FOREST INVENTORY OF THE SAL FORESTS OF BANGLADESH

VOLUME 1: TECHNICAL REPORT

FORESTRY SECTOR PROJECT
FOREST DEPARTMENT
MINISTRY OF ENVIRONMENT AND FORESTS
DHAKA, APRIL 2001

TECSULT International Ltd. in association with SODEV, NRP, HCL and EPC

FOREST INVENTORY OF THE SAL FORESTS OF BANGLADESH

FORESTRY SECTOR PROJECT (1997/8-2003/4)

VOLUME 1: TECHNICAL REPORT

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LIST OF ABBREVIATIONS

ACF – Assistant Conservator of Forests
ADB – Asian Development Bank
BAN – Bangladesh
BGD – Bangladesh
cm – centimeter
dbh – diameter at breast height
e.g. – for example
EPC – Engineering and Planning Consultants Ltd., Dhaka
et al. – and others
etc. – et cetera
FAO – Food and Agriculture Organization of the United Nations
FD – Forest Department
GoB – Government of Bangladesh
GIS - Geographic Information System
GPS – Global Positioning System
ha – hectare
h – height
HCL – House of Consultants Limited, Dhaka
id - identification
i.e. – that is
m – meter
m^2 – square meter
m^3 – cubic meter
NRP – Natural Resources Planners Ltd., Dhaka
pp – pages
r – radius
SODEV – SODEVconsult, Dhaka
sp. – species
SPOT – le Systeme Pour l'Observation de la Terre
TECSULT – TECSULT International Ltd.
UNDP – United Nations Development Programme
WGS – World Geodetic System

>, + greater than
≥ greater than or equal to
< less than
≤ less than or equal to

EXECUTIVE SUMMARY

The sal (*Shorea robusta*) forests of the central and northwestern parts of Bangladesh are natural tropical deciduous forests primarily of coppice origin. The main areas are found in Dhaka, Tangail and Mymensingh Forest Divisions, with smaller patches found in Dinajpur, Rangpur and Rajshahi Divisions. These forests are the main source of forest products for the people of these regions, but are declining in both extent and condition. Some sal forest areas have recently been transformed to woodlots and agroforestry.

A forest inventory was carried out during November 1999 – May 2000 in these sal forests and immediately adjacent areas. A systematic sampling design was used, with 400 m between lines (500 m in Tangail Division) and 200 m between circular volume plots along each line. Plots were 100 m^2 in area in Dhaka, Tangail and Mymensingh Divisions and 200 m^2 in area in Dinajpur, Rangpur and Rajshahi Divisions. The variations in line spacing and plot size reflected differences in forest area and characteristics, and were set to maximise sampling efficiency. A total of 5287 volume plots were sampled on forest land. Species, dbh and tree quality (damage, infestation and stem quality) were recorded for all trees with dbh ≥ 10 cm within each plot. Heights of the dominant tree and one randomly selected tree also were recorded in each plot. Number of seedlings, saplings and small trees were counted within a 2 m radius plot centered in each volume plot. Each volume plot and immediate surrounding area (radius 17.84 m) was classified into one of six main management classes (degraded sal forest, young sal forest, immature sal forest, mature sal forest, woodlots and agroforestry). Total areas of management classes subsequently were estimated on the basis of number of plots occurring in each class, each plot representing 8 ha (10 ha in Tangail Division) within the systematic sampling grid.

Total forest area was estimated at approximately 46,000 ha, of which 5500 ha were classified as temporarily unstocked. Area of sal forest was estimated at approximately 22,000 ha, woodlots at 17,000 ha, and agroforestry areas at 1500 ha. Mean volume of mature sal varies between 42 and 71 m^3 per ha in the central Divisions; higher mean volumes in the northern Divisions reflects sampling in areas of more mature trees. Woodlot volumes vary between 37 and 53 m^3 per ha in the central Divisions with a trend toward somewhat higher volumes in the northern Divisions, although standard errors in the latter are high. Akashmoni (*Acacia auriculiformis*) is the most widely planted species in both woodlot and agroforestry areas.

Encroached areas could not be separated from privately owned agricultural areas due to uncertainties regarding legal ownership, and are not included in the above forest area estimates.

Detailed results of the inventory are presented in tabular form in five accompanying volumes, aggregated at Division, Range and Beat level as appropriate. These are:

Volume 2: Summary for all Sal Forest Divisions Combined
Volume 3: Dhaka Forest Division
Volume 4: Tangail Forest Division
Volume 5: Mymensingh Forest Division
Volume 6: Dinajpur, Rangpur and Rajshahi Forest Divisions.

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1. BACKGROUND

The sal (*Shorea robusta*) forests of the central and northwestern parts of Bangladesh are natural tropical deciduous forests primarily of coppice origin. Sal is predominant but associated species also occur. These forests are the main source of forest products for the people of these regions, and are subject to a high level of harvesting pressure by the densely settled, contiguous human population. Both stocking and area are considered to be decreasing, and distribution is now limited to discontinuous forest patches of varying extent and condition. The Bangladesh Forest Department is currently trying to keep cleared sal forest areas under tree cover by planting fast-growing trees under woodlot and agroforestry programmes.

Maps of the forests of Dhaka, Tangail and parts of Mymensingh Forest Division were published in 1977, based on interpretation of aerial photographs taken in 1969. However, both forest area and stocking are considered likely to have changed considerably since then. As it is necessary to have information on the present stocking and spatial distribution of tree cover for proper forest management, Forest Department has undertaken a sal forest inventory under the survey, mapping and inventory component of the Forestry Sector Project, with the financial support of Asian Development Bank. This report presents the findings of this sal forest inventory.

Sal forests currently are found in the Forest Divisions of Dhaka, Tangail, Mymensingh, Dinajpur and Rangpur. A small patch of sal forest also is present in Rajshahi Division (Figure 1). The Forestry Sector Project includes the sal forests of all six of these Forest Divisions. Previously available estimates of forest cover in these Divisions are summarised in Table 1.

Table 1
Existing estimates of forest areas in Divisions having sal forests[1]

Forest Division	Area under forest type (hectares)				
	Wooded	Woodlot	Degraded and blank	Encroachment	Total
Dhaka	6734	917	15,414	3157	26,222
Tangail	9975	5157	12,836	13,889	41,877
Mymensingh	5787	3844	5401	12,640	27,673
Dinajpur	946	3450	515	4617	9538
Rangpur	84	1746	0	1360	3195
Total	23,526	15,114	34,166	35,663	108,505

[1]based on Ghani *et al.* 1990

2. OBJECTIVES OF THE SAL FOREST INVENTORY

The sal forest inventory was carried out in all Forest Divisions having sal forests (*i.e.*, Dhaka, Tangail, Mymensingh, Dinajpur, Rangpur and Rajshahi). The objectives and major expected outputs of the inventory per the Project Proforma (GoB 1997) were:

- to determine the distribution of the regeneration classes of sal;
- to determine the potential production of the above classes in terms of number of trees and volume of sal;
- to determine the distribution of woodlot areas and management classes; and,

- based on the inventory, to formulate management plans and make recommendations for the respective Divisions for a period of 20 years.

