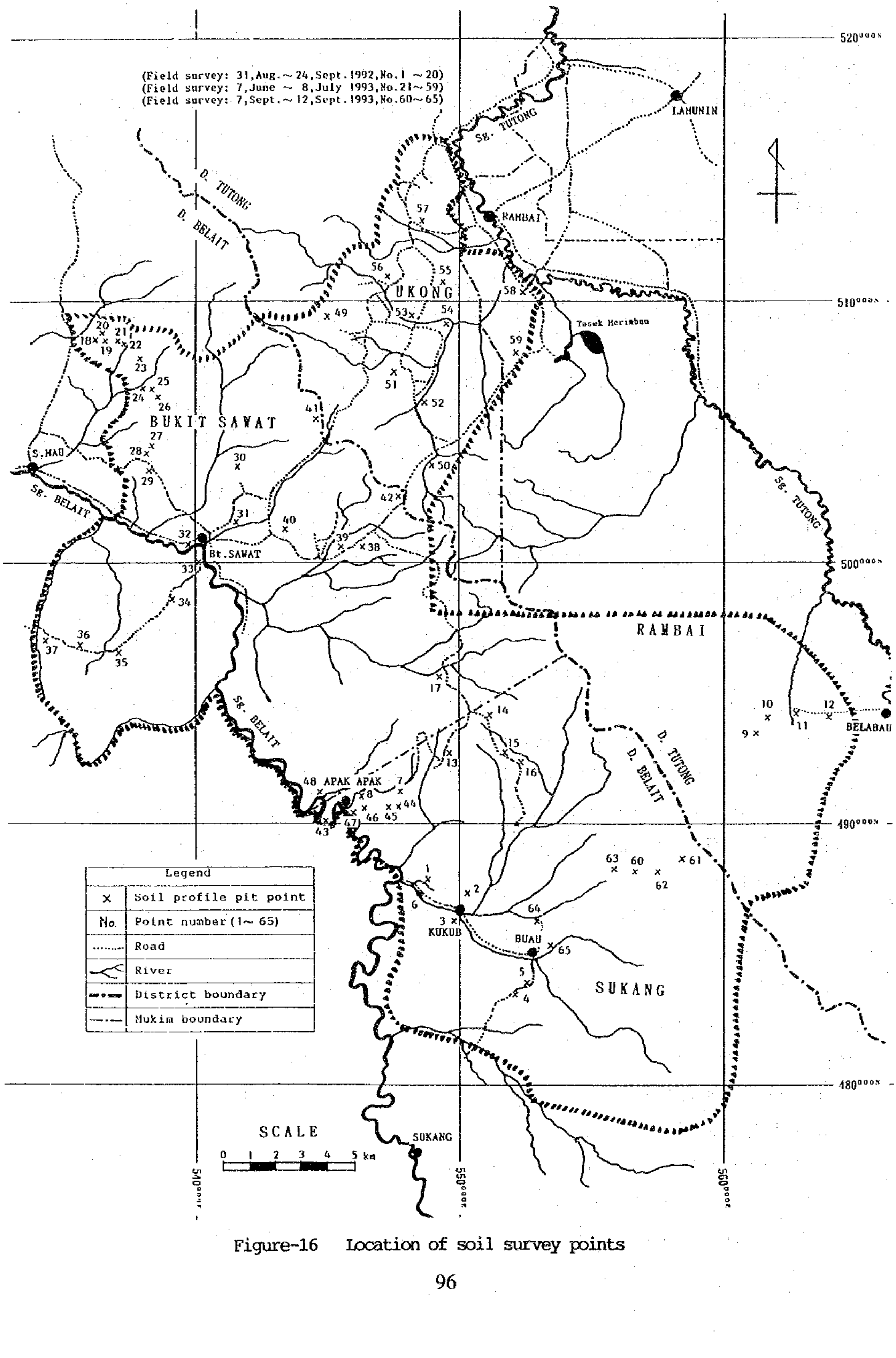


Figure-16 Location of soil survey points contains vegetation, such as tree names, at the typical survey points, land use, and other information.

In addition to excavating pits, simple test pitting was be performed using a soil auger to supplement surveys, in order to decide the boundary points of soil blocks, and to assist in preparing soil maps.

4.2. Results of Soil Survey

4.2.1. Soil characteristics

The results of the survey in the Phase 2 showed that the soil type distribution had no correlations with the area, but that it had a close relationship with topography. Except for peat swamp forests, correlations between the soil type and vegetation were not clear.

The southern area surveyed in the second year is sandwiched by the Belait and Tutong Rivers and geographically most part of it is wavy hill land and plateaus low in altitude. In addition, there is lowland in the watersheds of small rivers dissecting the hill land, with low swamps and river terraces in the periphery of the Belait River.

In terms of soil characteristics, soil types corresponding to the topographical classification were distributed. Soil in hills was mainly red-yellow podzolic soil. According to the major classification by the FAO/UNESCO system, the principal soil type was Acrisols. Cambisols and Gleysols were associated with it. Deposit of peat could be found in low swamps and valleys. Soil was the associated soil of alluvial soil, reduced soil, organic soil and red-yellow podzolic soil in hills. According to the FAO/UNESCO classification, soil was mainly Histosols and Gleysols associated with Cambisols and Acrisols. In some parts, Fluvisols could also be found. Sedimentary soil of quartz sand called "kerangas" could additionally be found. According to the FAO/UNESCO classification, this soil would be Arenosols.

As in Phase 2, the soil type distribution found during the survey in Phase 3 showed close correlation with the topography. The northern area sandwiched between the Belait and Tutong Rivers and surveyed in Phase 3 was relatively high in altitude compared with the southern area surveyed during the Phase 2 survey. Topographically, the area was mostly wavy hill land with high relief. The area also included lowland of the watersheds of small rivers dissecting the hill land, low swamps in the periphery of the Belait and Tutong Rivers, and river terraces.

In terms of soil characteristics, soil types corresponding to the topographical classification were also distributed as in the Phase 2 survey.

Topographically, most of the area deep inside the southern area surveyed in the supplementary survey, was gentle wavy hill land, low in altitude. The area also included lowland in the watersheds of small rivers dissecting the hill land and concave land in the headwaters.

In terms of soil characteristics, soil types corresponding to the topographical classification were distributed in both hill land and lowland.

The six major soil groups by the FAO/UNESCO system classification could be found as soil types distributed throughout the model plantation area, i.e., Acrisols, Arenosols, Cambisols, Fluvisols, Gleysols and Histosols. In terms of soil units in the medium classification, 14 units could be verified. The classification at each survey point is shown by single soil units. At some survey points, several soil units were associated or included.

Soil types found in the model plantation area were as follows: (By FAO/ UNESCO system classification)

Soil Unit	Symbol
Ferric Acrisols	ACf
Gleyic Acrisols	ACg
Haplic Acrisols	ACh
Plinthic Acrisols	ACp
Albic Arenosols	ARa
Chromic Cambisols	CMx
Dystric Cambisols	CMd
Gleyic Cambisols	CMg
Dystric Fluvisols	FLd
Dystric Gleysols	GLd
Eutric Gleysols	GLe
Mollic Gleysols	GLm
Fibric Histosols	HSf
Terric Histosols	HSs

The lists the classification of typical soil profiles found at all the survey points are shown in App. Table-35

4.2.2. Basic approach to soil classification

The basis of soil classification to be used in preparing the soil maps for this survey was the FAO/UNESCO Soil Map of the World Legend. This legend was revised in 1988 as FAO/UNESCO; Soil Map of the World, Revised Legend, incorporating subsequent new research and knowledge throughout the world. The soil maps were prepared and soil classification was explained based on the latest data.

In the past, because research of tropical soil in various regions was conducted independently by the various countries, and because results were accumulated without using a common vocabulary, cross reference to classification of tropical soils among the various regions was not possible. The impasse to this situation was the completion of the Soil Map of the World by FAO/UNESCO, as well as the method to name and define soil units used as units of measure in the world soil map. This was done in an effort to set a soil classification and soil naming method that could be used commonly throughout the world. The classification principle used in the FAO/UNESCO classification system employed soil profile morphology, physical, chemical and biological properties based on characteristics intrinsic to soils, as well as properties that made up the entirety in harmony with these properties, or properties that could be mutually explained, rather than using external factors such as climate which rule the formation of characteristic soils as in the past.

Volume 1 of the Soil Map of the World published in 1974 by FAO/ UNESCO contained a legend. The Southeast Asia Part of Volume 9 of the Soil Map of the World published in 1979 contained soils of Brunei Darussalam in the FAO/UNESCO classification system for the first time.

According to this part, three soil group symbols were used to show soils of Brunei Darussalam. They were 0d20-a for the coastal lowland part, Ao106-2/3b for the inland part, and Ao104-2/3c for the hinterland part. Symbol 0d20-a indicated that 0d (Dystric Histosols) was the main component. As associated soil, it contained Gh (Humic Gleysols). It also included R (Regosols) and Jd (Thionic Fluvisols). The symbol "a" showed that the slope was gently undulating. Symbol Ao106-2/3b indicated that Ao (Orthic Acrisols) was the main component. As associated soil, it included Af (Ferric Acrisols). It also included L (Luvisols) and Gd (Dystric Gleysols). The symbol "2/3b" showed that the soil property was medium- to fine-textured and that the slope was wavy to hilly. The symbol Ao104-2/3c indicated that Ao (Orthic Acrisols) was the main component. It associated and included Ah (Humic Acrisols), Bd (Dystric Cambisols), Bc (Chromic Cambisols) and Ag (Gleyic Acrisols). The symbol "2/3c" indicated that the soil property was medium- to fine-textured and that the slope was steeply dissected to mountainous.

The FAO/UNESCO Soil Map of the World: Revised Legend published in 1988 revised soil units and made changes (deleted and amended) in symbols, etc. The following is the soil classification of Brunei Darussalam in the Soil Map of the World modified to the new soil units. In this soil classification, it would appear appropriate to change Regosols in the coastal lowland part of Brunei Darussalam to Arenosols, if "kerangas" of quartz sand was to be classified.

