4 FOREST INVENTORY

4.1 PLANNING AND EXECUTING A FOREST INVENTORY

An inventory of a forest area can provide information for many different purposes; it may be part of:

- a natural resource survey with the aim of allocating land to different uses, i.e. land planning
- a national project to assess the potential for forest and wood-based industry development
- a wood-based industry feasibility study
- a management plan for a forest, *either*
  - — providing information as a basis for long term planning, *or*
  - — providing information for short term programmes such as a schedule of compartments or crops to be felled or thinned each year

Natural resource surveys require information on the location, extent and type of forest and wood resources, but need only relatively imprecise information on quantities, that is m^3, and only a crude classification by quality, that is, perhaps, forest types or species groups with similar wood properties rather than individual species. Most of this information can be obtained from up-to-date maps and aerial photographs, supported by a small amount of field work.

National projects to assess the potential for wood using industry and wood-based industry feasibility studies require more precise information on the location, quality and quantity of raw wood material. The area from which wood can be supplied to an industry, either on a sustained basis or for a limited period, may be called its 'wood catchment area'. For example, on a sustained yield basis a 200,000 tonne a year pulp mill will need a larger catchment than a 60,000 tonne a year particle board mill; or a plywood mill salvaging large over-mature trees and requiring 10,000 tonnes of veneer logs a year will need a larger catchment area if production is planned to last 15 years than if it is to be closed after only seven years. If the location and size of the industrial complex being planned is uncertain, then a comprehensive feasibility study will require information about the resource in each of the locations under consideration, and for different sized catchment areas at each. Careful planning and choice of inventory design and efficient inventory planning are needed to minimize costs and obtain satisfactory results.

Forest management planning may concern either or both of two time horizons:

- a long term approach, often as long as the rotation period of the crops
- a shorter term, often up to 5 or 10 years, for which relatively detailed programmes will be designed

Two sets of information may be needed – general information on area, species and growth rates for the whole forest, and more detailed information on those stands that may be partially or wholly harvested in the planning period, and their predicted outturn of forest produce.

Whatever the purpose and scale, forest inventory provides only part of the information required by the planner and manager, that is the part concerning the growing stock of trees. The remainder, for example information on markets, prices, labour costs, etc. must be obtained from other sources and surveys. Very often a forest inventory is only part of a whole system of information collection, and must be seen and designed with the overall purpose in mind.

Inventories for forest management planning are usually one of two types:

- a single inventory to provide information on the current growing stock and rates of growth
- a recurrent inventory to monitor growth rates and other changes in the forest. The design of this type must allow comparisons of the results from successive measurements made at relatively short intervals – say 5–10 years

Inventories for planning harvesting: the capital investment needed for modern harvesting operations and road construction is now very large. Decisions on the method of felling extraction and haulage and on the spacing and alignment of roads are now more critical in efficient management of the forest and wood-based industry than ever before. Effective decision making usually needs particular and accurate information so special surveys are frequently required; for example in tropical evergreen lowland forest harvest planning may entail identifying, locating and measuring all marketable trees within the current year's felling area in order to plan road making, extraction, log loading points, transport, processing and marketing.

These very different objects in the different categories of resource survey and forest inventory necessitate different methods, but all have in common the need for efficient inventory planning if the information required is to be obtained accurately and efficiently.

There are also two schools of thought about the strategy of inventory planning. In one, as advocated by Frayer (1974), the uncertainty concerning the information actually required by future forest managers and planners dictates that field data collection should err on the side of comprehensiveness. Frayer argues that the major element in the cost of field data collection is in the planning, organization and time spent on reaching the sampling unit and that, once there, the marginal cost of collecting additional information is low. The argument is developed to advocate the most comprehensive form of data collection, even without plans for its immediate use. For example, this school would advocate enumerating all species and size of woody plants (though, of course, not necessarily all at the same sampling intensity) in tropical evergreen forest, even though most were unmarketable. In contrast, Philip (1976) stresses that the useful life of information collected in the course of a forest inventory is relatively short, and emphasizes the speed needed in the execution of an inventory if the staff are to maintain their enthusiasm and accuracy. Philip concludes that only data whose use and analysis have been planned should be collected. He assumes that should additional information be required, then it may be collected efficiently using regression estimates linked to information already available. For example, if a survey is done omitting species *X*, but an associated species *Y* has been included, then supplementary information about *X* may be estimated efficiently using a new sub-sample to define the relationship between *X* and *Y*. Normally there is no need to re-enumerate the whole forest.