These objectives and outputs were to be achieved using a combination of mapping and field sampling techniques. The mapping work is ongoing under FD's GIS Section and will ultimately be based on interpretation of 1998-99 satellite (SPOT) imagery. This report describes the methodology and results of the field sampling component.

3. METHODOLOGY

3.1 Sampling Design

The field inventory was carried out over sal forest areas and adjacent surroundings in all of the sal forest Divisions. Sal forest distribution is discontinuous, with scattered patches of forest separated by other land use management classes, and in order to ensure complete coverage the best available information was used to identify forest area location (see below). A systematic sampling design was used, with lines and plots systematically distributed over known forest areas.

Sampling was designed to attain a sampling error of volume per hectare of less than 10% for each Division (at 95% probability level). Assuming a coefficient of variation of volume of 80%, not more than a few hundred volume plots would be required to attain this precision. However, due to mapping information needs, it was judged necessary to lay out plots at a higher density than strictly required to remain within the target sampling error. Therefore, area plots describing mainly land use/management classes were distributed between the volume plots, with three area plots between two volume plots.

Forest maps at 1:10,000 scale were used as a basis for the line and plot layout where available (Dhaka, Tangail and part of Mymensingh Division). These maps were based on interpretation of aerial photographs taken in 1969. North-south lines were drawn on the maps with 400 m between lines (500 m in Tangail FD, due to the large area of forest in this Division), 200 m between volume plots along each line, and 50 m between area plots. Compass bearings and measured distances from known tie points were used to determine the exact location of lines and sample plots in the field. Trees indicating start points of the sampling lines were marked with paint.

Forest maps have not been prepared for the northern part of Mymensingh Forest Division and for the northwestern parts of Bangladesh, but other maps providing at least an indication of forest boundaries (*e.g.*, 1:50,000 scale thana maps based on 1989-90 SPOT satellite imagery, and showing forest patches >25 ha in size) are available. In these areas, roads oriented more or less east-west were taken as baselines, and north-south transect lines were marked directly in the field at 400 m intervals, based on GPS measurements. Trees indicating start points of the sampling lines were marked with paint, and volume plots were then laid out at 200 m north-south intervals. Where baselines (roads) were not exactly east-west, plot locations were adjusted such that latitudes of plots on adjacent lines remained the same (*i.e.*, forming a rectangular grid 200 m north-south and 400 m east-west).

The sampling grid was designed to obtain data from 1000-2000 volume plots on forest land in each Division, and represents a sampling intensity of 0.125% for Dhaka and Mymensingh,

0.1% for Tangail and 0.25% for the North Bengal Divisions.

3.2 Measurements and Observations from Volume Plots

As described above, volume plot centers were located on the ground by means of compass bearings and measured distances. Once a volume plot center had been located a visual assessment of management class was made. If the sample plot fell entirely within one management class all necessary measurements were taken from the measured center point. However, if the plot fell partially in one class and partially within another, it was moved so that the whole plot fell within the initial plot center class (first movement option was backward or forward along the line, second was west or east, maximum 5 m). Management classes were defined as:

S1 private/encroached areas
S2 grass/degraded former forest land (less than 100 stems/ha)
S3 young re-growth of sal (h < 1.5 m)
S4 immature sal forest (h = 1.5 m – 5 m)
S5 mature sal forest (h > 5 m)
S6 woodlot
S7 agroforestry

Following derivation of the plot center, the nearest tree was marked with red paint for subsequent control inventory purposes. Latitude and longitude coordinates (using the WGS 84 system) of each plot center were recorded using a Garmin 45 GPS unit, for use in subsequent satellite image interpretation. The expected accuracy at 95% confidence level was 100 m, but obtained accuracy was considerably lower in some cases. The inventory was conducted while the selective availability disturbance signal was still operative, resulting in reduced accuracy.

Volume plots were circular and 100 m^2 (r = 5.64 m) in area in Dhaka, Tangail and Mymensingh Divisions, and 200 m^2 in area (r = 7.98 m) in North Bengal (Dinajpur, Rangpur and Rajshahi Divisions). Larger plot sizes were used in the latter Divisions, where trees tended to be both larger and more sparsely distributed, in order to obtain a better description of forest characteristics (with the aim of including at least five trees in each sample plot).

The following measurements and observations were recorded for each volume plot:

- location of the plot (Forest Division, Range and Beat);
- plot number, longitude and latitude (based on GPS readings);
- management class, forest type and stand condition;
- diameter at breast height (calipered at 1.3 m above ground level), species (code number), tree status (classifying damage, infestation and stem quality) for all trees with dbh ≥10 cm. Special care was taken with trees near the outer boundary of the plot, to ensure that the tree centre was within the plot radius;
- heights of two trees (measured by Suunto hypsometer), one the dominant (largest diameter) tree in the plot, and the second randomly selected;
- number of seedlings of each species with height ≤ 1.5 m in a 2.0 m radius regeneration plot centred in the volume plot;
- number of saplings with height > 1.5 m and dbh < 5 cm in the 2.0 m radius plot; and,
- number of small trees with dbh ≥ 5.0 cm but < 10.0 cm in the 2.0 m radius plot.

A diagram of plot layouts, data sheets and additional details on management classes and tree status classification are provided in Appendix 1. Note that at volume plot locations management class was recorded within the same radius as for area plots (see below).

3.3 Measurements and Observations from Area Plots

Area plots were 0.1 ha (r = 17.84 m) in size, and data recording was based mainly on ocular estimates to minimise the time needed at each plot. The main purpose of the area plots was to obtain additional data on the distribution of forest management classes for mapping purposes.

Area plots were given the same record number as the previous volume plot followed by A, B or C, from south to north. This means, for example, that area plot 19B is in the middle between volume plots 19 and 20 on the same line, while 19C is located 50 m north of 19B, and 50 m south of volume plot 20.

The following data were recorded for each area plot:

- Division, Range, Beat;
- map id, line number, plot number;
- management class, % of plot covered by management class;
- species; and,
- dominant height (in metres, of the fattest tree on the plot).

It should be noted that as a result of the large size of the area plots, small openings in otherwise forested areas were still classified as forest.

Data sheets and additional details on management classes are provided in Appendix 1.

3.4. Field Work

Field work was carried out by six groups divided into two teams for transportation and supervision purposes. Each group consisted of four people, three of whom had forestry training background (as Foresters or Forest Guards), and in many cases experience from previous inventory work. Day to day supervision was provided by two ACFs (each responsible for three groups) and the National Specialist, supplemented by periodic visits by the International Specialist and FD Headquarters staff.