Classification (Legend, 1974)		Classification (Revised Legend, 1988)
Brunei coastal lowland part (Od20)		
Od (Dystric Histosols)	→	HSf (Fibric Histosols)
		HSs (Terric Histosols)
		HSt (Thionic Histosols)
Gh (Humic Gleysols)	→	GLu (Umbric Gleysols)
R (Regosols)	→	RGd (Dystric Regosols)→ARa (Albic Arenosols)
Jd (Thionic Fluvisols)	→	FLt (Thionic Fluvisols)
Brunei inland part (Ao106)		
Ao (Orthic Acrisols)	→	ACh (Haplic Acrisols)
Af (Ferric Acrisols)	→	ACf (Ferric Acrisols)
L (Luvisols)	→	LVh (Haplic Luvisols)
Gd (Dystric Gleysols)	→	GLd (Dystric Gleysols)
Brunei hinterland part (Ao104)		
Ao (Orthic Acrisols)	→	ACh (Haplic Acrisols)
Ah (Humic Acrisols)	→	ACu (Humic Acrisols)
Bd (Dystric Cambisols)	→	CMd (Dystric Cambisols)
Bc (Chromic Cambisols)	→	CMx (Chromic Cambisols)
Ag (Gleyic Acrisols)	→	ACg (Gleyic Acrisols)

The name derivation of the major soil groups and soil units found during the survey and explained in the FAO/UNESCO: Soil Map of the World, Revised Legend is explained below.

Formative elements used for naming Major Soil Groupings (level 1)

ACRISOLS : from L. acer, cetum, strong acid; connotative of low base saturation.

ARENOSOLS : from L. arena, sand; connotative of weakly developed coarse textured soils.

CAMBISOLS : from late L. cambiare, to change; connotative of changes in colour, structure and consistence.

FLUVISOLS : from L. fluvius, river; connotative of alluvial deposits.

GLEYSOLS : from Russian local name gley, mucky soil mass; connotative of an excess of water.

HISTOSOLS : from Gr. histos, tissue; connotative of fresh or partly decomposed organic material.

Formative elements used for naming Soil Units (level 2)

ALBIC : from L. albus, white; connotative of strong bleaching.

CHROMIC : from Gr. chromos, colour; connotative of soils with bright colours.

DYSTRIC : from Gr. dys, ill, dystrophic, infertile; connotative of low base saturation.

EUTRIC : from Gr. eu, good, eutrophic, fertile; connotative of high base saturation.

FERRIC : from L. ferrum, iron; connotative of ferruginous mottling or an accumulation of iron.

FIBRIC : from L. fibra, fibre; connotative of weakly decomposed organic material.

GLEYIC : from Russian local name gley, mucky soil mass.

HAPLIC : from Gr. haplous, simple; connotative of soils with a simple, normal horizon sequence.

MOLLIC : from L. mollis, soft; connotative of good surface structure.

PLINTHIC : from Gr. plinthos, brick; connotative of mottled clay materials which harden irreversibly upon exposure.

TERRIC : from L. terra, earth; connotative of well decomposed and humified organic materials.

4.3. Soil Map

4.3.1. Preparation of soil maps

The soil maps were prepared using topographical maps 1/20000 in scale prepared in 1992 for the model plantation area. The soil map consists of five sheets, the same as the topography and vegetation maps.

Based on the soil survey of the model plantation area, the classification into major soil groups and soil units in accordance with the FAO/UNESCO; Soil Map of the World, Revised Legend, together with textural classes and slope classes were used as graphic units. However, the model plantation area included zones which had only one soil unit, zones which had several soil units associated with them, and zones which included several soil units with them. The soil units in the soil maps were colour-coded by colouring them solid, in crosses, horizontal, or in dots to identify them. The symbols were written in them.

4.3.2. Explanation of soil maps

The FAO/UNESCO Soil Map of the World, Revised Legend, defines the characteristics and identification of the major soil groups and soil units found in the survey groups as follows:

ACRISOLS (AC)

Soils having an argic B horizon which has a cation exchange capacity of less than 24 cmol(+) kg^{-1} clay and a base saturation (by NH_4 OAc) of less than 50 percent in at least some part of the B horizon within 125 cm of the surface; lacking the E horizon abruptly overlying a slowly permeable horizon, the distribution pattern of the clay and the tonguing which are diagnostic for Planosols, Nitisols and Podzoluvisols respectively.

Ferric Acrisols (ACf) Acrisols which are not strongly humic; showing ferric proterties within 125 cm of the surface; lacking plinthite within 125 cm of the surface; lacking gleyic properties within 100 cm of the surface.

Gleyic Acrisols (ACg) Acrisols showing gleyic properties within 100 cm of the surface; lacking plinthite within 125 cm of the surface.

Haplic Acrisols (ACh) Acrisols which are not strongly humic; lacking ferric properties; lacking plinthite within 125 cm of the surface; lacking gleyic properties within 100 cm of the surface.

Plinthic Acrisols (ACp) Acrisols having plinthite within 125 cm of the surface.

ARENOSOLS (AR)

Soils which are coarser than sandy loam to a depth of at least 100 cm of the surface, having less than 35 per cent of rock fragments or other coarse fragments in all subhorizons within 100 cm of the surface, exclusive of materials which show fluvic or andic properties; having no diagnostic horizons other than an ochric A horizon or an albic E horizon.

Albic Arenosols (ARa) Arenosols having an albic E horizon with a minimum thickness of 50 cm within 125 cm from the surface; lacking gleyic properties within 100 cm of the surface; non-calcaric.

CAMBISOLS (CM)

Soils having a cambic B horizon and no diagnostic horizons other than an ochric or an umbric A horizon or a mollic A horizon overlying a cambic B horizon with a base saturation (by NH_4OAc) of less than 50 percent; lacking salic properties; lacking the characteristics diagnostic for Vertisols or Andosols; lacking gleyic properties within 50 cm of the surface.

Chromic Cambisols (CMx) Cambisols having a ochric A horizon and a base saturation (by NH_4 OAc) of 50 percent or more at least between 20 and 50 cm from the surface but which are not calcareous within this same depth; having a strong brown to red camblic B horizon; lacking ferralic properties in the cambic B horizon; lacking vertic properties; lacking gleyic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

Dystric Cambisols (CMd) Cambisols having an ochric A horizon and a base saturation (by NH_4 OAc) of less than 50 percent at least between 20 and 50 cm from the surface; lacking vertic properties; lacking ferralic properties in the cambic B horizon; lacking gleyic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

Gleyic Cambisol (CMg) Cambisols showing gleyic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

FLUVISOLS (FL)

Soils showing fluvic properties and having no diagnostic horizons other than an ochric, a mollic or an umbric A horizon, or a histic H horizon, or a sulfuric horizon, or sulfidic material within 125 cm of the surface.

Dystric Fluvisols (FLd) Fluvisols having a base saturation (by NH_4 OAc) of less than 50 percent at least between 20 and 50 cm from the surface; lacking a sulfuric horizon and sulfidic material within 125 cm of the surface.

GLEYSOLS (GL)

Soils formed from unconsolidted materials, exclusive of coarse textured materials (except when a Histic H horizon is present) and alluvial deposits which show fluvic properties, showing gleyic properties within 50 cm of the surface; having no diagnostic horizons other than an A horizon, a histic H horizon, a cambic B horizon, a sulfuric, a calcic or a gypsic horizon; lacking the characteristics which are diagnostic for Vertisols or Arenosols; lacking salic properties; lacking plinthite within 125 cm of the surface.

Dystric Gleysols (GLd) Gleysols having a base saturation (by NH_4 OAc) of less than 50 percent at least between 20 and 50 cm from the surface; having no diagnostic horizons other than an ochric A horizon and a cambic B horizon; lacking andic properties; lacking permafrost within 200 cm of the surface.

Eutric Gleysols (GLe) Gleysols having a base saturation (by NH_4 OAc) of 50 percent or more at least between 20 and 50 cm from the surface; having no diagnostic horizons other than an ochric A horizon and a cambic B horizon; lacking andic properties; lacking permafrost within 200 cm of the surface.

Mollic Gleysols (GLm) Gleysols having a mollic A horizon or a eutric histic H horizon; lacking andic properties; lacking permafrost within 200 cm of the surface.

HISTOSOLS (HS)

Soils having 40 cm or more of organic soil materials (60 cm or more if the organic material consists mainly of sphagnum or moss or has a bulk density of less than 0.1 Mg m^{-3}) either extending down from the surface or taken cumulatively within the upper 80 cm of the soil; the thickness of the H horizon may be less when it rests on rock or on fragmental material in which the interstices are filled with organic matter.

Fibric Histosols (HSf) Histosols having raw or weakly decomposed organic matrials, the fiber content of which is dominant to a depth of 35 cm or more from the surface; having a very poor drainage or being undrained; lacking a sulfuric horizon or sulfidic materials within 125 cm of the surface; lacking permafrost within 200 cm of the surface.

Terric HIstosols (HSs) Historsols having highly decomposed organic materials with strongly reduced amounts of visible plant fibers and a very dark gray to black colour to a depth of 35 cm or more from the surface; having an imperfect to very poor drainage; lacking a sulfuric horizon or sulfidic materials within 125 cm of the surface; lacking permafrost within 200 cm of the surface.

Explanation of diagnostic horizons are shown in App. Table-36.

(Note) Plinthite: Iron-rich clay with a quartz, commonly red mottles. Irreversible change to ironstone on drying. Low organic matter.

The distribution of these soil types in the Model Plantation area is presented below:

Ferric Acrisols: Ferric Acrisols were widely distributed in hill land zones in the model plantation area of relatively high altitude. The Haplic Acrisols were also associated in these zones. In some parts, Gleyic Acrisols and Albic Arenosols were also mixed.

Sandy Ferric Acrisols was distributed extensively in hill land and ridges with high relief in the central part (near the development road along the boundary between Bukit Sawat and Sukang areas) and northwest part (plantation area in the upstream part of Sg. Mau in Bukit Sawat area) of the model plantation area, as well as in the Rambai area near Tasek Merimbun and other areas. The slope was large in these areas and danger of soil erosion by forest development was high. Ferric Acrisols distributed in the western area of Bukit Sawat on the left bank of the Belait River was fine-textured soil. Ferric Acrisols in the southern parts of Sukang and Rambai was medium-textured soil. The soil condition in these parts was relatively good in the model plantation area. The area had a large proportion of slope land with high relief, and forest development of the area must take soil conservation into consideration.

Haplic Acrisols: Haplic Acrisols were widely distributed in hill land as in Ferric Acrisols and were associated with Ferric Acrisols in many places.

Sandy Haplic Acrisols were distributed in the plantation area in the upstream part of Sg. Mau in Bukit Sawat, in central parts around Merangking, and in part of the Sukang area. As in Ferric Acrisols, danger of soil erosion existed in these areas. In other areas, medium- and fine-textured Haplic Acrisols were distributed.