In tropical countries, especially in tropical moist evergreen forest with its complex flora, and where there is a shortage of workers trained in inventory field techniques, limited inventory objects and limited data collection regimes are more appropriate than more comprehensive schemes of data collection. None the less in some long term surveys monitoring changes – especially changes whose exact nature cannot be clearly foreseen, a broader approach may be desirable (Dawkins, 1978). Also, inventories may be planned as a complete exercise, or as part of a programme that will continue to provide updated information to managers over a long period, i.e. continuous or recurrent inventory.

The professional staff involved in planning and executing a forest inventory may need training to acquire extra skills in:

- cartography, aerial photographic interpretation and photogrammetry (Spurr, 1960; Howard, 1991; Avery & Berlin, 1992)
- statistical principles and analyses, and data capture and processing techniques
- tree and crop mensuration techniques
- planning, budgeting and financial forecasting
- man management
- costing, operation control, and experience in the logistics of maintaining and controlling inventory crews in the field
- mechanical engineering to maintain vehicles, equipment, etc.

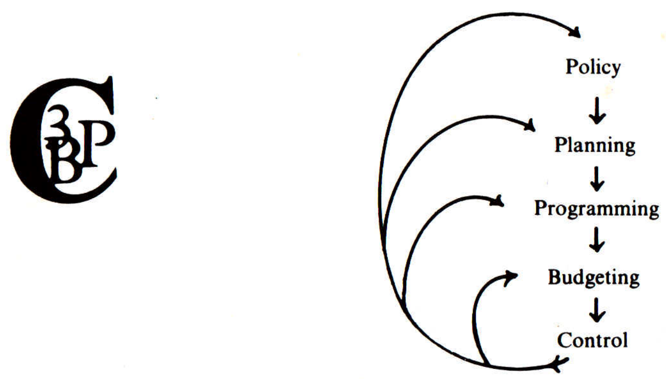
The information derived from an inventory may be used over a period of several years and the penalty resulting from errors in that information may be high. Careful planning is needed to ensure that the objects of the inventory are achieved as efficiently as possible. Failure in either planning or execution can result in:

- inaccurate estimates
- incomplete information
- excessive cost

The methods employed in a particular inventory, a record of the experience gained and the results must be recorded in an inventory report. It is very important to give the reasons behind the decisions and, especially, for any unusual procedures. Then once the inventory has been completed the efficacy of the plan can be assessed and the correctness of assumptions checked. Such reports are then sources of information in planning later inventory operations in the same or similar areas. The following format and headings for such an inventory report will help the inexperienced inventory planner to foresee and avoid some of the difficulties that otherwise might lower the effectiveness and efficiency of the work. However, the stages in planning are not distinct and cannot be ordered; for example a realistic estimate of the cost of providing the information needed to satisfy the objects at first declared may force the planners to re-define the objects.

One useful approach common to many planning situations is summarized in Figure 43.

FIGURE 43 Planning



The 3PBC mnemonic reminds the planner of the five important heads. *The links between the letters* imply that the planning process is continuous or dynamic and the enclosure of the 3PB within the C stresses the importance of the controls.

The main purpose of the head *policy* is to ensure that the objects of the inventory are both defined and agreed among all concerned. *Planning* involves the choice of methods to be employed. *Programming* details the procedures and their order and timetable, whereas the provision of staff, materials, money and management required to complete the programmes are included in the *budget*. *Controls* compare actualities and predictions to provide a continuous monitoring system to ensure that wrong assumptions are identified and their implications to the programme recognized as soon as possible and incorporated into revised plans, programmes and budgets. Vanclay (1992) summarizes many considerations in inventory planning in his article entitled 'Before you begin your inventory'.

Further reading

ON FOREST INVENTORIES

Goulding, C.J. & Lawrence, M.E. (1992) *Inventory Practice for Managed Forests.* FRI Bulletin No. 171, Rotorua, New Zealand.

Lanly, J.P. (1973) *Manual of Forest Inventory, With Special Reference to Mixed Tropical Forests.* FAO, Rome.

4.1.1 The Inventory Report – Part I

The aim of this part of the report is to ensure that the inventory produces the desired information and results efficiently. The following outline provides a check list of topics to be considered and decisions to be taken. The items in the outline are:

- objects
- sources of information
- field measurements and ready reckoners
- statistical considerations
- staff management
- training field teams
- field staff
- field instructions
- field checks and controls
- management of the inventory teams in the field
- calculations, analyses and data capture
- programmes, budgets and logistics

4.1.1.1 *Objects*

The objects of the inventory must be defined unambiguously, written down and agreed by all concerned. They must be feasible – that is framed within any constraints such as the amount of money available – and may have to be revised if new demands are made on the inventory or new information is collected during the preliminary planning stages. Often those initiating the inventory – particularly where it is part of a wider natural resources survey, or land planning exercise or an industrial feasibility study – are unfamiliar with the techniques, difficulties and costs of forest inventories; in such cases the objects may have to be defined by the forest inventory planner himself. Nevertheless the complete understanding of and agreement to the objects must be sought from those who will use the information collected.