A summary of information on the field work accomplished is provided in Table 2.

Table 2
Summary of sal forest inventory plots

Forest	Volume Plots		Area Plots		
Division/Area	Total	Class S2-S7	Total	Class S2-S7	Duration of field work
Dhaka	3317	1587	12,847	5908	21/11/99-2/01/00
Tangail	5157	1905	20,234	6940	16/01/00-26/02/00
Mymensingh	2282	1173	8876	4448	26/02/00-6/04/00
North Bengal	930	622	3645	2260	19/04/00-13/05/00
Total	**11,686**	**5287**	**45,602**	**19,556**	21/11/99-13/05/00

3.5 Validation of Data: Control Inventory

A control inventory was carried out to certify the quality of the inventory. The control inventory comprised repeat counting of number of saplings and small trees on 2.0 m radius plots, and repeat measurements (dbh, total height, tree status *etc*.) of trees on volume plots. A separate team carried out the control inventory, covering about 3% of previous sample plots. The control inventory was carried out on randomly chosen maps having a minimum of approximately 30% forest cover.

3.6 Area Estimates

The most common method for estimating areas of different land use/management classes is to measure them from maps on which they have been delineated. However, forest maps of the inventory area are outdated and no useful recent information is available. This made it necessary to base area estimates on the systematically distributed point samples which each plot center represents, as shown on Figure 2. Each volume plot represents 8 ha in all Divisions, except for Tangail where each plot represents 10 ha.

Standard error was calculated using Chevrou's (1976) formula for systematically distributed point samples, as follows:

$$e^2 = 0.0707 \times CF \times a^4 \times \sqrt{n}$$

where e = standard error
CF = factor describing form of the areas, calculated as circumference divided by square root of area (normally values vary between 5 and 7)
a = distance between quadratically distributed plots
n= number of plots.

Use of the formula for the 400 x 400 m sampling grid shows standard errors from 3.7 down to 0.4 % for areas of between 800 and 16,000 ha. The same formula was used for Tangail Division (sampling grid 500 x 500 m), thereby introducing a minor bias in the standard error estimations.

3.7 Volume Estimates

3.7.1 Volume Estimation of Individual Trees

Usable volume tables are available in Bangladesh for plantations of eucalypts (Davidson *et al*. 1985), mangium (Latif *et al*. 1993), akashmoni and minjiri (Latif *et al*. 1995), and for sal plantations (Das *et al*. 1992). However, volume tables for sal forests of coppice origin were not available for use in this inventory. Therefore, a tree volume study was undertaken in order to test the validity of using existing sal plantation volume tables for sal coppice forest in the inventory area.

A total of 150 trees was randomly selected for detailed volume measurements by cross-sectioning (Table 3). The trees were selected from all sal forest Divisions, with emphasis on getting good representation over all diameter classes. The dbh of the selected trees was measured first, followed by measurement of total height by Suunto hypsometer. Diameters were then measured at stump height (0.3 m) and at 1 m intervals from the base of the tree at

ground level (Figure 3). A small portion of bark was removed from each point of diameter measurement, and bark thickness was measured to estimate the under-bark diameter.

Table 3
Number of trees measured for validation of sal volume tables

dbh class (cm)	Forest Division/Area				
	Dhaka	Tangail	Mymensingh	North Bengal	Total
10 - 15	5	4	4	9	22
15 - 20	8	8	7	11	34
20 - 25	5	5	7	11	28
25 - 30	4	5	6	9	24
30 - 35	4	2	2	7	15
35 - 40	3	6	3	8	20
40 +	1	0	1	5	7
Total	30	30	30	60	150

The volumes of all sections, except top sections, were calculated by using the mean cross-sectional areas of the two ends of each section (Smalian formula). The top section was assumed to be a cone and volume was calculated by using the top end diameter measurement for each tree as the base diameter of the cone. Individual tree volumes were estimated by summing the volumes of each section.

The following formulae were used:

0.3 1.0 2.0 3.0 4.0 5.0.....N = distance from the base of the tree in meters
---------- ----------
| | | | | |..... | = point of diameter measurements
d_1 d_2 d_3 d_4 d_5 d_6 d_n (diameter in cm)

Volume of i^{th} section except the top-most section:

V_i = volume of a cylinder
$= \pi * (\text{radius})^2 * \text{height}$
$= \pi * (\text{diameter}/2)^2 * \text{height}$
V in $cm^3 = [\{\pi * (d_i/2)^2 + \pi * (d_{i+1}/2)^2\}/2] * L_i$
V in $m^3 = 1/(100 * 100) * [\{\pi * (d_i/2)^2 + \pi * (d_{i+1}/2)^2\}/2] * L_i$

Volume of the topmost section:

V_{top} = volume of a cone
$= (1/3)\pi * (\text{diameter}/2)^2 * \text{height}$
V in $cm^3 = (1/3)\pi * (d_n/2)^2 * L$
V in $m^3 = 1/(100 * 100) * 1/3\pi * (d_n/2)^2 * L$

Total volume of a tree: $V_t = \Sigma V_i + V_{top}$

V_i = volume of the ith section of the tree,
V_{top} = volume of the top most section of the tree,
V_t = total volume of the tree,
d_i = bottom (base) diameter of the section,

d_{i+1} = top end diameter of the section,
d_n = base diameter of the topmost section of the tree,
L_i = length of the section.

Regression techniques were used to relate the individual tree volume (V) to dbh (D) and total height (H) by using various functions and equations. The following two best fit volume equations were derived from the measurement data:

-for Dhaka, Tangail and Mymensingh Divisions $V = 0.00010347*D^{2.501816}$

-for North Bengal (Dinajpur, Rangpur and Rajshahi Divisions) $V = 0.00017448*D^{2.403486}$

Individual tree volumes also were estimated using existing volume equations for sal plantations (Das *et al*. 1992), and the two sets of estimates were compared using paired t-tests and chi-square goodness of fit. As there was no statistically significant difference between these volume estimates, it can be concluded that the volume equations developed by Das *et al*. (1992) also can be used for sal coppice forests.

The volume functions used for other species included in this inventory are listed in Appendix 2.

3.7.2 Total Volumes

The volumes of individual trees were calculated and summed for each volume plot. These plot volumes were multiplied by 100 for Dhaka, Tangail and Mymensingh Divisions, and by 50 for Dinajpur, Rangpur and Rajshahi Divisions, to arrive at volumes per hectare. Volumes were aggregated by Beat, Range, Division and management class. Standard errors were calculated at 68% probability level.

3.8 Data Entry and Processing

Data entry, processing and validity testing were carried out using Microsoft Access Software. Formulae and definitions used for data processing are given in Appendix 3.