Soil pH of Haplic Acrisols was low among the soil groups excluding Histosols, and soil of Haplic Acrisols was fairly acid in many cases. The base of the soil was extensively leached and the productivity of the soil was low. If Haplic Acrisols soil specially strong in acidity (mostly in sandy soil) is to be used in plantations, tree species resistant to acidity must be selected. This also applies to Ferric Acrisols.

Gleyic Acrisols: Gleyic Acrisols could be found in some of lower parts of hill land slopes. In some parts, associated Gleyic Acrisols with Ferric Acrisols could be found. Associated with Dystric Gleysols and Fibric Histosols could be found in lowland parts along small and medium rivers and Gleyic Acrisols appeared in places affected by ground water. Gleyic Acrisols were found scattered over the whole area, rather than distributed in limited areas.

Plinthic Acrisols: Plinthic Acrisols could be found only in lowland parts of hill land slopes, along the development road to Buau in the central and southern parts of the model plantation area. The distribution of Plinthic Acrisols would be limited and partial even if it is distributed over the various areas.

Albic Arenosols: The distribution of Albic Arenosols in the model plantation area was relatively light, mainly in Bukit Sawat in the northwestern part. In other areas, Albic Arenosols were scattered lightly. Sedimentary layers of quartz sand and a mixture of Albic Arenosols were scattered extensively in sectional profiles of other soil types. In many cases, these soil types do not become Arenosols if they are classified on the basis of diagnostic horizons, which are the main part of soil sectional profiles.

Albic Arenosols provide poor nutritional soils, and suitable tree species have to be selected if land is to be used as a plantation. This also applies to soils mixed with Arenosols. Arenosols is sandy soil of quartz sand, and danger of soil erosion on slope land of Arenosols is high.

Chromic Cambisols: Cambisols were distributed widely throughout the model plantation area as were Acrisols. They were distributed extensively in lowland parts of hill land and around watersheds of small rivers dissecting hill land.

Chromic Cambisols could be found in lowland parts around Sg. Buau and around small tributary rivers of Sg. Buau in the southern part, where drainage is relatively good.

Dystric Cambisols: Dystric Cambisols were distributed mainly on slopes and lowland parts of hill land. In some parts, Haplic Acrisols were also associated with them. In lowland parts around river watersheds, Dystric Fluvisols and Gleyic Cambisols were associated together.

Gleyic Cambisols: Gleyic Cambisols were distributed in the lowland around watersheds upstream of small rivers in the southern and southeastern areas, associated with Eutric Gleysols. Water is trapped temporarily in this soil type, but it is fine-textured and has a relatively high productivity.

Dystric Fluvisols: Dystric Fluvisols were distributed in alluvial lowland around the Belait River and Sg. Malayan. In some parts, Dystric Fluvisols were associated with Dystric Cambisols. Soil texture was sandy, medium- or fine-textured in accordance with the location, and the soil texture distribution was not fixed.

Dystric Gleysols: Dystric Gleysols were distributed mainly in low swamps around the Belait and Tutong Rivers, and in low swamps in the watersheds of small rivers between hills in the Bukit Sawat and Ukong areas. Dystric Gleysols were associated with Histosols in peat swamps around the Belait River. Most was medium and fine-textured soil. In some parts, sandy soil could be found. The only concern regarding plantations was the overhumid condition of the soil.

Eutric Gleysols: Eutric Gleysols were distributed in the lowland around watersheds in the upstream watersheds of small rivers in the southern and southeastern parts. In nearly all cases, Eutric Gleysols were associated with Gleyic Cambisols.

Mollic Gleysols: Mollic Gleysols were distributed in low swamps along the banks of large and medium rivers. It dries and becomes moist rapidly in accordance with the water level of rivers. Soil of this type is soft and easily collapses.

Fibric Histosols: Fibric Histosols were distributed mainly in low swamps around large rivers and around medium and small rivers dissecting hill land called peat swamps. In most areas, it is associated with Terric Histosols. Associated Gleysols and other soil types could be found in many places.

Water always stays in Fibric Histosols. Drainage is poor and tree roots, grass and trees in the ground remain undecomposed or in a muck condition, which is a condition slightly advanced in decomposition. The pH of this soil type is low and this soil type is strongly acid. Drainage is poor with this soil type and plantation is not suitable for this soil type except for species found in peat swamps.

Terric Histosols: Terric Histosols were distributed in almost the same places as those in which Fibric Histosols could be found. In nearly all places, it could be found mixed with Fibric Histosols. Decomposition of organic matter is more advanced with Terric Histosols than with Fibric Histosols, but is also strongly acidic and drainage is also poor.

A comparison between the soil classification used in Brunei Darussalam previously, and the soil classification by the FAO/UNESCO system based on the results of the recent soil survey in the model plantation area is shown below. The fundamentals of classification methods of the soil unit by the FAO system and of the soil series of Brunei Darussalam differ, and both cannot be compared item to item. A comparison is made by adding symbols to the soil groups and soil types by major classification.

FAO/UNESCO classification	Brunei classification
Acrisols (ACf, ACg, ACh, ACp)	Upland soils (Red-yellow podzolic soils) (BKT, BTN, SKN)
Arenosols (ARa)	Regosol-pallid sand (Kerangas) (TKL)
Cambisols (CMx, CMd, CMg)	Upland soils and Alluvial soils (BKT, BTN, TTN, ALL)
Fluvisols (FLd)	Alluvial soils (ALL, BDG, TTN)
Gleysols (GLd, GLe, GLm)	Alluvial soils (BDG, BUU, TTN, ALL)
Histosols (HSf, HSs)	Organic soils (AND)

4.4. General Considerations of Soil Survey Results

In the model plantation area, Acrisols low in base saturation and produced by downward movement of clay were mainly distributed in high-relief hill land. In gently undulating land and lowland, Cambisols were mainly distributed. Arenosols, with a sedimentation layer of quartz sand, could be found in parts of hill land and lowland. Fluvisols and Gleysols were distributed in lowland and low swamps in watersheds. Histosols were distributed in peat swamps. These soils were distributed nearly matching the topography.

The following problems can be pointed out based on the results of the soil survey.

Special soil conservation consideration is necessary for plantation in sandy Haplic Acrisols, Ferric Acrisols and Arenosols distributed in steep slope areas, because soil easily moves and danger of soil erosion is high. Soils in many of these areas are strongly acidic, and careful selection of species of trees to be planted will therefore be necessary.

Acrisols will be suitable as plantations if slope is not steep, and soil is medium or fine-textured. However, the soil fertility is low, and a plantation method that will minimize losses of the organic matter layer in the ground surface, must be employed.

Cambisols and Fluvisols are suitable for plantations. Forests on Cambisols and Fluvisols around rivers must be kept intact to prevent the flow of sediment into rivers in conjunction with establishment of plantations along watersheds.

Gleysols were distributed in lowland of watersheds and low swamps, and in many cases secondary forests could be found. Generally, soil texture was fine-grained and drainage was rather poor. Plantation will have to be managed bearing in mind these points, and exercising care. Gleysols around rivers require the same precautions as those given to Cambisols and Fluvisols.

Histosols were distributed in peat swamps and the present conditions must be preserved to conserve and sustain peat swamp forests in low swamps.

As a specific example, the soil condition of the plantation area in the upstream part of Sg. Mau in the Bukit Sawat area in the northwestern part, was not good. Soil in that area was mostly sandy and was strongly acidic. The area was high in relief and presented problems in soil conservation.

Much of the area around the development road near the boundary between the Bukit Sawat and Sukang areas from Merangking to Buau or to Apak-Apak is also sandy and steep. Such areas present soil conservation problems.

The area near the boundary between D. Belait and D. Tutong in the southeastern part had no roads. Forests of *Dipterocarp* species grown to a substantially high level could be found and the soil condition was good. However, if large forest roads are built for establishing plantations, forests may be lost and soil may change. Under the circumstances, a timber production method maintaining the current status, by opening small forest roads and natural forest operations, will be desirable for this area.

Acacia mangium is recommended as a plantation species where soil is sandy and consists of strongly-acidic Acrisols or Arenosols. In other areas, species should preferably be selected in accordance with the plantation establishment method, soil drainage and utilisation of timber.

5. Forest Inventory Book

Table-24 shows an example of the format and descriptive items of the forest inventory book. By referring to a specific forest compartment in the vegetation maps, various information about this forest compartment can be obtained.

(1) Forest compartment

Compartment numbers on the 1,000- and 2,000-levels were assigned to compartments in Daerah Tutong and Daerah Belait, respectively. Land other than forests such as farmland (areas left over from forest management) was also divided and compartments in it were given compartment numbers on the 500-level. For example, "2111" is a forest compartment in Daerah Belait and "1505", non-forest land in Daerah Tutong.

(2) Area

Areas of forest land and non-forest land (areas left over from forest management) inside forest compartments are described. Areas of non-forest land were calculated if land was not divided independently such as by valleys and rights of way and if it included areas of forest land which were of considerable size. Non-forest land of a sizable area was divided independently.

(3) Land description

The land descriptions are altitudes, inclinations and soil types. The altitudes were calculated based on a topographic map. Because the gradients could not be shown in degrees due to the topographical condition, they were indicated in three divisions; flat, gentle and steep. The soil types were shown in accordance with the FAO/UNESCO system classification after overlapping soil maps on vegetation maps, and interpreting soil types of the forest compartments.

(4) Forest description

The forest descriptions included information such as crown diameters and crown densities by photo interpretation, as well as forest stand compositions, diameter breast heights, clear lengths and the numbers of trees per ha measured by the field survey. The forest descriptions also included volumes per ha of forest types and total volumes of forest compartments.

The five top species by volume were listed under forest composition.

Table-24 Forest inventory book(ex.)

