From: Husch, B.; T.W. Beers, and J.A. Kershaw, Jr. 2003, 4th Ed. Forest Mensuration. John Wiley and Sons, Inc., New York. 443 p.

12

FOREST INVENTORY

A forest inventory is the procedure for obtaining information on the quantity, quality, and condition of the forest resource, associated vegetation and components, and many of the characteristics of the land area on which the forest is located. Most forest inventories have been, and will continue to be, focused on timber estimation. However, the need for information on forest health, water, soils, recreation, wildlife and scenic values, and other nontimber values has stimulated the development of integrated or multiresource inventories. When nontimber information is required, specialists in the pertinent fields should cooperate in planning and executing the inventory.

12-1. TIMBER ESTIMATION

A complete forest inventory for timber evaluation provides the following information: estimates of the area, description of topography, ownership patterns, accessibility, transportation facilities, estimates of timber quantity and quality, and estimates of growth and drain. The emphasis placed on specific elements will differ with the purpose of the inventory (Husch, 1971). For example, if the purpose of an inventory is for the preparation of a harvesting plan, major emphasis should be put on a description of topography, determination of accessibility and transportation facilities, and estimation of timber quantity. The other elements would be given little emphasis or even be eliminated. If the purpose of an inventory is for the preparation of a management plan, major emphasis would be put on timber quantity, growth, and drain with lesser detail on other elements.

Information is obtained in a forest inventory for timber evaluation by measuring and assessing the trees and various characteristics of the land. The information may be obtained from measurements made on the ground or on remote-sensed imagery (aerial photographs, satellite imagery, radar, etc.). When measurements are made on all trees in a forest, the inventory is a complete or 100 percent inventory. When measurements are made for a sample of the forest, it is a sampling inventory. The terms *cruise* in North America and *enumeration* in other English-speaking areas are frequently used instead of inventory.

In executing a forest inventory for timber evaluation, it is impossible to measure directly quantities such as volume or weight of standing trees. Consequently, a relationship is established between directly measurable tree or stand characteristics (e.g., dbh, height) and the desired quantity. This may be done as follows:

1. Make detailed field measurements of trees or stands and compute the desired quantities from these measurements. For example, one might make detailed diameter measurements at predetermined heights along the stem of standing trees and determine volumes by formulas or graphical methods (Section 6-1).
2. Estimate the desired quantities in trees or stands by utilizing relationships derived previously from other trees or stands. For example, one might measure tree or stand characteristics such as dbh, height, and form and determine the corresponding volume or weight from an equation or a table (Section 6-2).

12-1.1 Estimation of Net Usable Volume

Timber inventories can estimate gross and net quantities, normally volume. An estimate of *gross volume* shows the volume of wood, usually without bark, based on the exterior measurements of the trees: dbh, height, and form, without any deductions for defects. An estimate of *net volume* reduces the gross volume due to defects such as rot, diseased portions, and stem irregularities. The reduction for defect can be determined in two ways: (1) at the time of measurement of each tree, the external defects can be noted, internal defects estimated (or directly determined by boring) and recorded, and the loss in volume estimated per tree; and (2) by applying a cull factor expressed as a percentage that will reduce the gross volume of the inventory to net volume. This cull percentage can be determined directly by carrying out a study that requires the felling of a sample of trees and determining their gross and net volumes to determine cull percentages. Frequently, cull percentages are used based on previous experience in the kind of timber being inventoried.

Inventories can be designed to estimate net volumes or quantities by product classes such as poles, pulpwood, sawtimber, and veneer logs. Of course, this requires specifying the criteria such as minimum diameter and length, form and extent of defect, to be used at the time of measurement of sample trees during fieldwork.

Another factor in estimating net usable quantity of timber depends not on the defects in the trees themselves but on the following external causes:

- Accessibility
- Legal restrictions (protected areas, silvicultural requirements)
- Nonutilizable species
- Minimum quality characteristics and sizes of logs
- Losses due to breakage in logging and transport

Estimates of the reduction in timber quantity due to these causes are required to obtain an estimate of the net usable volume.

12-2. NONTIMBER ESTIMATION

As Hassan et al. (1996) have pointed out "the need to look into non-wood benefits of forestry is . . . becoming an increasingly important component of forest management planning in view of the fact that the contribution of forestry goes beyond wood production." Inventories that include estimates of nontimber parameters in a forest are called *multiple resource inventories*. The parameters measured in this type of inventory vary, depending on the information required. These parameters may include timber estimates together with data on nontimber vegetation and/or the other characteristics of the forest area. For example, the U.S. Forest Service, in their resource inventories, collects the following nontimber information (USDA, 1992):

1. Nontree vegetation
   a. Species abundance
   b. Vegetation profile
   c. Biomass
2. Wildlife habitat
   a. Edge
   b. Animal use, browsing
   c. Snags
   d. Down woody material
   e. Cover, shelter
   f. Suitability
3. Forested range for livestock
   a. Grazing

4. Recreation
   a. Opportunity assessment
   b. Use
5. Soils
   a. Landscape context
   b. Physical characteristics
6. Water
   a. Type
   b. Proximity
7. Other data
   a. Logging operability
   b. Spatial coordinates
   c. Residential fuelwood
   d. Fire fuel quantities
   e. Woodland assessment
   f. Resource zone

Multiple forest resource inventories may also collect additional information on such characteristics as biodiversity, forest health, scenic values, carbon storage, and ownership.