4. RESULTS AND DISCUSSION

4.1 Total Area Estimates

Estimates of forest cover in each Division are summarised in Table 4. The estimates include all areas under sal forest (management classes S3-S5), woodlots (S6) and agroforestry (S7). Total area under forest cover (S3-S7) amounts to 40,590 ha, of which 39.1% is in Tangail, 30.4% in Dhaka, 19.2% in Mymensingh, 8.7% in Dinajpur, 1.8% in Rangpur and 0.8% in Rajshahi Forest Division.

Table 4
Summary of area estimates by Forest Division

Forest Division	Area under forest cover (ha)	Temporarily unstocked area (ha)	Total area (ha)	Standard error (%)
Dhaka	12,344	352	12,696	0.4
Tangail	15,870	3180	19,050	0.4
Mymensingh	7808	1576	9384	0.4
Dinajpur	3544	360	3904	0.7
Rangpur	680	48	728	2.2
Rajshahi	344	-	344	3.8
Total	40,590	5516	46,106	0.2

[1] standard errors are calculated at Division level. In Dhaka Division, for example, 0.4% of 12,696 ha represents around 51 ha, which means that the total forest area in 95 cases of 100 will fall between 12,645 and 12,747 ha if the sampling procedure is repeated 100 times.

Temporarily unstocked areas in Table 4 correspond to management class S2 (grassland/ degraded former forest land); these areas are considered to be under FD management and are, therefore, included under total land area estimates. Total temporarily unstocked area amounts to 5516 ha, mostly (86.2%) in Tangail and Mymensingh Divisions. Temporarily unstocked areas comprise nearly 12% of total FD land over all Divisions combined.

The area estimates do not include agriculture/encroached areas (management class S1) as it was not possible during the fieldwork to determine legal ownership of these lands.

The inventory results correspond reasonably well with the information reported by Ghani *et al.* (1990), who calculated a total forest cover of nearly 39,000 ha, including plantations, over the sal forest Divisions. Division-wise and total estimates of forest cover from the two studies are summarised in Figure 4. However, it should be noted that direct comparisons, or inferences regarding increases or decreases in sal forest cover or woodlots, are not possible due to the fundamentally different methodology used by Ghani *et al.* (estimates from maps, field visits and interviews, but no true sampling) and the present study, which represents a systematic inventory of known forest areas.

4.2 Forest Area Distribution by Management Classes

Mature sal forest (S5) is the predominant management class, comprising 45.7% of forest cover overall (Table 5). However, it remains as the major forest cover only in Dhaka Division. Although relatively large areas of mature sal also remain in Tangail, Mymensingh and Dinajpur, woodlots (S6) have become the predominant forest cover in these Divisions. Woodlots also predominate in Rangpur and Rajshahi Divisions, where only small areas of mature sal forest remain.

Table 5
Forest area estimates by management class and Forest Division

	Area in management class (ha)					
Forest Division	S2	S3	S4	S5	S6	S7
Dhaka	352	528	1432	7920	2040	424
Tangail	3180	360	780	6990	7250	490
Mymensingh	1576	72	168	2080	5136	352
Dinajpur	360	64	24	1384	1856	216
Rangpur	48	-	-	64	568	48
Rajshahi	-	-	-	128	200	16
Total	5516	1024	2404	18,566	17,050	1546

Areas under young sal (S3) and immature sal (S4) are comparatively small in all Divisions, comprising only 2.5% and 5.9% of total forest cover. Areas under agroforestry (S7) also are relatively small, comprising only 3.8% of total forest cover. As noted above total disforested area (S2) is quite high, particularly in Tangail and Mymensingh Divisions. These latter areas represent a potential focal point for enrichment planting, protection and re-establishment of sal forest cover.

It should be noted that areas with sparse sal forests or plantations generally were excluded from sampling, as there was little chance of locating volume plots with tree cover. However, sparse tree cover sometimes was located between lines, or between two plots in the same line.

4.3 Woodlot Areas and Species

Woodlots (S6) comprise the second largest management class overall, accounting for 42.0% of total forest cover, and as noted above they now comprise the predominant forest cover in all except Dhaka Division. Akashmoni (*Acacia auriculiformis*) is the most widely planted species, accounting for 73.2% of woodlot area, followed by eucalyptus (12.2%) and mangium (*Acacia mangium*) at 4.9% of total area (Table 6). Minjiri (*Cassia siamea*) has been widely planted in Dinajpur, but is not common in other Divisions. The same species are predominant in agroforestry areas.

Table 6
Woodlot and agroforestry area distribution by species and Forest Division

Management Class	Forest Division	Species and area (ha)					Total
		Akashmoni	Eucalyptus	Mangium	Minjiri	Others	
Woodlot	Dhaka	1520	264	120	32	104	2040
	Tangail	5800	380	590	80	400	7250
	Mymensingh	4296	504	120	64	152	5136
	Dinajpur	600	688	8	328	232	1856
	Rangpur	128	224	0	88	128	568
	Rajshahi	152	24	0	0	24	200
	Total	12,496	2084	838	592	1040	17,050
Agroforestry	Dhaka	296	88	40	0	0	424
	Tangail	340	70	70	0	10	490
	Mymensingh	336	8	8	0	0	352
	Dinajpur	64	144	8	0	0	216
	Rangpur	8	32	0	8	0	48
	Rajshahi	16	-	-	0	0	16
	Total	1060	342	126	8	10	1546

4.4 Volume Estimates

4.4.1 Sal Forests

Estimated tree volumes in mature sal forest (S5 in Table 7) indicate similar forest conditions in Dhaka and Tangail Divisions (48 and 42 m^3/ha, respectively). The higher volume estimated for Mymensingh Division (71 m^3/ha) may reflect more limited harvesting pressure. Volume estimates are roughly similar for two of the Divisions in North Bengal (70 m^3/ha in Rajshahi and 91 m^3/ha in Dinajpur), indicating generally similar forest conditions.

Table 7
Volumes in management classes S5, S6 and S7

Forest Division	Management Class S5		Management Class S6		Management Class S7	
	m^3/ha	SE (%)	m^3/ha	SE (%)	m^3/ha	SE (%)
Dhaka	48.1	2.6	37.3	6.5	454.7	11.1
Tangail	41.5	3.7	45.7	3.1	76.4	8.1
Mymensingh	70.8	5.1	52.9	3.0	45.3	8.5
Dinajpur	91.1	6.4	60.3	5.9	64.5	16.0
Rangpur	275.4	24.1	62.6	13.2	56.1	24.2
Rajshahi	70.5	12.1	59.3	25.2	10.0	100.0
Total	53.6	2.1	48.5	2.0	55.3	5.4

The high volume estimate for Rangpur Division (275 m^3/ha) reflects the presence of sal trees that are much older than in other Divisions. Eight of the volume plots in Rangpur were located in the Hatibanda sal forest, where there is a small patch of large trees around the Beat Office. Similarly, a majority of the volume plots in Dinajpur were from sal forests of large size trees in Thakurgaon Range.