FOREST INVENTORY BOOK

District	Working Area
Belait	Apak Apak

Sheet No. ______

Division			Area			Site condition			Forest condition by aerial photos		Forest condition by Sample plots: Forest composition		Mean value			Volume		Remarks
			ha	ha	ha	m			m			%	cm	m	/ha	/ha		
xxxx			101	0	101												48,668	
	3.3(3)	F	60	0	60	27	Ge	HSs	11	De	AL	75	44	16	215	505	30,300	
											Ke	6						
											Ra	3						
											M.T	3						
											Ta	2						
	3.1(1)	F	41	0	41	15	Ge	GLd	6	De	K.P	24	30	18	473	448	18,368	
											Ra	15						
											Ke	10						
											Ba	9						
											Ub	9						

6. Natural Environmental Assessment Survey

6.1. Purpose of Environmental Assessment in Model Plantation Area

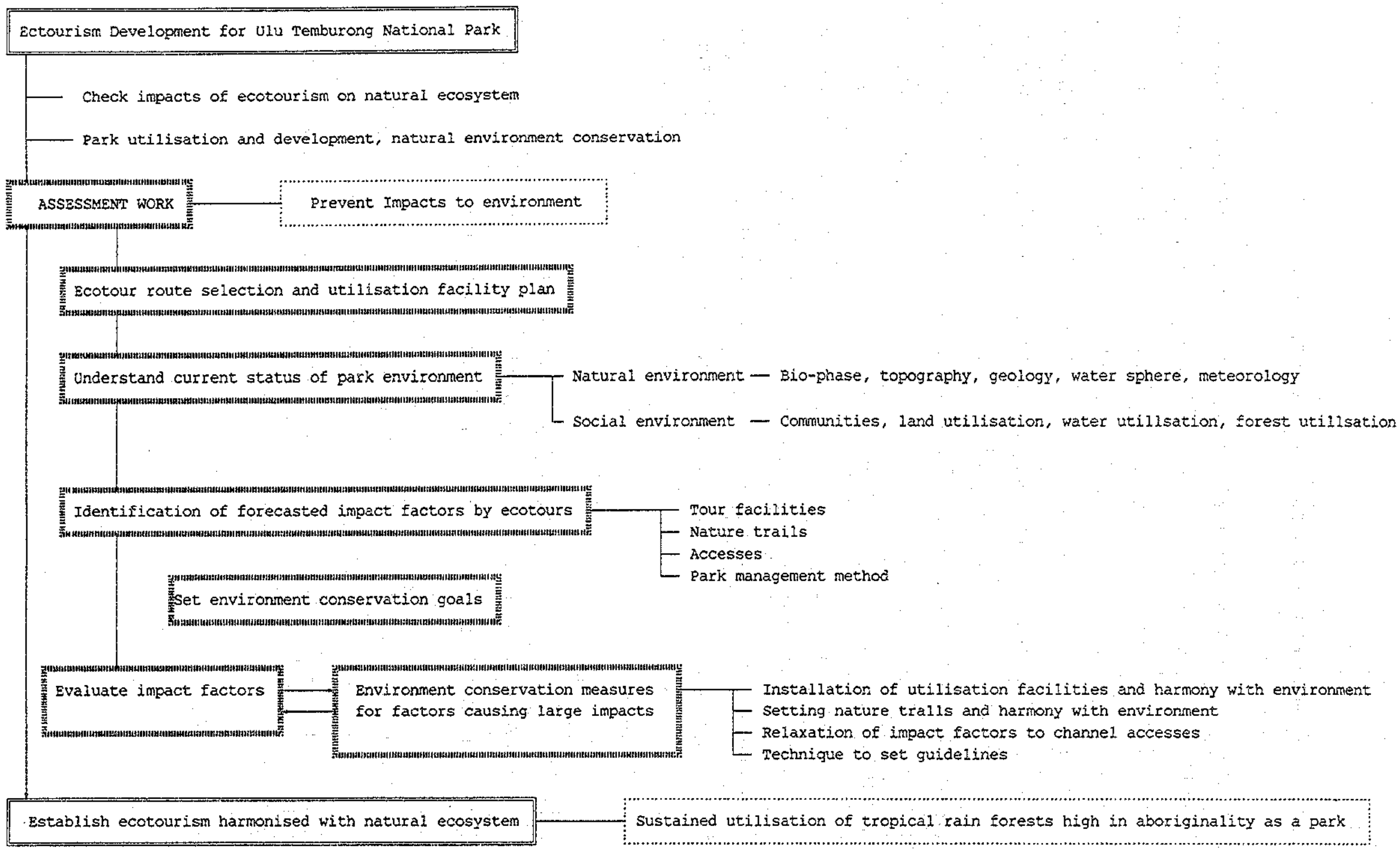
Tropical rain forests are playing a very significant role in conserving the earth's environment. Forest production with a sustainability must be expected to minimise impacts to the ecosystem in regions were artificial forests are established. In the Model Plantation, plants for forest establishment by promoting plantation involves clear-cutting and controlled burning of large area and the introduction of exotic species, as an approach to an artficial forest regeneration technique. The aims of the Assesment Work are to study the expected factors that impact on the environment by implementing and executing these plans, and to devise appropriate conservation measures. Two factors that impact on the environment were identified, erosion caused by clear cutting and controlled burning of large area, and disturbance to natural ecosystem by introducing exotic species such as *Acacia mangium* and Klinki pine. Assessment work was performed to check factors that impact on the environment and to harmonise between forest establishment/development and environment.

6.2. Flowchart for Environmental Assessment

Model plantations also are an example of one type of forest development. Figure-17 shows the flowchart of processes that require to be studied when executing the plan for the model plantation.

The assessment work identified factors expected to affect environment as a result of implementing the execution plans, and fact-finding research and case studies in taking conservation measures were undertaken. Figure-18 shows the locations of the survey sites.

Figure-17 Flowchart of environmental assessment in Model Plantation Area



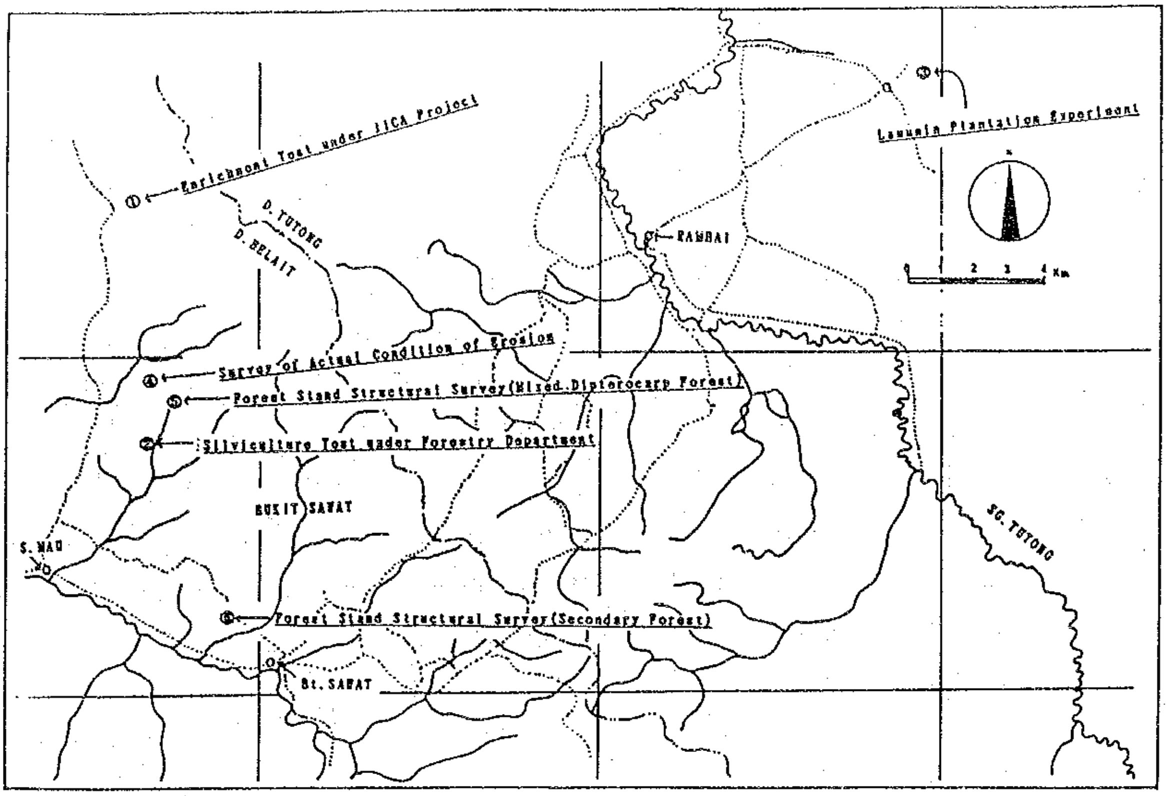


Figure-18 Location of environmental assessment survey plots

6.3. Identification of Factors Affecting Environment

6.3.1. Erosion conditions in plantations prepared by clear cutting and controlled burning of large areas

At present, plantation was in progress at the Saw Timber Plantation No. 9 by clear cutting and controlled burning of a large area. Erosion of the ground surface was occurring after tree planting, mainly due to rainfalls, while the forest floors were covered by natural vegetation or fallen leaves so that a large volume of sediment flowed into forest stands around the plantation.

The actual state of erosion as a factor impacting on the ambient environment was surveyed to analyse problems with the present forest operation method.

(1) General condition of survey site

Location: Saw Timber Plantation No. 9
(Sg. Mau, Bukit Sawat, Daerah Belait)

Total Area:	1km x 1km = 1 km^2 = 100ha
Clear cut Area:	80ha
Topography:	Hilly mountains with low relief
Geology:	Tertiary soft rocks with low consolidation
Stand:	Before: Kapur bukit, Kapur paya, Ubah, Nyatoh, Ramin, Meranti and other species
	Nov. 1991 to Mar. 1992 — Felling
	Apr. 1992 — Controlled burning
	Sep. to Oct. 1992 — Tree planting *(Acacia mangium)*

(2) Erosion modes

The land at the survey site was bare land vulnerable to rainwater, and many parts were eroded. Gully and sheet erosion was in progress simultaneously. The sediment volume produced by gully erosion was far greater. Degree of erosion is classified as follows.

Rank	Scale	Condition	Ditch width/depth
A Gully erosion	Large	Landslide	Greater than 1.0 m
B Gully erosion	Medium	Gully	0.5 - 1.0 m
C Gully erosion	Small	Rill	Less than 0.5 m
D Sheet erosion	——	——	——

a. Gully erosion

The extent of gully erosion varied in accordance with the condition of gully, ranging from rills in the initial stage of erosion to landslide conditions after erosion progressed.

Gully erosion occurs as a result of land made bare by controlled burning (primary factor), and by rainfall and overland flows on it (inducing factor). Steep slopes in the upper parts of hillsides are damaged by sheet erosion, and Layer B is exposed. Gullies then develop easily, and grow to Rank D ---> C ---> B ---> A.