In addition to the general objects, the geographical limits to the area to be surveyed and the definitions of the species and tree sizes to be included must be stated. The limits of the resources available – such as money, time, supervisory and technological skills, etc. – must be given and, if necessary, the maximum tolerable level of sampling errors must be set. It is feasible that the constraint on the money available will conflict with this maximum sampling error; then, either more money must be provided or a relaxation in the maximum sampling error permitted must be agreed.

Clarification of the objects is aided by the design and presentation of an outline of the final inventory report including the form and tabulation of the results. For example, in an inventory of tropical high forest the format of the table showing the stand structure by species, species groups and diameter classes should be presented so that no misunderstandings about the species to be included, their groupings, and the limits to the size classes are possible.

4.1.1.2 *Sources of Information*

Assembly and digestion of the information already available about an area are essential. Common sources are

- maps – topographical, geological, soil and vegetation
- aerial photographs and other imagery such as SLA (Side Looking Airborne) radar or satellite imagery
- reports from previous inventories
- forest records

If these sources are inadequate then pilot surveys to collect data on species and size frequencies and variances will be essential. Nowadays extensive forest inventories of natural vegetation or intensive inventories of plantations are rarely done without recent aerial photographs or other imagery and up-to-date maps – often made from aerial photographs. If these are not available then their procurement must be included in the planning procedures and budgets.

4.1.1.3 *Field Measurements and Ready Reckoners*

The choice and definition of the population and parameters to be included in the inventory has to be made. Also the precise field techniques and procedures must be decided and written into field instructions, for example:

- the point of measurement on buttressed trees
- the definition of the point of measurement for height, e.g. total height, or timber height, or bole length
- the treatment of forked or defective stems

These decisions must be derived from the nature of the final output desired from the inventory, for example:

- if diameter distributions are required, then total basal area estimates from relascope sweeps alone will not be adequate
- if volumes per tree or per hectare are required, then the means of estimating volume and the field measurements needed will depend upon the types of ready reckoner such as volume tables or volume equations, available. If such ready reckoners are not available and are needed, then the inventory plan must include the collection of data, their analysis and the calculations needed to prepare them. Alternatively detailed and precise

instructions must be given to the field staff to measure volume directly – by height accumulation or other techniques

4.1.1.4 *Statistical Considerations* (see Chapter 5 for more detailed considerations)

Decisions on sampling concern

- the design or pattern of sampling
- the nature of the sampling units used
- the statistical analyses and the calculation of estimates and, where required, their precision

Often the assistance of a forest statistician or biometrician is needed. The design also concerns

- subdivision of the inventory area into more homogeneous parts
- the choice between using subjective and objective selection of the sampling units
- the choice between systematic and random sampling designs if objectivity is required

Considerations of the nature of the sampling units include:

- the choice of sampling unit – plot, point, transect, etc.
- the choice of shape of the sampling unit – circular, square, rectangular, etc.
- the choice of the size of the sampling unit

These and similar considerations affect enormously the cost effectiveness of the inventory. To make rational choices requires a great deal of detailed information – both statistical and logistic; much of this information may have to be collected in preliminary pilot trials, though some may be derived from accounts of inventories in similar conditions elsewhere.

4.1.1.5 *Staff Management*

Forest inventory is usually onerous, laborious and somewhat boring and is frequently done in remote areas and in harsh physical conditions with additional hazards from heat, rain, noxious insects, stinging plants, steep terrain, etc. The information collected will only be as good as those who do the field work. Therefore the planner and executive supervisor of the inventory must pay great attention to the morale, well-being and training of the field staff.

One aspect of staff management that must be decided is whether to select and train special teams to be employed on inventory field work for protracted periods and far from their home areas, or whether to train persons to do this work for relatively short periods only, recruited locally near to the inventory area. Usually the second alternative is preferable as the field instructions and training needed for field teams should be made as simple as possible. Sufficient teams should be engaged and trained so that the field work is completed over a relatively short period – 3–6 months – during which time it is feasible to maintain the morale of the teams. However, specialists will also be needed.

The importance of effective personnel management cannot be overstressed. Common complaints of field staff are:

- lack of effective transport
- leaking tents
- irregular payment of salaries
- inadequate protective clothing
- irregular deliveries of food
- inadequate first aid and medical facilities
- inadequate equipment and facilities for its repair and maintenance

In mixed forest such as tropical high forest and miombo woodland, one important constraint is the number of persons available who are capable of identifying species and using somewhat complex optical instruments such as the Spiegel relaskop. Planners must assess such constraints realistically.