The planned standard error of volume estimates (maximum 10% at 95% probability) was reached in Dhaka, Tangail, Mymensingh and Dinajpur Divisions and was only slightly exceeded in Rajshahi Division, indicating that the derived estimates are reasonably reliable. The high standard error for Rangpur Division reflects the small area of sal forest and low number of volume plots in this Division.

Although local people estimate that many mature sal forests are more than 20 years old, no official records are available. Dominant height and diameter measurements can, however, provide a rough estimate of sal forest age.

4.4.2 Woodlots and Agroforestry

Estimated volumes in woodlots (S6) are between 37 and 53 m^3/ha in the central (Dhaka, Tangail, Mymensingh) Divisions, with a trend toward somewhat higher volumes in the northern (Dinajpur, Rangpur, Rajshahi) Divisions, although it should be noted that in the latter areas standard errors are high (Table 7). During field visits it was noted that most of the plots have not been thinned, resulting in reduced diameter development.

Volumes in agroforestry (S7) areas are highly variable, ranging from <50 to >450 m^3/ha, but averaging 55 m^3/ha (Table 7). Considering the large parts of these areas which lack trees completely, shifting of plots to stocked parts of the agroforestry areas by field crews is likely to have occurred, and the resultant data are probably biased toward increased values. Also, the standard plot size of 100 m^2 used in the inventory is not adequate for description of areas under agroforestry, where 10 m radius (area 314 m^2) plots would be more suitable.

4.5 Regeneration

All growth stages of sal forest (S3-S5) have high numbers of seedlings (Table 8), indicating profuse regeneration. Calculated seedling densities vary from a low of 7785/ha (in Mymensingh S3) to a high of 40,506/ha (in Dinajpur S3).

Table 8
Density of seedlings, saplings and small trees by management class and Forest Division

Forest Division	Management Class	Seedlings/ha			Saplings/ha			Small trees/ha		
		Sal	Others	Total	Sal	Others	Total	Sal	Others	Total
Dhaka	S2	199	724	923	0	18	18	0	0	0
	S3	30,098	519	30,617	3269	109	3378	422	0	422
	S4	25,140	307	25,447	3483	182	3665	2397	9	2406
	S5	21,539	544	22,083	937	125	1062	1091	23	1114
	S6	2164	1895	4059	459	106	565	425	752	1177
	S7	3906	751	4657	150	135	285	451	661	1112
Tangail	S2	25	0	25	3	0	3	3	0	3
	S3	30,012	442	30,454	2101	44	2145	354	0	354
	S4	25,825	214	26,039	2838	51	2889	2695	82	2776
	S5	23,773	235	24,007	985	155	1140	1276	141	1417
	S6	1557	813	2370	101	51	152	250	644	894
	S7	1982	4485	6467	49	97	146	65	764	829
Mymensingh	S2	0	0	0	0	0	0	0	0	0
	S3	7785	0	7785	708	0	708	0	0	0
	S4	25,023	872	25,895	4170	190	4360	2009	114	2123
	S5	19,574	475	20,048	1038	230	1268	808	31	839
	S6	2819	134	2953	372	130	502	130	532	662
	S7	271	0	271	0	109	109	579	290	869
Dinajpur	S3	40,506	0	40,506	498	0	498	0	0	0
	S4	13,004	7962	20,966	2123	0	2123	531	0	531
	S5	20,848	911	21,759	723	18	741	442	97	538
	S6	2574	487	3061	206	69	275	24	566	590
	S7	0	265	265	0	147	147	0	855	855
Rangpur	S2	0	0	0	0	0	0	0	0	0
	S5	8260	8858	17,118	1294	0	1294	1194	0	1194
	S6	0	78	78	0	157	157	0	505	505
	S7	0	0	0	0	133	133	0	531	531
Rajshahi	S5	16,720	0	16,720	2189	0	2189	945	0	945
	S6	1083	0	1083	96	318	414	32	1656	1688
	S7	0	0	0	0	398	398	0	796	796

Saplings also are present in all growth stages of sal forest, indicating continuing regeneration. Although numbers of saplings are much lower than numbers of seedlings, they are still consistently above 2000/ha in mid-aged (S4) forests, ranging from 2123/ha in Dinajpur to 4360/ha in Mymensingh (Table 8).

Number of small trees tends to be highest in the mid-aged forests classified as S4, ranging from 531/ha in Dinajpur to 2776/ha in Tangail. Small trees also are relatively abundant in mature sal forests (S5), where they comprise a middle story.

Sal is overwhelmingly the predominant species in all management classes of sal forest (S3-S5) and at all growth stages (seedling-small tree). Other species are far less abundant, although present in all Divisions.

It is noteworthy that regeneration, in the form of seedlings, saplings and small trees of sal and other species, is present, sometimes in abundance, in woodlots (S6) and agroforestry (S7) areas.

4.6 Inventory Documentation

Complete documentation of the results of the sal forest inventory is provided in tabular form in Volumes 2-6 accompanying this report. These are:

Volume 2: Summary for all Sal Forest Divisions Combined

Volume 2 contains the following tables:

Table I: Summary of plot data by management class (6 management classes (S2-S7))

Management class, number of volume plots, dominant height, area in hectares, seedlings per ha, saplings per ha, small trees per ha, trees per ha, mean dbh, basal area per ha, sal volume per ha, volume of other trees per ha, standard error of total volume per hectare.

Table II: Summary of plot data by management class (10 management classes (S2-S7, and dividing mature sal forest (S5) into 5 height subclasses as follows: 5.0 m < h < 7.99 m, 8.0 m < h < 10.99 m, 11.0 m < h < 13.99 m, 14.0 m < h < 17.99 m and > 18.0 m)

Management class, number of volume plots, dominant height, area in hectares, seedlings per ha, saplings per ha, small trees per ha, trees per ha, mean dbh, basal area per ha, sal volume per ha, volume of other trees per ha, standard error of total volume per hectare.

Table III: Summary of mature sal forest (S5) composition by species and dbh class

Species name, number of volume plots, number of trees measured, dominant height, estimated area in hectares for the whole country, number of sal and other trees and their total volume per ha in dbh classes < 10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25+ cm.

Table IV: Summary of damage, infestation and stem quality in mature sal forest (S5) by species

Species name, number of volume plots, number of trees measured, dominant height, number of trees per hectare, and percentage of trees in each damage, infestation and stem quality class.

Table V: Summary data for woodlots and agroforestry areas by species

Species name, number of volume plots, dominant height, estimated area in hectares, number of sal and other trees and their total volume in dbh classes <10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25+ cm.

Table VI: Summary of damage, infestation and stem quality in woodlots and agroforestry areas by species

Species name, number of volume plots, dominant height, estimated area in hectares, number of trees per hectare, and percentage of trees in each damage, infestation and stem quality class.