Forest roads and spur roads are also a significant factor. Road surfaces compacted by trucks and bulldozers running on them do not permeate rainwater and surface runoffs occur. Surface runoffs not only cause gully erosion on road surfaces, but also frequently induce gully erosion by flowing down the slopes on both sides of roads built on ridges.

b. Sheet erosion

The following factors affect this type of erosion:

1) Overlay of ground surface
2) Slope of ground surface
3) Hardness of ground surface

Factors such as whether or not the ground surface is covered by the root systems of trees which grew before, i.e., whether Layer A is remaining or removed, greatly affects erosion. The ground surface left with Layer A has a resistance to erosion. The ground surface with Layer B exposed, after Layer A is lost, is eroded extensively. Roads such as spur roads are largely responsible for removal of Layer A. In addition to sheet erosion, gully erosion is also induced as mentioned earlier.

Generally, the flow velocity of surface water is faster, and erosion is more extensive, the steeper the slopes. In places where sheet erosion is progressing, there is a high risk of gully erosion in future.

(3) Experimental plot setting

Nine experimental plots were set, i.e., three gully erosion experimental plots, and six sheet erosion experimental plots, as shown in Figure-19.

a. Gully erosion

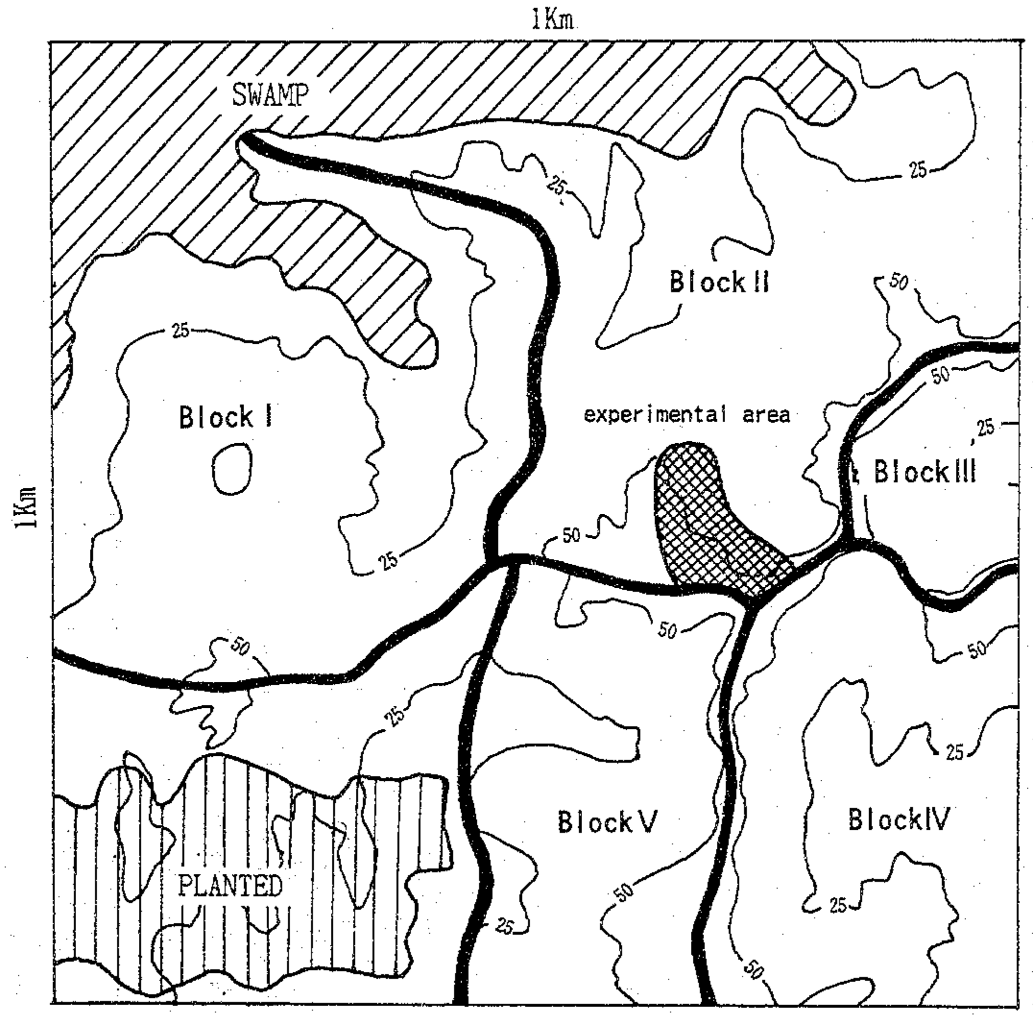
One experimental plot was set for each type of gully-eroded land in Ranks A, B and C.

Cross sectional surveying was conducted to identify changes of the ground surface caused by gully erosion. The condition of vegetation invasion was also identified. App. Figures-3 and 4 show the model diagrams of the experimental plots.

b. Sheet erosion

Combining the overlay and inclination of the ground surface, experimental plots at the following six sites were set:

1) Layer A remaining	Gentle inclination
2) Layer A remaining	Medium inclination
3) Layer A remaining	Steep inclination
4) Layer A removed	Gentle inclination
5) Layer A removed	Medium inclination



Positions of the experimental plots

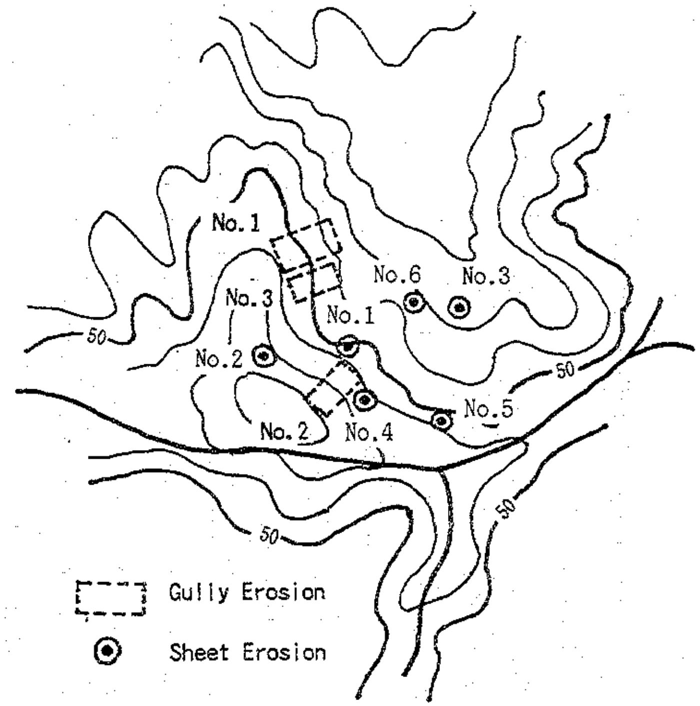


Figure-19 Location of experimental area

6) Layer A removed Steep inclination

Concrete reinforcing bars were driven to four corners of 2m-square plots and the ground surface was marked. The condition of vegetation invasion was identified. App. Figure-5 shows the model diagram of the experimental plots.

(4) Test results

a. Ground surface changes by erosion

The ground surface was observed in June, 1992, and September, 1993.

1) Gully-erosion experimental plots

Plotting of sectional profiles of the gully eroded land in Ranks A, B and C, incorporated with the results of the field observation produced the following trends. Figure-20 shows a typical sectional profile.

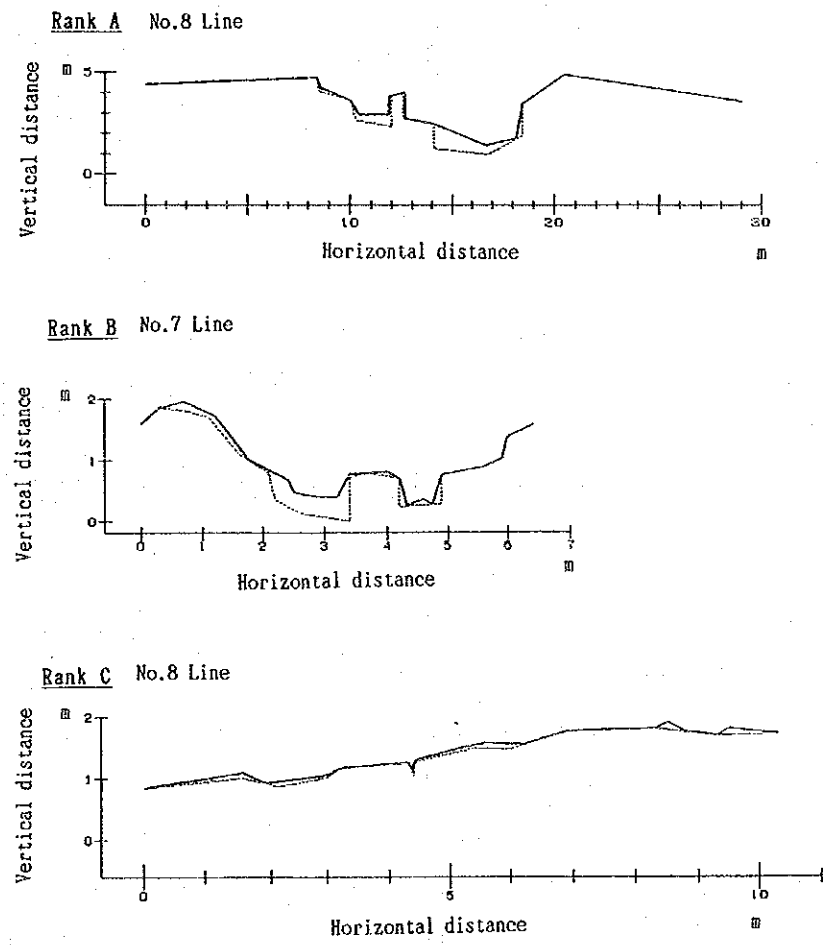


Figure-20 Progress of gully erosion

(i) Erosion clearly was in progress at each experimental plot.

(ii) The extent of erosion was large in the order of Ranks A, B and C. This was because rainwater is concentrated more easily in these orders.

(iii) Gullies with a concentration of rainwater in them tended to expand by longitudinal erosion. This trend was prevalent in Ranks A and B.
(iv) Some longitudinal erosion was as deep as 4m and continued to develop by retreating uphill.
(v) Bare land other than land with gully erosion displayed sheet erosion. This trend was prevalent in Rank C.