Each section or field team contributing to an inventory should be informed of the general outline and programme as well as their own contribution; then, should they be unable to attain their targets, they can contribute to or suggest a feasible revised programme to the planner.

4.1.1.5.1 Training field teams

The skills needed by the staff involved in a forest inventory vary with their responsibilities and the techniques being employed.

Field supervisors commonly need training to acquire extra skills in:

- map reading, surveying and simple appreciation of aerial photographs or other types of imagery
- vehicle, tool and equipment maintenance
- tree measuring and data recording techniques
- botanical identification, specimen collection and preservation techniques

Field workers commonly need training to acquire extra skills in:

- simple ground surveying techniques – such as the correct handling of a prismatic compass and chain or steel band
- tree measuring techniques
- botanical identification

4.1.1.5.2 Field instructions

As, usually, data are collected by a number of persons and field teams working in different areas, precise written instructions are essential to ensure that all use the same procedures so that data from different sources are comparable. Examples of situations that occur commonly in forest inventories and must be foreseen in field instructions are:

- method of sampling unit definition and location – especially action to be initiated when the surveyed location is inaccessible or outside the popu-

lation definition: for example, if the plot is situated in a swamp, or on a road or area of cultivation
- method of boundary survey, especially method of slope correction if the plot is in steep terrain
- method of boundary demarcation and treatment of trees on the boundary
- definition of points of measurement – especially on trees with buttresses, forks or other defects
- procedures for measurement on abnormal stems
- procedures when the tree cannot be identified, etc.

Field instructions are often printed on weather resistant cards or plastic, and may be accompanied by ready reckoners such as:

- slope corrections
- critical distances for trees of different diameters when using an angle gauge
- field keys to assist in botanical identification, etc.

The instructions should also prescribe the precautions and checks to be carried out in the field to establish and correct human errors, and later to protect the data from loss. Data security is a major consideration for inventory planners and supervisors.

4.1.1.5.3 Field checks and controls

Checks of the field records and procedures are essential in order to assess and minimize the frequency and extent of human errors.

Checks mostly consist of repeating the measurements in a number of identifiable sampling units, or parts of units, and comparing the two sets of measurements and records. The frequency of such field checks should be greatest at the start of the inventory and be reduced thereafter as long as the comparison reveals that the standard of work is acceptable. The check reveals the efficacy of the training.

Normally checks should be done by or in the presence of the field team that was responsible for the first measurement – but with an independent supervisor. The inventory and field instructions must detail the checking procedures and frequency and, most important, the limits to the number and types of errors that render the records unacceptable. For example, gross errors must not exceed an average of 1 in 100 or occur more frequently than 2 in 50 observations; totals of additive data for a single sampling unit must not deviate from the check by more than 1%. A gross error may be a species misidentification, omission, addition or a single reading difference greater than, say, 5% of the check. The definition of an unacceptable record is not easy; different measures may require different definitions. For example, the diameter or girth of an irregularly shaped or sharply buttressed bole may be far less precise than that of a plantation grown eucalypt; similarly height measurements are less precise than girth measurements. Checks must cover:

- plot location and identity

- plot demarcation
- tree measurements and identification
- records, etc.

Should a check reveal errors outside the acceptable limits, then the team responsible must be given additional training and their work done since the previous acceptable check must be re-done. No inventory result can be better than the field work from which it was derived, so every effort must be made to collect data without error.

During the period of training, the teams must be taught to check themselves continually and to accept that independent checks are part of the inventory routine. The permanent field supervisor with each team must institute his own random checks many times each day. Checking is done to assess and minimize errors and not just to find fault. A 10% independent check should be the goal of the inventory supervisor.

4.1.1.6 *The Management of the Inventory Teams in the Field*

However good the training and intensive the checking, the field parties will not work well and accurately unless the effectiveness of the rest of the organization matches their own. Human nature is such that high morale among those in the field can only be maintained if they believe that the inventory organizers know of and to some extent share in their difficulties and hardships, and have tried to alleviate them as much as possible. In fact, one additional and very important role of the check done in the presence of an independent supervisor is to provide the opportunity for those responsible for planning and supervision to visit the forest and to be seen working alongside the field teams. At the same time as checking, the supervisors can

- see the forest for themselves
- familiarize themselves with the working conditions at all times and in all parts of the forest
- assess the efficacy of the back up service for the field teams, e.g. provision of food, transport, pay, equipment, etc.
- become familiar to and know the field teams