Table VII: Summary of species details by Forest Division

Division, species name, number of volume plots, dbh, volume, basal area, dominant height and form factor.

Volume 3: Dhaka Forest Division
Volume 4: Tangail Forest Division
Volume 5: Mymensingh Forest Division
Volume 6: Dinajpur, Rangpur and Rajshahi Forest Divisions

Each of Volumes 3-6 contains the following data tables categorised by Forest Division:

Table VIII: Summary of Divisional plot data by management class (6 management classes (S2-S7))

Management class, number of volume plots, dominant height, area in hectares, seedlings per ha, saplings per ha, small trees per ha, trees per ha, mean dbh, basal area per ha, sal volume per ha, volume of other trees per ha, standard error of total volume per hectare.

Table IX: Summary of Divisional plot data by management class (10 management classes (S2-S7, and dividing mature sal forest (S5) into 5 height subclasses as follows: 5.0 m < h < 7.99 m, 8.0 m < h < 10.99 m, 11.0 m < h < 13.99 m, 14.0 m < h < 17.99 m and > 18.0 m)

Management class, number of volume plots, dominant height, area in hectares, seedlings per ha, saplings per ha, small trees per ha, trees per ha, mean dbh, basal area per ha, sal volume per ha, volume of other trees per ha, standard error of total volume per hectare.

Table X: Divisional data on mature sal forest (S5) composition by species and dbh class

Species name, number of volume plots, number of trees measured, dominant height, estimated area in hectares for the whole country, number of sal and other trees and their total volume per ha in dbh classes < 10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25+ cm.

Table XI: Divisional data on damage, infestation and stem quality in mature sal forest (S5) by species

Species name, number of volume plots, number of trees measured, dominant height, number of trees per hectare, and percentage of trees in each damage, infestation and stem quality class.

Table XII: Divisional data for woodlots and agroforestry areas by species

Species name, number of volume plots, dominant height, estimated area in hectares, number of sal and other trees and their total volume in dbh classes <10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25+ cm.

Table XIII: Divisional data on damage, infestation and stem quality in woodlots and agroforestry areas by species

Species name, number of volume plots, dominant height, estimated area in hectares, number of trees per hectare, and percentage of trees in each damage, infestation and stem quality class.

Each of Volumes 3-6 contains the following data tables categorised by Forest Division and Range:

Table XIV: Summary of Divisional plot data by management class, categorised by Range (6 management classes (S2-S7))

Management class, number of volume plots, dominant height, area in hectares, seedlings per ha, saplings per ha, small trees per ha, trees per ha, mean dbh, basal area per ha, sal volume per ha, volume of other trees per ha, standard error of total volume per hectare.

Table XV: Summary of Divisional plot data by management class, categorised by Range (10 management classes (S2-S7, and dividing mature sal forest (S5) into 5 height subclasses as follows: 5.0 m < h < 7.99 m, 8.0 m < h < 10.99 m, 11.0 m < h < 13.99 m, 14.0 m < h < 17.99 m and > 18.0 m)

Management class, number of volume plots, dominant height, area in hectares, seedlings per ha, saplings per ha, small trees per ha, trees per ha, mean dbh, basal area per ha, sal volume per ha, volume of other trees per ha, standard error of total volume per hectare.

Table XVI: Divisional data on mature sal forest (S5) composition by species and dbh class, categorised by Range

Species name, number of volume plots, number of trees measured, dominant height, estimated area in hectares for the whole country, number of sal and other trees and their total volume per ha in dbh classes < 10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25+ cm.

Table XVII: Divisional data on damage, infestation and stem quality in mature sal forest (S5) by species, categorised by Range

Species name, number of volume plots, number of trees measured, dominant height, number of trees per hectare, and percentage of trees in each damage, infestation and stem quality class.

Table XVIII: Divisional data for woodlots and agroforestry areas by species, categorised by Range

Species name, number of volume plots, dominant height, estimated area in hectares, number of sal and other trees and their total volume in dbh classes <10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25+ cm.

Table XIX: Divisional data on damage, infestation and stem quality in woodlots and agroforestry areas by species, categorised by Range

Species name, number of volume plots, dominant height, estimated area in hectares, number of trees per hectare, and percentage of trees in each damage, infestation and stem quality class.

Each of Volumes 3-6 contains the following data tables categorised by Forest Division, Range and Beat:

Table XX: Summary of Divisional plot data by management class, categorised by Range and Beat (6 management classes (S2-S7))

Management class, number of volume plots, dominant height, area in hectares, seedlings per ha, saplings per ha, small trees per ha, trees per ha, mean dbh, basal area per ha, sal volume per ha, volume of other trees per ha, standard error of total volume per hectare.

Table XXI: Divisional data on mature sal forest (S5) composition by species and dbh class, categorised by Range and Beat

Species name, number of volume plots, number of trees measured, dominant height, estimated area in hectares for the whole country, number of sal and other trees and their total volume per ha in dbh classes < 10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25+ cm.

Table XXII: Divisional data on damage, infestation and stem quality in mature sal forest (S5) by species, categorised by Range and Beat

Species name, number of volume plots, number of trees measured, dominant height, number of trees per hectare, and percentage of trees in each damage, infestation and stem quality class.

Table XXIII: Divisional data for woodlots and agroforestry areas by species, categorised by Range and Beat

Species name, number of volume plots, dominant height, estimated area in hectares, number of sal and other trees and their total volume in dbh classes <10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25+ cm.

Table XXIV: Divisional data on damage, infestation and stem quality in woodlots and agroforestry areas by species, categorised by Range and Beat

Species name, number of volume plots, dominant height, estimated area in hectares, number of trees per hectare, and percentage of trees in each damage, infestation and stem quality class.

Table XXV: Plot details by Division, Range and Beat

Map/line/plot number, management class, species, average dbh, dominant height, trees per ha, volume per ha, longitude and latitude.