12-3. INVENTORY PLANNING

An important step in designing a forest inventory is the development of a comprehensive plan before initiating work. Such a plan ensures that all facets of the inventory, including the data to be collected, financial and logistical support, and compilation procedures, are thought through before the inventory begins. The reader is referred to Husch (1971) for a discussion of inventory planning.

The following checklist includes all, or almost all, items that should be considered in planning a forest inventory. The items do not always have the same importance, and are not needed in all plans.

1. Purpose of the inventory
   a. Timber and nontimber parameters to be estimated
   b. How the information will be used
2. Background information
   a. Past surveys, reports, maps, photographs, etc.
   b. Individual or organization supporting the inventory
   c. Funds available

3. Description of area
   - a. Location
   - b. Size
   - c. Terrain, accessibility, transport facilities
   - d. General character of forest
4. Information required in final report
   - a. Tables and graphs
   - b. Maps, mosaics, or other pictorial material
   - c. Narrative report
5. Inventory design
   - a. Estimation of area (from aerial photographs, orthophotos, maps or field measurements)
   - b. Determination of timber quantity (e.g., volume tables, units of volume)
   - c. Methods for estimation of nontimber parameters (e.g., regeneration, lesser vegetation, woody debris, soil, water, scenic and recreational values)
   - d. Size and shape of fixed-size sampling units
   - e. Probability sampling
     - i. Simple random sampling
     - ii. Stratified random sampling
     - iii. Multistage sampling
     - iv. Double and regression sampling
     - v. Sampling with varying probability (e.g., PPS, 3P)
   - f. Nonrandom sampling
     - i. Selective sampling
     - ii. Systematic sampling
   - g. Setting precision for inventory
   - h. Sampling intensity to meet required precision
   - i. Times and costs for all phases of work
6. Procedures for interpretation of photo, satellite imagery, or other remote sensing material
   - a. Location and establishment of sampling units
   - b. Determination of current stand information, including instructions on measurement of appropriate tree and stand characteristics coordinated with fieldwork
   - c. Determination of insect damage, forest cover types, forest fuel types, area, and so on, coordinated with fieldwork
   - d. Personnel
   - e. Instruments

   - f. Recording of information
   - g. Quality control
   - h. Data conversion and editing
7. Procedures for fieldwork
   - a. Crew organization
   - b. Logistical support and transportation
   - c. Location and establishment of sampling units
   - d. Determination of current stand information, including instructions on measurement of trees and sample units coordinated with photo interpretation
   - e. Determination of growth, regeneration, insect damage, mortality, forest cover types, forest fuel types, area, and so on, coordinated with photo interpretation
   - f. Instruments
   - g. Recording of observations
   - h. Quality control
   - i. Data conversion and editing
8. Compilation and calculation procedures
   - a. Instructions for reduction of remote sensing and field measurements
     - i. Conversion of remote sensing material or field measurements to desired expressions of quantity
     - ii. Calculation of sampling errors
     - iii. Specific methods and computer programs to use
     - iv. Description of all phases from handling of raw data to final results, including programs
9. Final report
   - a. Outline
   - b. Estimated time to prepare
   - c. Personnel responsible for preparation
   - d. Method of reproduction
   - e. Number of copies
   - f. Distribution
10. Maintenance
    - a. Storage and retrieval of data
    - b. Plans for updating inventory

The decision to conduct an inventory depends on the need for information. An inventory is an information-gathering process that provides one of the bases for rational decisions. These decisions may be required for many reasons, such as the purchase or sale of timber, for preparation of timber-harvesting plans, in forest and wildlife management, for obtaining a loan, and so on. If the purpose is clarified, one can foresee how the information will be used and thus know the relative emphasis to put on the different elements of the inventory.

As a first step in planning an inventory, one should obtain the requisite background information and prepare a description of the area. One should then decide on the information required from the inventory and prepare the outlines of tables that will appear in the final report. Table outlines should include titles, column headings, class limits, measurement units, and other categories needed to indicate the inventory results. These table outlines should be prepared before detailed planning begins because the inventory design will depend on the information required for the final report. Area information is usually shown by such categories as land-use class, forest-type or condition class, and ownership. Timber quantities are usually given in stand and stock tables. A *stand table* gives the number of trees by species, dbh, and height classes. A *stock table* gives volumes or weights according to similar classifications (see Chapter 11 for details on construction of stand and stock tables). Stand and stock tables may be on a per unit area basis (per acre or hectare) or for the total forest area and may be prepared for forest types or other classifications (e.g., compartments, watersheds).