4.1.1.7 *Calculations, Analyses and Data Capture*

Before the field instructions can be prepared and before training the field teams can begin, the methods of calculation, analysis and data capture must be finalized. Detailed flow charts showing each step should be prepared and, where applicable, appropriate computer programs and data input instructions must be designed and tested. Then, but not before, the technique for data capture can be chosen and the design of the printed forms or other aid to data capture can be finalized. The original field record should be in a form that can be readily re-read, so that the comparison of the original data with that collected in the checking procedure may be compared immediately. Then

- the impact of the check is strong and affects the field teams beneficially
- the result of the check is known immediately
- retaining or repetition of the work can be put in hand without delay
- the field staff can themselves carry out checks additional to those done by the supervisory staff

The use of modern high speed computers for calculation and analysis means that some data items have to be coded; for example, species are given identity numbers. If this encoding is done in the field then the original record should show both the raw uncoded and the coded input so that the coding step itself can be checked.

The security of data against loss is vital but also copying must be avoided if errors are to be minimized. If for any reason field data have to be copied manually then a rigorous and independent check of the accuracy of copying must be done and certified to have been done. If field data are to be kept safe and in good order, field teams must be given adequate resources to ensure this. Good quality paper, water-proof holders for forms in current use and more permanent means for their safe, dry storage to protect and maintain them in correct order are essential. The field supervisors must be trained to ensure correct recording in the field, to check daily for omissions or ambiguity in field records and to store records safely. Safe lines of despatch to the inventory office for calculation, analysis and storage are equally essential.

4.1.1.8 Programmes, Budgets and Logistics

4.1.1.8.1 Schedules of progress and controls

Once the main decisions on the objects of and methods for an inventory have been taken, then follows the task of compiling detailed programmes for:

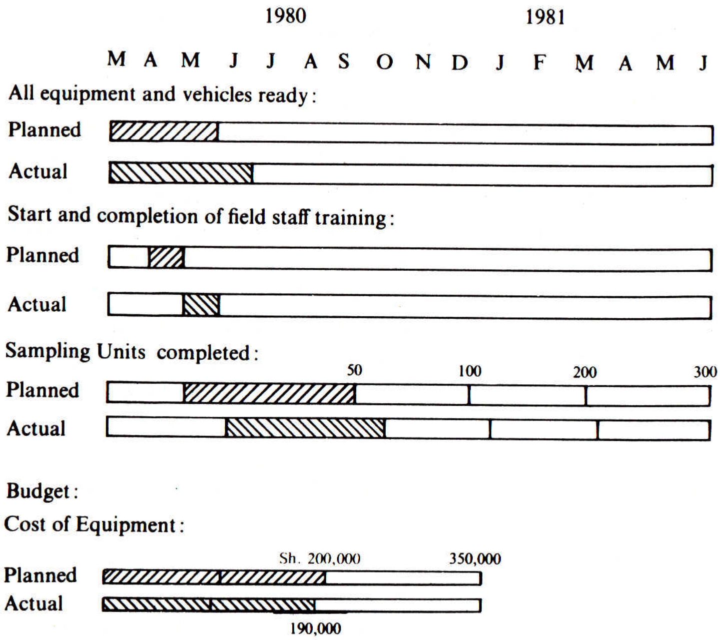
- preliminary organization
- acquisition of information, aids such as maps and aerial photographs, and equipment
- training
- field work
- calculation, analysis and presentation of the results

These programmes then become the bases of continuous control of the progress of the inventory so that the supervisor can compare the actual progress with that expected in the inventory plan. Deviations from the expected will be highlighted in periodic regular reviews and, either additional resources applied to make up lost time, or timetables and targets amended. A visual control chart is illustrated in Figure 44.

4.1.1.8.2 Budgets and control of resources

Inventory uses skilled supervisors, field staff, vehicles, equipment and money, all of which have other uses within the forest enterprise. Hence their allocation to the inventory affects the progress of other works; their use on the inventory must be as effective as possible and must be rigorously controlled to ensure that the allocation is adequate, is used efficiently and is not exceeded.

FIGURE 44 A control of progress in a simple forest inventory



Budgeting commonly refers only to money, but this is too narrow a view. If untimely wet weather interferes with and delays the field work, not only will more money be required to complete the planned amount of data collection, but also persons, vehicles and equipment will be tied up for a longer period and not be available for use elsewhere. Consequently budgets for all these resources must be prepared and maintained through control comparing the planned and actual usages. These then reveal deviations from the plans and allow the initiation of revisions.

4.1.1.8.3 Logistics of staff, transport, equipment, food and other resources

Not only must the plan predict the use of resources but it must also ensure that the resources are available at the right place at the right time. For this an effective organization must be built. This organization must be given realistic and feasible targets and the means to achieve them. Field teams must be supplied with pay, food and transport when and where needed. If they are kept without these supplies then the progress of the field work will falter; similarly, if the field work is delayed then the delivery schedules for supplies will have to be altered at short notice.