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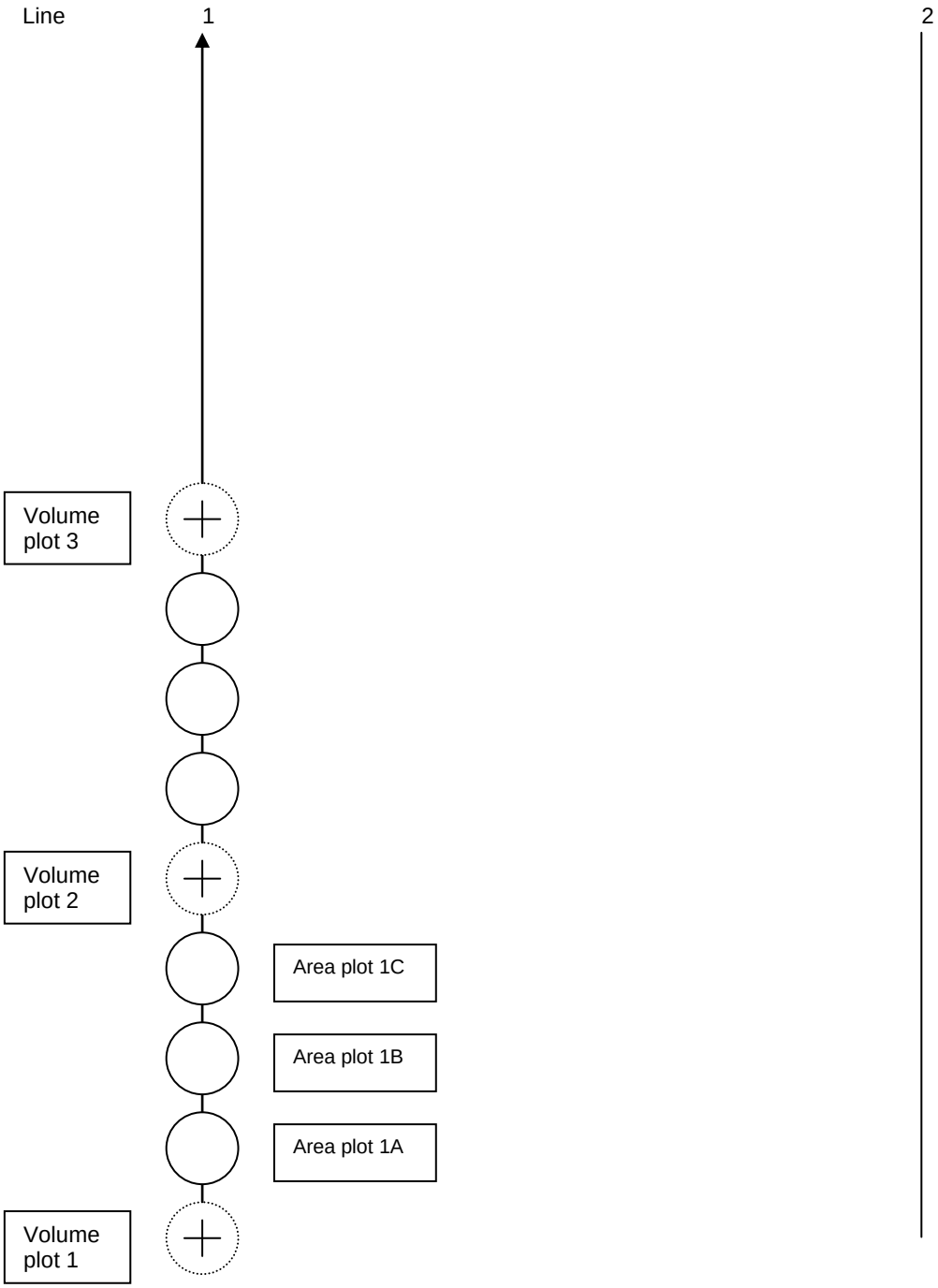
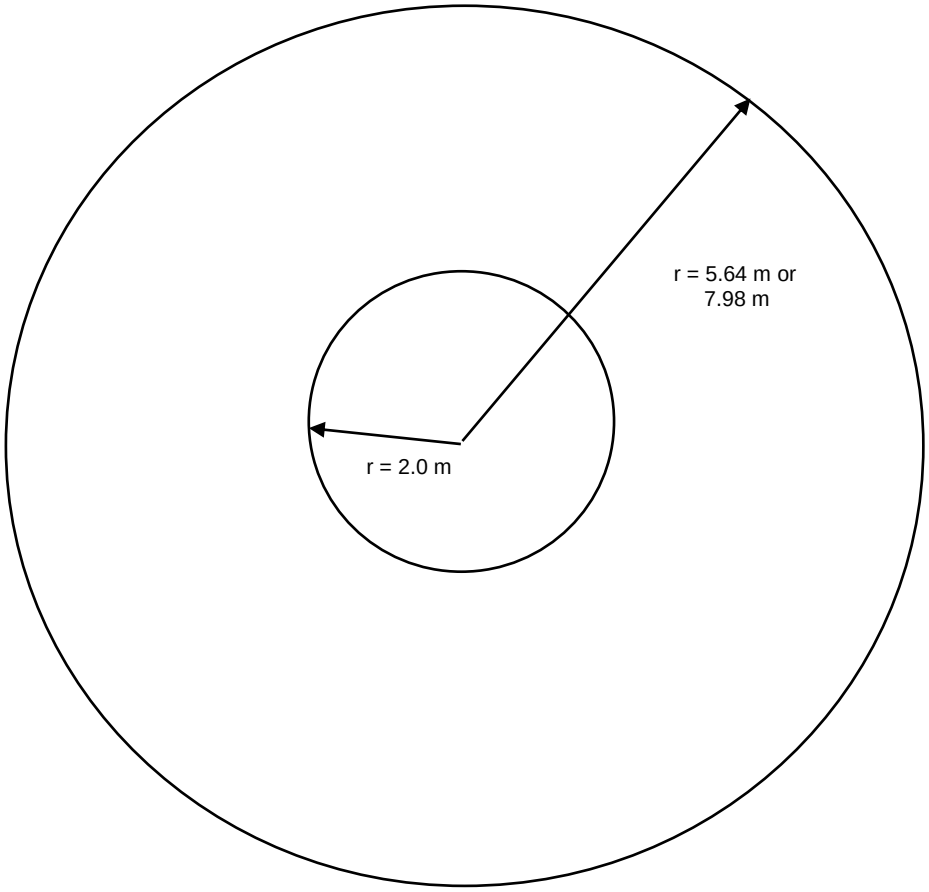
Latif, M. A., S.S. Islam, and J. Davidson. 1986. Metric volume tables for some tree species found in the natural forests of Bangladesh. Inventory Division, Bangladesh Forest Research Institute, Chittagong. Bulletin No. 6. 79 pp.

APPENDIX 1
PLOT LAYOUTS AND DATA SHEETS

Schematic diagram of line, volume and area plot layouts



Distance between lines = 400 m (500 m in Tangail Division)
Distance between volume plots = 200 m
Distance between area plots = 50 m
Volume plot radius = 5.64 m, area = 100 m^2 in Dhaka, Tangail and Mymensingh Divisions; radius =7.98 m, area = 200 m^2 in Dinajpur, Rangpur and Rajshahi Divisions. Management class was recorded within the same radius as for area plots (see below).
Area plot radius = 17.84 m, area = 0.1 ha in all Divisions



Schematic diagram of volume and regeneration plots

Volume plot (radius = 5.64 m, area = 100 m^2 in Dhaka, Tangail and Mymensingh Divisions; radius =7.98 m, area = 200 m^2 in Dinajpur, Rangpur and Rajshahi Divisions): dbh of all trees with dbh≥10.0 cm and height of two trees were measured

Regeneration plot (radius = 2.0 m): number of seedlings, saplings and small trees were recorded

Data Sheet for Volume Plots

Volume plot					
Division		Range		Map ID	
Management class		Species		Beat	
Forest fire		Dom. Height		Line	
% of plot		O↑N		Plot	

Regeneration and small trees < 10 cm DBH			
	Number by height class		
Species	< 1.5 meter	> 1.5 meter	DBH: 5 – 9.9 cm
Sal			
Others			

Individual trees				
Tree #	Species code	DBH (cm) xx.x	Total height (meter) xx.x	Tree status code

Distance and direction to the nearest tree from plot center: ……
Group # ……
Date:……..