2) Sheet-erosion experimental plots

The following changes took place in the ground surface of the experimental plots:

	Layer A		
	Remaining	Removed	Average
Steep Slope	1.70 cm	4.75 cm	3.23 cm
Medium Slope	2.85	1.80	2.33
Gentle Slope	1.60	0.60	1.10
Average	2.05	2.38	2.22

The changes indicate the following trends:
(i) Erosion was prominent on slopes with Layer A removed, rather than on slopes with Layer A remaining.
(ii) Erosion became more prominent the steeper the slope inclination.

b. Growth of planted trees

Acacia mangium trees were planted in the gully-erosion experimental plots immediately after the experimental plots were set in September, 1992. The heights of the ten planted trees inside and outside of the No. 2 gully experimental plot (Rank B) were measured. The tree heights were 1.57m for the trees inside the experimental plots and 2.79m, outside the experimental plots, indicating that the tree growth was extremely poor inside the experimental plots. The same results were obtained with the other experimental plots and this may be explained by the following reasons:
(i) The surface soil layer was removed and soil had low nutrition.
(ii) Overland flow occurred during rain, and only a small amount of rainwater permeates.
(iii) Layer A covering the ground surface was removed and rainwater could not

be retained so that the soil became dry easily.

c. Invasion of natural vegetation

1) Gully-erosion experimental plots

Natural vegetation could not be found inside the gullies. Only Kedok kedok could be found in them. Vegetation overlay could be found in 37% of the gully exteriors.

2) Sheet-erosion experimental plots

The following results were obtained for the experimental plots. Vegetation overlay averaged 32%, and the overlay rate was lower the steeper the inclination.

	Layer A		
	Remaining	Removed	Average
Steep Slope	22.50 %	2.50 %	12.50 %
Medium Slope	2.50	48.75	25.63
Gentle Slop	42.50	72.50	57.50
Average	22.50	41.25	31.88

5) Distribution of eroded land

a. Distribution characteristics of eroded land

A topographic map was drawn in September, 1992 classifying eroded land inside the saw timber plantation No. 9 (1km x 1km = 1 km^2 = 100 ha) into Ranks A, B and C (all gully erosion) and D (sheet erosion) to study the distribution and scale of these erosion types. Eroded land was more concentrated in places where the inclination was steep. Forest roads and spur roads were also substantially affected.

Table-25 shows the numbers of eroded land locations for the various ranks. Eroded land locations totaled 325, including 30 places, or about 10%, in Rank A.

Table-25 Eerosion in Saw Timber Plantation

Area	Item	Rank of Erosion				
		A	B	C	D	Total
I	Number	3	17	24	25	69
	Percentage	4.3	24.6	34.8	36.2	100.0
II	Number	4	20	24	38	86
	Percentage	4.7	23.3	27.9	44.2	100.0
III	Number	3	8	6	9	26
	Percentage	11.5	30.8	23.1	34.6	100.0
IV	Number	13	15	22	21	71
	Percentage	18.3	21.1	31.0	29.6	100.0
V	Number	7	9	34	23	73
	Percentage	9.6	12.3	46.6	31.5	100.0
Total	Number	30	69	110	116	325
	Percentage	9.2	21.2	33.8	35.7	100.0

b. Changes in distribution of eroded land

In June, 1993, the distribution of eroded land was checked again. However, the visibility was poor due to planted trees and it was not possible to survey the entire area by the same method as that used in September, 1992. Under the circumstances, observation was made as to how new eroded land occurred, how already existing eroded land had expanded, and how eroded land was restored, selecting Block III (area 3.7ha) as a sample. The observation showed that most eroded land had expanded or remained in the same condition as that in the previous survey. There was only a small portion of eroded land which showed some restoration.

(6) Impacts to nearby forest stands

a. Sediment flow to downstream watersheds

The condition of sediment deposition was surveyed at the downstream edge of Block III (edge of forests in Saw Timber Plantation No. 9). Sediment runoff downstream from this point was also traced. The deposition depths of new sediment produced by erosion was 60cm at the downstream edge of Block III, 60cm at a point 50m further downstream, 45cm at a point 100m downstream, and 25cm at a point 150m downstream. Sediment produced by erosion was sandy, and lacked a viscosity so that it could be moved easily by surface water during rainfall.

b. Growth of trees in nearby forest stands

A survey was made in Block III of how preparation of sites by clear cutting and controlled burning of Saw Timber Plantation No. 9, affected trees growing in nearby forests. A total of 47 trees withered in a section of about 130m along the edge of a forest stand. An additional 30 trees were about to wither. These trees included merchantable trees such as Meranti and Damar hitam. In addition to sediment runoff as mentioned above, this can be explained by controlled burning, exposure of root system and rapid opening up of forests.

6.3.2. Disturbance to natural ecosystem by introducing exotic species

(1) Local adaptability of exotic species

Of the three candidate species for planting, *Acacia mangium* as a fast growing species and Klinki pine as a merchantable species are exotic species. Generally, fast growing species are used for planting trees in areas which are devastated after secondary forests become grassland or in areas which have a poor location environment. The habitat for *Acacia mangium* is Australia and this species is planted in devastated land in Sabah and in Madang of Papua New Guinea for producing pulpwood. Klinki pine (*Araucaria hunsteinii*), which is a species of Araucaria, is a merchantable species inhabiting subalpine zones and high mountains in Papua New Guinea. Many plantations of this species can be found in the Bulolo district of Papua New Guinea (about 700 to 1000m in altitude). The diversity of species in tropical rain forests is said to be characteristic. Such being the case, modifying the environment by site preparation using controlled burning of large areas, and accomplishing simple uniform forests by introducing exotic species, causes disturbance of the natural ecosystem in the area. A thorough study of local adaptability by case studies and by other means is needed if exotic species are to be introduced to sites which differ from their habitats of natural distribution, in altitude, topography and soil.

(2) Pest insect damage by introducing exotic species

If diverse domestic species which existed before are replaced by a single exotic species, the areas are changed to an environment which is conducive to the generation of pest insects. to generate. For example, *Eucalyptus deglupta* which originates in Australia, and is planted in large areas of the plantations in the Mindanao Island of the Philippines, were damaged by Agrilus sp., a species of Buprestidae. In addition to this case, a large number of reports have been published on pest insect damage to exotic pines. As explained, pure forests of exotic species are vulnerable to pest damage. Therefore, necessary measures must be taken to control pest insect damage to conserve the natural ecosystem, when exotic species are introduced.

(3) Changes in plant and animal phases of regional ecosystem

The diverse biological phase of the tropics is characterised by tropical rain forests of abundant species and by abundant animal species living there. The tree species diversity has a correlation with the animal diversity, and maintains the ecosystem in the region. The natural ecosystem, which is forcibly modified by the introduction of exotic species, is disturbed. It can be said therefore, that impacts to the environment will be reduced, the smaller the clear-cutting area.

6.4. Environment Conservation Control of Impact Factors

6.4.1. Erosion control

(1) Preventive measures

Efforts are made to prevent or minimise erosion, by appropriate and practical application of scientific, economic and social principles to the administration and working of forest estate for specified objectives, taking conservation of forest land into consideration.

a. Cutting method

Clear cutting of a large area of the Saw Timber Plantation No. 9 in the Bukit Sawat is in progress. Nevertheless, clear cutting itself does not trigger erosion. This is because unused trees and tree branches are left in forest land after clear cutting. Furthermore, undergrowth and forest soil remain nearly intact. Under these circumstances, ground surface overlay and permeability are maintained and erosion does not occur at this stage. However, crown interception by trees no longer exists and the rainfall reaching the ground surface undoubtedly increases, causing surface flow to occur more easily, compared to previously when trees were still standing.

As explained above, erosion necessarily does not occur soon after trees are cut by clear cutting. However, problems remain compared with selection cutting. In clear cutting also, measures are necessary such as dispersing clear cutting areas to small areas and not to large areas, or to adopt the strip clear-cutting method. When restricting clear cutting to small areas, it will be sensible to disperse these areas over more watersheds than concentrating them in one watershed thereby conserving watersheds.

b. Skidding method

Felled trees were pulled in the Saw Timber Plantation No. 9 by heavy equipment of the crawler type such as bulldozers and the surface horizon of the forest land was partially damaged by the crawlers and pulled timber. If Layers A_0 and A, which are tied by the root system and have a good permeability, are removed, ground surface flow occurs and erosion advances rapidly. Danger of such erosion becoming gully erosion is high. In fact, the greatest cause of erosion is the skidding method. If a ropeway is used, damage to the forest land can be avoided. However, ropeways cannot be installed in an area which has low relief and gentle slopes. The skidding efficiency and economy of the bulldozer skidding method are superior to ropeway skidding. In tropical areas, therefore, bulldozer skidding has become the regular skidding method, even though the problems of bulldozer skidding have been pointed out.

The only way to reduce erosion under these circumstances is to avoid clear cutting in large areas, and to employ clear cutting, or preferably selection cutting, in as small areas as possible, thus dispersing possible erosion sites, instead of clear cutting of large areas.

c. Site preparation method

In site preparation by controlled burning, land is prepared by drying and burning cut unused trees and weeds. This method is generally used in tropical rain forests. Land is prepared in the Saw Timber Plantation No. 9 by a similar method. However, the removal of unused trees, weeds and soil organic matter drastically reduces the resistance which forest land has against erosion. Unused trees and weeds prevent raindrops from reaching the ground surface directly and causing erosion. They also function as a filter to lower the speed of rainwater flowing over the ground surface. The loss of unused trees and weeds, which have these benefits presents a problem. In the case of clear cutting, however, site preparation must depend on controlled burning as felled trees must be removed for subsequent tree planting. Therefore, as mentioned earlier, erosion should preferably be prevented or reduced by employing selection cutting or introducing clear cutting only in small areas.

d. Precautions for opening forest roads

Forest roads have greatly accelerated erosion in the Saw Timber Plantation No. 9. Erosion caused by forest roads was found frequently. Surfaces of forest roads are bare land and the rainwater infiltration capacity is low with the result that ground surface flow occurs. As a result, road surfaces themselves were naturally eroded. Ground surface flow of forest roads on ridges flowed down hillside slopes on both sides of the ridges and many of these slopes were eroded. Basic problems remain such as opening forest roads on ridges and steep longitudinal slopes, but the minimum action that has to be taken at present to prevent erosion is the method of treating surface water. Gutters excavated without timbering must be provided to concentrate surface water and to avoid it flowing down hillside slopes. By concentrating surface water, erosion occurs in those places where water is concentrated. However, this is better than erosion occurring on many parts of road surfaces. Erosion around gutters excavated without timbering is minimized by putting tree branches on gutter bottoms to regulate the flow velocity. Water flowing down from gutters is drained in short sections. At these points, further erosion is feared, and these places must be provided with simple sheathing work using logs and tree branches, to prevent erosion.