Inventories of extensive tracts entail a great deal of transport of personnel, supplies and equipment. The provision and maintenance of an efficient transport service is frequently a key and often difficult task; without such a service the planned progress of the field teams cannot be maintained. The importance of adequate provision, effective planning and tight control of the resources and transport to service the field teams cannot be over-stressed.

4.1.1.8.4 Revision of plans and programmes

The controls built into the budgets and schedules of progress for the inventory provide a continuous flow of information back to the planner, enabling him or her to revise them as necessary to minimize the effect of unforeseen events and changes in the timetable. This continual revision is a normal part of planning and the execution of a plan. For events not to occur as expected is normal and to be anticipated but this does not negate the need for plans or render planning ineffective. Without plans, decisions taken on the spur of the moment may have unforeseen and unwanted consequences that could have been avoided had other feasible courses of action been considered. Part I of the inventory report includes the record of this continuous planning process.

4.1.2 The Execution of the Field Work and its Control

Of equal importance to this background organization is the organization of the field work on whose quality and progress the results of the inventory depend. Throughout the duration of the field work, the field teams will be both collecting data and feeding information on the progress of the inventory and use of resources back to the planner; they will also receive revised programmes, schedules and controls. The repetition here of information already included in Sections 4.1.1.5 to 4.1.1.7 is intended to stress the importance of these considerations both in planning and in execution.

4.1.2.1 Team Management

The success of the inventory will depend largely on the skill of the planner and field supervisors in matching their demands to the resources available – especially the abilities of the persons in the field. Effective personnel management must have a high priority in the training of the field supervisors. The capabilities of the field teams will be greatly enhanced by

- effective training
- effective organization
- adequate and efficient equipment
- good examples from all staff

Close companionship between the planner and those responsible for the tree measurements is essential; then any hardships and failures in the organization supplying the field teams is seen to be known and in part shared by all.

Also inadequacies in the instructions, equipment, etc. can be rectified without delay and the comparability between the work of different teams working far apart can be ensured. The planners must try to work in the field alongside the field teams for at least 10% of the duration of the field work – especially in the early stage. Short flying visits to teams camping in remote areas are ineffective and to be discouraged. As a working rule the duration of a visit to a field team should be at least three days. Then the real daily routine can be experienced. The field staff have time to exchange views with the planner and the planner has the opportunity to be in the field with a team long enough to encounter difficulties that occur only occasionally.

4.1.2.2 *Control of Accuracy*

The field instructions must define the level of errors that render the field work unacceptable. Normal field procedures must incorporate provisions for random checks continuously. For example:

1. On the completion of a field record sheet the field supervisor must check that there are no omissions; the design of the field forms must facilitate this check.

2. The field supervisor must ensure that all operators follow exactly the field instructions and should themselves incorporate continuous random checking by calling for measurements to be repeated. Also the supervisor must ensure the safety of the field records after completion until they are forwarded for calculation of the results.

3. Usually independent checks are done in the presence of an independent supervisor but with the original field team. Discrepancies must be identified immediately by comparing the two records while in the field, and the standard of field work accepted or additional training and repeating of past field work implemented without delay.

4. The frequency of these checks should be greatest early in the period allocated to the field work to ensure that the field training has been effective.

5. A possible and frequently encountered source of large errors is in the demarcation of the sampling unit. If the unit is small, for example 0.04 ha, then any error in the plot area or in the data collected will be exaggerated twenty-five fold when the data are converted to a 'per hectare' basis. Whatever their size, sampling units must be accurately surveyed and carefully demarcated; field checks must include checking this survey and demarcation of sampling units. Small plots can, with advantage, be marked by a continuous string or tape so that the boundaries cannot be mistaken by the measuring crew. Very large plots of long transects must be subdivided both on the ground and in the field records so that checks may be made on portions of a unit, and the measurements unambiguously related to the original records. Objective routines must be devised to ensure that only a representative number or portions of trees growing on plot boundaries are recorded; the details of the routine to be followed in such cases must be set out in the field instructions.

4.1.2.3 *Control, Feedback and Revision of Programmes*

Continuously throughout the periods of preliminary planning, organization and field work, information should flow back to the planner, for example:

- on the progress of flying to obtain special aerial photographic cover
- on the progress in ordering and receiving equipment
- on the progress of recruitment and training of staff
- on the progress of the field work
- on the rate of expenditure, etc.

This flow of information must be compared with the predictions of the plan and the allocations in the budget and schedules of work. Where discrepancies appear, then immediate action should be taken to minimize their effects on the achievement of the objects of the inventory. The earlier the intimation of such upsets the easier it is to revise the plans and programmes to cope.