_____
Signature

Data Sheet for Area Plots

Area plot					
Division		Range		Map ID	
Management class		Species		Beat	
Forest fire		Dom. Height		Line	
% of plot		O↑N		Plot	

Area plot					
Division		Range		Map ID	
Management class		Species		Beat	
Forest fire		Dom. Height		Line	
% of plot		O↑N		Plot	

Area plot					
Division		Range		Map ID	
Management class		Species		Beat	
Forest fire		Dom. Height		Line	
% of plot		O↑N		Plot	

Group # ……
Date:……..

_____
Signature

Management classes:

S1 Private/encroached areas
S2 Grass/degraded former forest land (less than 100 stems/ha)
S3 Young re-growth of sal (h < 1.5 m)
S4 Immature sal forest (h = 1.5 m – 5 m)
S5 Mature sal forest (h > 5 m)
S6 Woodlot
S7 Agroforestry

Heights refer to mean heights. Heights of dominant trees may be higher (*e.g.*, up to 6-7 m in S4).

Tree status:

Damage

1 No visible damage
2 Slightly damaged: tree will survive
3 Heavy damage: tree will die
4 Uprooted
5 Felled
6 Broken below 3 m
7 Dead

Infestation

1 No infestation
2 Insect infestation
3 Climbed by rattan
4 Slightly infested by climbers
5 Severely infested by climbers
6 Infested with mistletoe (*Loranthus* sp.)
7 Others

Stem quality

1 Straight bole
2 Slightly bent or crooked >1/2 of tree usable
3 Crooked >1/4 of tree usable
4 Not usable for timber/pole

Site and species codes are included in:

Sylvander, R. and M.A. Latif. 1999. An inventory design for the sal forests of Bangladesh. Forestry Sector Project (1997/8 – 2003/4), Forest Department, Ministry of Environment and Forests, Dhaka. ADB Project BAN No. 1486. TECSULT in association with SODEV, NRP, HCL and EPC.

APPENDIX 2
VOLUME FUNCTIONS USED FOR SAL FOREST INVENTORY

Natural Forest

Code

1 Sal (*Shorea robusta*)
Dhaka Division (code 13), Tangail (12) and Mymensingh (10) combined:
$V = 0.00010347 \times D^{2.501816}$
North Bengal (codes 01, 02, 03): $V = 0.00017448 \times D^{2.403486}$

2 Kaika (*Adina cordifolia*): $V = 0.0003208 \times D^{2.1338}$

3 Koroi (*Albizia procera*): $V = 0.0009847 \times D^{2.502194}$

5 Shimul (*Bombax ceiba*): $V = 0.0002114 \times D^{2.3088}$

15 Jam (*Syzygium nervosum*): $V = 0.00552016 - 0.0028213 \times D + 0.0007843 \times D2$

16 Bohera (*Terminalia bellirica*): $V= 0.0003208 \times D^{2.1338}$

17 Others: $V = 0.0005131 \times D^{2.08627}$

Plantations

21 Akashmoni (*Acacia auriculiformis*): $V= 0.000272465 \times D^{2.2389}$

22 Mangium (*Acacia mangium*): $V = 0.0002721 \times D^{2.2178}$

23 Minjiri (*Cassia siamea*): $V = 0.00018374 \times D^{2.4038}$

24 *Eucalyptus*: $V= 0.0002043 \times D^{2.38682}$

25 Gamari (*Gmelina arborea*): $V = 0.0003699 \times D^{2.1472}$

26 Segun (*Tectona grandis*): $V= 0.00051676 \times D^{2.12337}$

27 Arjun (*Terminalia arjuna*): $V= 0.00017605 \times D^{2.222144}$

28 Others: $V = 0.0005131 \times D^{2.08627}$

APPENDIX 3
DEFINITIONS, FORMULAE AND CALCULATIONS USED FOR PLANNING AND PROCESSING OF SAL FOREST INVENTORY DATA

DATA PROCESSING

Mean diameter: $\Sigma Di /n$, where n= number of trees and Di = diameter of each tree expressed in cm. Note that this refers only to trees larger than 10 cm dbh. In mixed stands mean diameter is calculated for each species. Also separate estimations for mean diameter are made on a plot and stratum basis since the weight of each plot is different depending on number of trees.

Basal area: sum of the cross-sectional area of trees at breast height (1.3 m above ground level), normally expressed in m^2/ha.

To calculate basal area in m^2 from tree and plot data recorded in cm, $\pi\Sigma (Di)^2 /4$ per tree is divided by 10,000. Sum of basal areas of all trees is multiplied by a factor of 100 (50 in North Bengal) to obtain basal area in m^2/ha.

Volume per ha: to obtain volume per ha, the basal area is multiplied by mean height and a form factor of 0.5.

Standard error for volume per ha: $S/\sqrt{n}$ (calculated as standard deviation of volume per ha per plot in m^3 (S) divided by square root of number of plots).

Relative standard error (SE%): $CV\% / \sqrt{n}$ (calculated as (S/m x 100 divided by square root of number of plots, where CV = coefficient of variation of volume, m= mean volume/ha, and n=number of plots).

Volume per plot: $V = \Sigma Vi /n$, where Vi = total volume on each plot and n = number of plots.

Total volume for each Division is obtained by multiplying area estimate for each management class by volume per ha for that class.

PLANNING

Some of these formulae were used in planning the inventory, as follows:

- based on experience from Sweden and observations during planning field visits to sal forest areas, assumed CV%=80.

- to calculate required number of plots (n) at a standard error of 5%, the formula is:

$$80\%/\sqrt{n} = 5\%$$
$$\Rightarrow n = 80^2/5^2 = 256$$
$$n = 256$$

This means that a minimum of 256 plots is required for reliable volume estimations of the important management classes in each Forest Division, assuming confidence limits of 10% (+/- 2 SE) with 95% probability.

Strictly speaking there are no generally applicable formulae for estimation of standard errors using systematic sampling in forestry. However, experience from Sweden and other countries shows that in most cases an overestimation of standard errors is obtained by use of the formula for random sampling, as used in this inventory.