(2) Restoration

If erosion is left unchecked, it will expand and will most probably continue to produce sediment. Early foundation work and revegetation work has to be undertaken to restore the effects of erosion.

a. Foundation work

Underground work to stabilize gully heads and side walls, which are in an unstable condition, must be undertaken to restore gully-eroded land. The Saw Timber Plantation No. 9 is low in relief and has a gentle inclination. The eroded surface soil layer is sandy and does not contain gravel. Simple underground work of a small scale using small logs and branches available at the site is sufficient. Gabion underground work will be required where longitudinal erosion is deep. Sediment deposited near gullies is put back into gullies after finishing the underground work. Brush culvert work should be provided on the bottoms of the gullies, by putting branches there. This will facilitate draining of seepage water in the bottoms of the gullies and will prevent erosion. Runoff of surface soil and growth of gullies can be prevented by putting log crib work obtained by arranging logs on the ground surface in a reticulate form. Underground, culvert and crib work as foundation work should preferably be employed in accordance with the degree of gully erosion (Ranks A, B and C).

b. Revegetation work

After providing foundation work, fence work is provided on the ground surface under which earth is filled back on bare land around it, which is attacked by sheet erosion, to disperse surface flow and to slow the flow velocity. Logs and tree branches that can be procured locally should be used as the material for crib work. Once surface soil becomes stable as a result of crib work, pioneer vegetation such as Kedok kedok enters stable slopes and gradual vegetation overlay can be expected.

(3) Sediment runoff control

Sediment produced by erosion action is sandy and is low in viscosity. It is not mixed with stones and can be carried easily by the tractive force of flowing water. The fact-finding survey of the Saw Timber Plantation No. 9 also verified runoff and deposition of sediment produced by erosion in the downstream areas. Damage caused directly by sediment runoff is the withering of trees in sediment deposition areas. It indirectly raises river beds of rivers downstream, possibly causing floods. Check dams will have to be built in the plantation area for minimizing sediment deposition and to prevent sediment runoff. An analysis of the soil and geological conditions of the plantation area shows that there is no possibility of stones and boulders being carried down, and therefore dams of a simple structure will be sufficient for the purpose. The foundation ground in the dam construction sites is soft, for example as in swamps, and the dams should preferably have a flexible structure. The desired type of check dams are therefore the simple gabion dams.

6.4.2. Recommendation for afforestation utilising natural forests

A study of afforestation methods utilising natural forests was made as a conservation measure considering impacts on the environment. One of the methods is to recommend the enrichment technique. The other method is a study of afforestation technology by studying forest stand structures. The utilisation of natural forests reduces the scope of disturbance to the ecosystem caused by introducing exotic species. It will also be effective in preventing erosion and in minimising further expansion of erosion.

(1) Proposal for enrichment technique by case studies

The enrichment method and effects of preventing natural environment deterioration can be summarised as follows:

1) Clear cutting and controlled burning on a large scale result in deterioration of the natural environment. The enrichment method is employed to improve this situation.

2) The enrichment method is a regeneration method that combines improvements of forest stands of natural forests, and artificial regeneration. This method is a technique that can be called a forest restoration method for tropical rain forests.

3) The enrichment method is divided into three techniques, i.e., line planting, gap planting and forest patch improvement. All these techniques do not result in bare land in large areas as in clear cutting, but safely regenerate Dipterocarp species, which are merchantable domestic species, while being protected by naturally regenerated forests, such as secondary forests.

4) The clear cutting method to produce bare land of large areas cuts and burns a large variety of woody plant groups including the advance growth that has not reached the required diameter class. It destroys the litter which supplies nutrition to the soil. Nutrition will no longer be supplied to roots of planted trees if the litter, as a source of nutrition, is destroyed. If canopies are lost by clear cutting, the surface of soil previously protected from strong rains, will suddenly be exposed to erosion, and rills occur. In these instances, an afforestation method which combines advance growth in the area such as secondary forests, will become an effective regeneration method that will prevent soil deterioration.

5) In line planting, secondary forests are cleared in a belt shape and nursery stocks are planted there in a line shape. The decision on the line width is important in this process. If the line width is too narrow, planted trees will be suppressed by the growth of trees in the remaining zones, so that the illumination will become low, and tree growth will be poor. In gap planting, secondary and other forests are cleared in a gap shape and gaps are produced artificially. A better way for the growth of planted trees is to clear, so that one side of a quadrat shaped gap will equal the tree height of advance growth forests. In forest patch improvement, lower trees and shrubs are removed from areas where succeeding young growths are already growing, and where young growths of Dipterocarp species will be distributed.

a. Enrichment test under JICA project

Experimental plots employing the three methods were set in Bukit Sawat in 1988 and 1989 under the JICA project. (See Figure-18, No. ①.) Four and half years have passed up to the time of the survey.

1) In line planting, the clearing widths of 4, 6, 10 and 15m, planting spacing of 3x3m and test species of Kapur (Kapur perringgi and Kapur paji) and Kawang jantong were selected. A plot with the clearing width of 4m, for which data was gathered, had Kapur perringgi trees 1.6 to 3.7m in tree height. A plot with the clearing width of 15m had 1.7 to 3.8m in tree height.

2) Two quadrats with gap sizes of 20x20m and 10x10m were set for gap planting.

a) Experimental plot with gap size of 10x10m (See Figure-21 (5.))

The growth of planted trees not affected by upper-storey trees around the gaps was good and tree heights reached 3m. The growth of Kapur paji was better than with Kapur perringgi. The heights of the planted trees which were suppressed by crowns of upper trees were low. The relative illuminance in that location was 1.8 to 3.2% which is lower than 5%, which is regarded as the value necessary for trees to grow.

b) Experimental and comparison plots of gap size 20x20m

The ground surface in the gap centre area of the Plot No. 1 experimental plot shown in Figure-22 was dry. The soil lacked a litter layer and the survival rate of planted trees in that area was low. The Kapur perringgi trees planted near the edges of this plot grew well, reaching 4 to 6m in tree height. The litter layer of soil in that area was 5cm thick and the relative illuminance was 32 to 65%. Plot No. 2 planted with trees without setting gaps was a comparison plot to Plot No. 1. The growth of the trees planted there was poor and nearly all of the trees were less than 1m in height. The relative illuminance of Plot No.2 was 0.92%, which was below the 3% considered to be the boundary value for survival of nursery stock of Dipterocarp species.

The growth of the trees planted in the Plot No. 13 shown in Figure-23 was good. The growth of Kapur perringgi was better than that of Kapur paji. Many of the trees were more than 3m high and the maximum height was 5.8m. The relative illuminance on the edges of the gaps of this experimental plot was 8 to 12.5%. A litter layer could be found in this soil even in the central area of the plot. The soil hardness was 8 to 13. This hardness would be suitable for the growth of roots.

3) Forest patch improvement

The gap size of this experimental plot was 20x20m. The upper trees were opened up and more than 150 naturally regenerated saplings of Damar hitam were regenerated in a 2x2m patch in the gap. The saplings were 0.5 to 1.0m in height. The heights of the regenerated saplings in the plot, in which upper trees were not opened up, were about 0.2 to 0.3m, which was low.

b. Silviculture test by Forestry Department

This experimental plot using the enrichment technique (No.② in Figure-18) was set in Bukit Sawat in March, 1989 and is four years old. In this plot, only upper trees suppressing planted trees were cleared, and Kapur bukit trees were planted. The survival and tree height growth of the planted trees were good. Half of the trees were more than 2m high and the maximum height was 3.7m. The relative illuminance of the plot was about 10% which was sufficient for the growth of planted trees. However, as can be interpreted from the survey map, the planted trees were suppressed by crowns of the remaining upper trees of Meranti, Keruing and other species which were excessively closed. The crowns of these upper trees must be opened up as quickly as possible to accelerate the growth of planted trees. (See Figure-24.)

c. Lamunin plantation experiment

This plantation is an experimental plot of Kapur bukit planted 23 years ago. (See No.③ in Figure18.) Advance growths such as Kempas, Selangan batu and Meranti merah kesumba became upper trees of Kapur bukit and provided enrichment. Planted Kapur bukit trees were straight and tree heights were 17 to 24m. (See Figure-25.) The litter layer of soil in the plantation was 6cm thick and Layer A was also developing to 6cm thick. The soil hardness was less than 15, suitable for root growth. The root system grew to a depth of 55cm.

(2) Study of silviculture technology by forest stand structure survey

A forest stand structure survey of naturally regenerated forests scheduled to be developed as a plantation was conducted to find a regeneration method which would, as a result match the environment in the area. The purpose of this survey was to obtain suggestions for using model plantation technologies in the future. The survey was made by conducting a forest stand survey by the belt-transect method, to prepare forest profile diagrams and crown projection diagrams, and to analyse the results. Two locations were surveyed, namely, a mixed Dipterocarp forest and a secondary forest.

a. Exploited Mixed Dipterocarp forests

1) Figure-26 shows No. 1 Belt-transect set in a wild wood of Bukit Sawat shown in No.⑤ of Figure-18. The number of living trees per ha was 1,480. The wild wood was a mixed Dipterocarp forest containing Dipterocarp species such as Meranti, Kapur bukit, Resak and Damar hitam. The tree classes of the typical tropical rain forests have five layers. The tree layer is divided into three layers, i.e., emergent layer (41m or more), large tree layer (21 to 40m) and small tree layer (11 to 20m). In addition, the low tree layer (6 to 10m) and ground layer (less than 6m) are generally added to them to make five layers in total. The diagram shows the small tree layer and above. This forest stand did not have emergents and the maximum tree height was 32m. This stand was relatively low. Probably due to felling of trees before, its canopy was partially opened up.

2) Soil had 4cm-thick litter. The first layer was Layer A 15cm thick, 3.76 in pH and 8 in soil hardness. The second layer was 15cm thick, 4.81 in pH and 13 in soil hardness. Roots were distributed to depths of 60cm.