Normally such information from the field is received in routine progress reports; consequently these must be submitted without delay. Each field team must know its own part in the whole programme and be in a position to suggest any remedial action or programme revision necessary.

4.1.2.4 *Security of Data*

Only in exceptional circumstances should original field data be copied by hand. If, owing to rain, the original field sheet is damaged, then a copy must be made immediately. The copy must be checked by an independent person against the original and the two copies attached together. As, normally, there will only be one copy of the field data, its security is very important. Field forms must be numbered to provide an unambiguous identity and stored in weather-proof, hard-backed ring files. Careful attention to the correct identification on field forms and their security while still in the field must be stressed during the training period.

The data are at risk both while in the field and during transit to the computing centre. Data must be available in the field for the purpose of the random check of accuracy. Immediately after, the data should be transferred to the computing centre – usually in the care of a senior officer. Precautions against loss during transit through a road accident or other mishap must be considered carefully. All supervisors must ensure that the instructions covering the security of data are followed without omission.

4.1.3 The Inventory Report – Part II

This second part of the inventory report summarizes the results and also the experience gained – that is experience in planning, in field work, and in the records obtained from the inventory on such aspects as:

- costs
- rate of progress in field work

- variances of different parameters in different crops
- success of recommended practices, etc.

4.1.3.1 *Record of Events*

The record of events provides an account of the general experience gained, especially on the rates of progress and duration of different stages. The information is assembled from the progress control charts used in the inventory.

4.1.3.2 *Results*

The objects of the inventory were defined in Part I and suitable output tables were designed. These tables are now completed and augmented as necessary to display the results. Additional explanation may be provided. Considerable resources of skilled manpower, specialist services, material and equipment, time and money were deployed for the inventory. An analysis of the activities and the use of resources is made and summarized to show the total of the resources used, their contribution in the final results, and their deployment in time. These are vital pieces of information for future inventory planning. Difficulties must be highlighted, critical points and paths in the planning system should be identified, and the causes of the deviations from the original predictions should be highlighted.

Suitable sub-headings for the analyses of time and costs might be:

- planning
- pilot surveys
- equipment
- training
- field work:
  - — transport
  - — salaries
  - — allowances
  - — services
- computing and analysis
- publication

Sometimes a special section is allocated to a discussion and record of the statistical analyses performed on the data to provide the population estimates.

4.2 RECURRENT FOREST INVENTORY

In both even-aged plantations of one or a few species as well as in mixed uneven-aged crops, forest inventory may be repeated at regular intervals. The aims of such recurrent or continuous forest inventories may vary from forest to forest.

On the national scale recurrent forest inventory is done to ascertain the balance between 'gain' and 'drain' in order to plan and control the development of the growing stock and the dependent industries. Gain is the sum of both growth of the existing forest and of its extensions; drain is the sum of harvesting and forest destruction. This type of information is vital when the protection of the forest and both cutting and regeneration operations are in the hands of large numbers of individuals, co-operatives and other organizations.

In extensive plantations recurrent forest inventory is the tool of management at the forest level providing information on:

- the results of treatments applied – for example the actual spacing achieved, the stocking once the plantations have been established, the stocking before and after thinning, damage, etc.
- the growth of the crops in order to compare the field results with predictions made from yield tables or other form of growth model

Recurrent inventory is especially useful where growth prediction is based on inadequate data and also where large wood processing industries with high capital investment are dependent on the forest. Recurrent forest inventory also produces the raw data for more detailed growth modelling in the future and is part of a management system providing up-dated information on the growing stock.

In uneven-aged mixed forest some form of recurrent forest inventory is the only means of estimating change within the forest and predicting future growth. In this type of forest mortality and recruitment as well as removals must be estimated in order to predict changes in the growing stock. Such inventories may be done using all permanent plots, or sometimes a combination of temporary and permanent plots. The latter is more suitable for very extensive forests where all permanent plots would be prohibitively expensive.

Effective recurrent forest inventory depends on

- efficient field work and plot maintenance
- efficient maintenance of records, security and continuity

Before a recurrent forest inventory system is introduced, great care and thought in the selection of suitable procedures and techniques are essential; the system must be sustainable within the resources likely to be available immediately and in the future, and must be designed to provide

- accurate field records
- continuous and true representation of the population by the sample
- continuity of measurement procedures in order to provide consistent data
- security of the records
- accessibility of data, analyses and results in a form that is easy to comprehend

4.2.1 Field Work for Recurrent Inventory with Permanent Plots – in Simple Crops such as Plantations

The type of permanent sample plot depends on the degree of variation in the crops. In even-aged plantations of one species, and in mixed crops with a simple structure, small sample plots with summaries expressed as average stand parameters are adequate. The main points for consideration are:

1. *Location.* The plots must be representative of the crop and easily relocated. Their location must be surveyed and marked on maps. This is simple in intensively managed and well roaded forests – but more difficult and costly in extensively managed areas.