Since a forest is a living, changing complex, the inventory plan should consider the inclusion of estimates of growth and drain. For a discussion of tree and stand growth, see Chapters 15 and 16.

12-4. FOREST INVENTORY DESIGN

There must be wide latitude in designing an inventory to meet the variety of forest vegetation, topographic, economic, and transportation conditions that may be encountered. The required forest inventory information can be obtained by observations and measurements in the field and on aerial photographs, satellite images, and other remote sensing sources. The most useful and practical approach is a procedure in which remote sensing materials are used for forest classification or stratification, mapping, and area determination, while fieldwork is employed for detailed information about forest conditions, timber quantities and qualities, and additional nontimber characteristics. One can design a forest inventory utilizing only fieldwork, but it is less efficient. If aerial photographs and satellite imagery are available, they should be used. (Under some circumstances, it is possible to design a forest inventory based entirely on photographic interpretations and measurements. However, this method will provide only rough approximations of timber species and the quantity, quality, and sizes present and information on the nontimber parameters.)

The funds available and the cost of an inventory will strongly influence the design chosen. The main factors that will affect costs are the type of information required, the standard of precision chosen, the total size of the area to be

surveyed, and the minimum size of the unit area for which estimates are required. General information is relatively inexpensive, but the costs increase as more details are required. The standard of precision chosen greatly influences costs; the greater the precision, the higher the costs since this usually requires more intensive sampling. Costs per unit area will decrease as the size of the inventory area increases. If independent estimates are required for subdivisions of a large forest area, this will also raise costs. Descriptions of basic sampling designs applicable to forest inventory are given in Chapter 13.

12-5. INVENTORY FIELDWORK

The size and organization of field crews will vary with sampling procedures, the observations or measurements required, forest conditions, and tradition. For timber inventory work in temperate-zone forests, crews of one or two workers are widely used. If additional nontimber information is required, additional members are needed. Small crews have proved satisfactory in these areas because roads are usually abundant (access by vehicle is good), forest travel is relatively easy (little brush cutting is required), and well-trained technicians are generally available (they require little supervision).

For inventory work in tropical zone forests, large crews are widely used because roads are generally sparse (access by vehicle is poor), forest travel is difficult (workers are required to cut vegetation), and few trained technicians are available (they require considerable supervision). Whatever the crew size or the assigned tasks, however, specific, clear instructions should be given to each crewmember.

A basic rule of forest inventory is to prepare complete written instructions before fieldwork starts. To minimize later changes, instructions should be tested before operations begin. Instructions should be clear and specific enough so that individual judgment by field crews on where and how to take measurements is eliminated. For example, field crews should not be permitted to choose the position of a sampling unit subjectively or to move it to a more accessible position or more "typical" stand. The aim should be to standardize all work to obtain uniform quality and the best possible reliability of the measurements, regardless of which person does the work. The occurrence of mistakes or nonrandom errors must be eliminated or, at least, held to a minimum.

It is best to settle on a standard set of instruments. The use of several kinds of instruments to make the same type of measurements should be avoided. To minimize errors, the instruments should be checked periodically to see if they are in adjustment.

Decisions should be made on the precision required for each measurement. Thus, tree diameters (dbh) may be stipulated to the nearest centimeter, inch, tenth of an inch, and so on, and heights to the nearest foot, meter, one-half log, and so on.

If estimates of timber quantity are to be made by quality or product classes, field instructions must include tree measurement specifications on minimum dbh and upper stem diameter, section lengths, and total usable length and criteria such as crook, scars, catfaces, evidence of rot, and so on, on individual sections and for the entire tree.

Inventory field operations must include a checking or quality control procedure. Whether plots, strips, or points are used, a certain percentage of the sampling units should be remeasured. The results of the remeasurements should be compared to the original measurement to see if the work meets the required standards. If it does not, remedial steps should be taken.

There is no standard form or system for recording field observations. The manner in which measurements are recorded depends in large part on the way they will be processed. Here are four methods that have been used for recording field measurements:

1. The use of forms that are designed without concern for subsequent calculations. The information needed is extracted from the forms and computations done apart from them. This is the least efficient method.
2. The use of forms with space for subsequent calculations. This is useful for small inventories for which limited information is required.
3. The use of forms designed for efficient transfer of data to computer input devices.
4. The use of methods and instruments that permit direct data entry into a computer (electronic data recorders).

12-6. CALCULATION AND COMPILATION

Plans for calculation and compilation of photo-interpretation data and field measurements should be made before fieldwork begins. It is illogical to postpone consideration of these things until data are obtained because foreknowledge of the calculation and compilation procedures can influence collection of data. For example, if volume tables will be used to determine tree volumes, there would be no point in measuring diameters to a tenth of a centimeter in the field if the volume tables give volumes by full centimeter dbh classes.

The statistical formulas or computer programs to be used for estimating means, totals, and standard errors should be selected early in the planning process. It is worthwhile to check the formulas with simulated data to verify the applicability of the program or to work out the optimum sequence of computational steps.