3) A survey plot of 10x2.5m was set inside the transect to observe natural regeneration. (See Figure-27.) Many Dipterocarp species could be found with shrubs below 10m in tree height, and with saplings below 1m shown in the

diagram, such as Resak, Damar hitam, Merawan and Meranti.

4) Rearing of naturally regenerated seedlings of Dipterocarp species, many of which could be found, by patch improvement can be considered first as a regenerating method for artificial forests. Line planting and other methods should also be studied. The basic approach to regeneration as artificial forests, is to adopt a method that harmonises with the forest descriptions of the area.

b. Secondary forest

1) This was a secondary forest established in hilly land at Merangking (No. ⑥ in Figure-18). The No. 5 belt-transect set here was a moderate slope with an inclination of 9°. The species found were non-Dipterocarp species. The tree classes were dominantly trees in the small tree layer and trees in the large tree layer were few. The number of living trees per ha in the tree layer was 1,000. More than 1,500 seedlings per ha were regenerated in the lo tree layer and the layers below it. Again, seedlings of Dipterocarp species could not be found. (See Figure-28.) The forest profile diagram shows the 5x50m part in Block I.

2) Soil had a 2cm-thick litter layer. The Layer I was Layer A, 14cm in thickness, 4.19 in pH and 6 in soil hardness. The Layer II was Layer B1, 13cm in thickness, 4.54 in pH and 12 in soil hardness. The Layer III was Layer B2, 25cm in thickness, 4.45 in pH and 11 in soil hardness. The Layer A had many fine roots, and roots were distributed to depths of 50cm.

3) Afforestation by clear cutting of small areas, line planting and other methods can be considered as a regeneration method for this area. Site preparation by clear cutting and controlled burning of slopes over large areas may cause erosion.

6.4.3. Study of species to be planted

The future regeneration method will be studied by surveying previous cases, and evaluating afforestation performance of the species to be planted, with domestic species as principal species for afforestation. This will be effective in minimizing impacts to the natural ecosystem. The selection is also important in improving the nursery practice technology for Dipterocarp species, which are also extremely useful domestic species commercially.

(1) Evaluation of afforestation performance of the three principal species by case studies

a. Silviculture test by the Forestry Department

This experimental plot (No. ② in Figure 18) In Bukit Sawat prepared by clear cutting and controlled burning has a relatively moderate slope, and prominent gully erosion could not be found in the survey area. The experimental plot was set in June and July, 1990, so more than three years have elapsed since planting. Planting intervals were 6x2m for *Acacia mangium* and Klinki pine, and 6x3m for Kapur.

1) *Acacia mangium* (Figure-29)

The survival rate of *Acacia mangium* was high. Tree heights were 9 to 15m and trees grew well. However, the crown density had already exceeded 100% and the time for improvement cutting had arrived. Uniform forest afforestation of exotic species in large areas are vulnerable to disease and pest damage. As a generally accepted view, impacts on the regional ecosystem should be considered.

2) Klinki pine (Figure-30)

The survival rate of Klinki pine was 47% and was not high. However, half of living trees exceeded 3m in tree height. The reason for the high mortality in this area is suppression by large herbs exceeding 2m in plant height, and tending such as weeding is necessary.

3) Kapur (Figures-31 and 32))

Kapur bukit was selected for planting in hilly land and Kapur paya for swamps. Kapur bukit showed a survival rate of 83% and grew well. The average tree height was 3m and the maximum height was 4.5m. About 20% of Kapur paya trees, which were considered to be strong in swamps, withered, suppressed by large herbs. The average tree height of Kapur paya trees was 2.28m and the growth of these trees was slow compared with Kapur bukit.

b. Lamunin Plantation Experiment

1) This plot adjoined the Kapur bukit plantation in Lamunin shown in the case study for the enrichment method earlier. Klinki pine nursery stocks were planted in this experimental plot 23 years ago. From a belt-transect survey, the planting spacings seemed to be 3x2m, but withering of trees was prominent. Tree heights were mostly in the range of 22 to 32m. Variations of

the growth from one tree to another were large. (See Figure- 33 and 34.)

2) Soil was sandy and the soil hardness was 13 for Layer I (thickness 10cm) and 18 for Layer II (thickness 65cm). These hardnesses were suitable for the growth of roots. Root systems distributed widely to depths of 25cm.

3) This was an example of planting in lowland, a species which originally grew in an alpine region. Information such as condition of growth, and on disease and pest damage in uniform forests of Klinki pine must be obtained from the country of origin, Papua New Guinea, and a study will be necessary concerning its handling as an introduced species.

(2) Improvement in nursery practices technology for merchant able Dipterocarp species

a. Determination of phenology for merchantable species

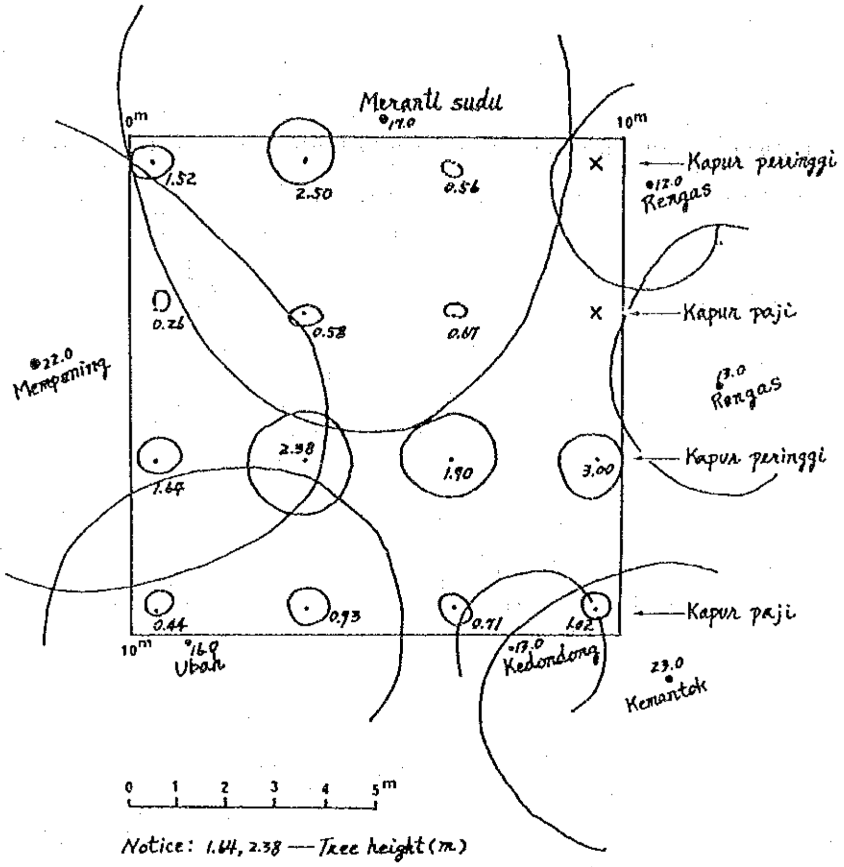
The phenology of species to be planted must be determined to secure nursery stocks of species needed for afforestation. The number of Dipterocarp species is large and the flowering and bearing seasons, as well as the bearing and off years, of these species, fluctuate annually. It is not easy to obtain phenology information. However, this process is the basis for securing stable seeds, and for improving nursery practice technology. There have been many cases in the tropical region in which plantation results have been poor because of a failure in securing seeds, due to insufficient phenology information, causing a delay in developing nursery practice technology. Thus, wildlings (inferior-quality nursery stocks that have not been transplanted in nurseries and before nursery stocks took root) were used.

b. Careful examination of species characteristics and securing stable seeds

Seed modes and germination depend on species characteristics and a stable supply of seeds can be secured by carefully examining these characteristics. The enhancement of seed technologies improves the nursery practice technology.

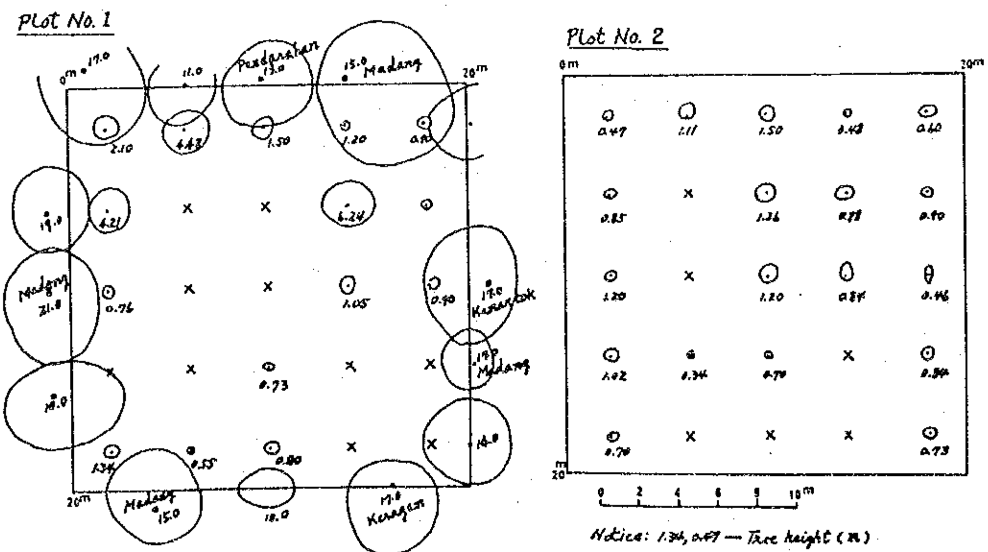
6.4.4. Regeneration of zones near conservation areas

A regeneration method that prevents erosion should be used when planting trees or developing forests near communities, main public roads, and rivers that are closely interrelated to traffic and setttlements. Places that need conservation require wild woods of certain tree belt widths to be left as they are, and conservation of regional landscapes by executing scenic-beauty forest operations in order to lessen impacts to environment.



Notice: 1.64, 2.38 — Tree height (m)
Gap size — 10×10 m
Tree species — Kapur peringgi, Kapur paji
Spacing — 3 x 3 m
Row No. — 4 x 4
Planted date — March 1989

Figure-21 Quadrat of gap planting (Plot No.12)



Notice: 1.34, 0.47 — Tree height (m)
Gap size — 20×20 m
Tree species — Kapur peringgi
Spacing — 4 x 4 m
Row No. — 5 x 5
Planted date — Oct. 1988

Figure-22 Quadrat of gap planting

(Plot No.1, Plot No.2)