2. *Demarcation.* Circular sample plots are defined by a centre point, other shapes by their corners. Trenches some 1–2 m by 0.3 m by 0.3 m are effective in boundary and corner demarcation and last long. Trees in sample plots should not be easily distinguishable from trees outside or field staff may treat them differently – in extreme cases leaving them unthinned, for example. Obvious paint marks should be avoided. Sampling units may be identified using a relascope at a marked centre point rather than a plot. In Switzerland plot centres are marked by metal tubes buried below ground and later located with a metal detector. The plots themselves are located systematically and near each, usually within 20 m of the plot centre, a conspicuous paint mark is placed near ground level on a large tree; the plot record gives precise survey data from the paint mark to the plot centre (Schmid-Haas & Werner, 1970).

3. *Plot size and shape* (see also Section 5.2.3). In plantations plot size depends upon the age of the crop and its tree spacing. The variance of the estimated mean volume per plot using single tree volume tables includes a component that is a function of the numbers of trees in the plot. Normally at least 20 trees per plot are needed to obtain a level of precision in accord with that of the variance between plots. Ideally all plots should be the same size; however, this is not essential so plots in older crops may be larger than those in denser, younger ones. All trees should be labelled individually and their positions marked on a plot chart. Then at subsequent enumerations missing stems can be identified. Plot size may be altered at a re-measurement provided that data for the old plot size are recorded; then the plot may be enlarged and the extra trees recorded separately in order to provide a 'previous' record at the next assessment. The survey of plots must include corrections for slope. With circular plots either one can demarcate a circle, the horizontal plane form of which has the desired area or, on broken ground, the radii to borderline trees may have to be corrected individually to establish the boundary of a circle on the horizontal plane. The recent literature on the methods of dealing with ingrowth when using point sampling is dealt with in Section 5.5.

4. *Tree identity.* Each tree in the sample should be numbered and its position plotted to scale on a plot chart. Numbered aluminium tags fastened with an aluminium nail are effective. The point of measurement may be accurately located by reference to the nail, e.g. 20 cm below the nail which is located 1.5 m above ground level.

5. *Calculations.* Before the field measurement and data capture procedures can be defined, the form of the calculations, analysis and summary must be decided. Usually this will include the determination of any volume equations to be used. The data summary for each plot and population will usually include:

v_1 volume at previous inventory
v_2 volume at current inventory
v_m mortality in period between inventories
v_r recruitment in period between inventories
v_f removals in period between inventories
gross increment
net change
stand structure frequency tables by species, diameter or volume classes
stand characters by species – if even-aged $N, V, G, \bar{h}, \bar{v}, d\bar{g}$, etc.

6. *Measurements.* Often all trees are measured for dbh. Other additional measurements will be needed for estimating volume – often taken on a subsample of trees only, e.g. height, timber height, bole length, diameter above buttress, etc. If heights are measured, either two measurements must be taken on each tree from opposite sides or the point of observation recorded on the plot chart; otherwise re-measurements may be inconsistent.

7. *Checking.* The previous records should be available to the field teams in order to spot and recheck inconsistent records. This is more important than to have independent observations and resultant inconsistencies that can be resolved only by a second field visit.

4.2.2 In Crops with a Complex Structure

In Uganda in tropical overgreen and semi-deciduous forest, permanent sample plots of 1.0 ha were established. Location is by an access route from a permanent road demarcated by a line of direction trenches 2.0 m by 0.3 m by 0.3 m at some 20 m intervals. No attempt is made to measure all the trees within the sample plot; instead the plot is subdivided into 25 sub-plots, each 20 m by 20 m, and the four largest trees from a short list of some 30 species within each sub-plot (i.e. 100 per ha) are located, marked and measured. The list of species to be measured is deemed to include those that would form the future utilizable crop.

The intention is to collect information on the growth rates of each species by size classes, in order to use the information in stand prediction (see Section 3.3.2) for growth estimation.

Further reading

Adlard, P.G. (1990) *Procedures for Monitoring Tree Growth and Site Change: a Field Manual.* Tropical Forestry Paper No. 23, Commonwealth Forestry Institute, Oxford.

Synnott, T.J. (1979) *A Manual of Permanent Plot Procedures for Tropical Rainforests.* Tropical Forest Paper No. 14. Commonwealth Forestry Institute, Oxford.

Synnott, T.J. (1980) *Rainforest Silviculture: A Research Project Report.* Commonwealth Forest Institute Occasional Paper No. 10, Oxford.