MEASUREMENT OF FOREST RESOURCES

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Management of a renewable resource for a sustained yield requires the ability to measure production. All measurements included in this unit are needed to estimate the amount of wood a forest can produce each year. Accurate records obtained from actual forest measurements are used by forest managers to create timber growth and yield estimates. Tables and graphs, prepared from actual forest measurements, can provide reasonably accurate estimates of future growth and predicted harvest volume. Completer models are available to model alternate management practices and to predict the outcomes.

OBJECTIVES

After completing this unit, you should be able to

- identify the types of information needed to develop a long-term forest management plan based on sustained yields
- explain the relationship of baselines and principal meridians to the initial point location from which each rectangular survey begins
- explain how instruments such as the stereoscope and the planimeter are used in preparing a forest-type map
- name some tools used to estimate the diameter and height of a standing tree, and explain how each tool is used
- describe the features of the two types of land surveys used in the United States
- define the role of a timber cruiser
- contrast the differences between a 100% cruise and a partial cruise and explain when each is appropriate to use
- list some assumptions that apply to partial cruises that may influence the accuracy of the results
- explain the formula for measuring forest growth and describe each of the formula components
- describe the most economical used methods for scaling logs

TERMS FOR UNDERSTANDING

acre
are
basal area
baseline
Biltmore stick
board foot
chain
cruise
cut
dot grid
Doyle's rule
forest growth
forest type map
forty
guide meridian
hectare
hypsometer
increment borer
ingrowth
initial point
International log rule
line-plot cruising
metes and bounds
mortality
photogammetry
planimeter
principal meridian
quarter section
range
rectangular survey
scaling
Scribner's rule
section
Smalian's formula
standard cord
standard parallel
stereoscope
survival growth
survivor trees
systematic sampling
timber cruiser
timber yield
township

LAND SURVEYS

Two types of land surveys were used to measure and record land area in the United States. The **metes and bounds** system used natural physical features of the land as starting points for land measurements. Markers such as streams, roads, rocks and other features were used. Many of these markers are difficult to locate because streams change their courses during flood seasons, roads are rerouted, rocks and boulders move, and features of the land change over time. This system did not prove very accurate.

Most areas of the United States, except for portions of the southeast, have been surveyed using the **rectangular survey** system. This system used an **initial point** as the beginning point for each survey. More than thirty initial points were established as the land survey was conducted. Each initial

point is a prominent and permanent physical feature in the landscape, and the exact location of each initial point is marked with a brass marker. This type of land survey was developed by Thomas Jefferson for the purpose of establishing property lines for the sale of public lands.

The rectangular survey system established a system of **baselines** that run east-west, and **principal meridians** that run north-south. These survey lines are marked with permanent markers, and are the reference points for defining property lines. A **standard parallel** line is established running east-west for each interval of 24 miles on either side of the baseline. A similar line called a **guide meridian** extends north to the next standard parallel. Because this line converges on due north, the curvature of the earth causes the northern border of each 24-mile tract to be slightly less than 24 miles long.

Each tract of land, measuring approximately 24 miles along each side of a square, is divided into sixteen townships. A township is shaped like a square, measuring approximately six miles long on each side. Each township, identified using consecutive numbers beginning at the baseline and proceeding north or south, consists of 36 sections. Each **section** is approximately one mile square with a surface area of 640 acres (1 **acre** = 43,560 square feet). A section consists of four quarter sections with each **quarter section** approximately equal to 160 acres. Quarter sections are further divided into four subdivisions, each of which contains slightly less than 40 acres. Each of these parcels of land is called a **forty**.

A **range** is the east-west location of a township from a principal meridian.

LAND AREA

Land area is a measurement of the amount of surface area within established boundaries. The land area measurement used in forestry can be expressed two different ways. An acre is a land area equal to 43,560 square feet. When metric measurements are used, hectare is the unit of measurement for land area. One hectare is equal to 10,000 square meters, or 100 ares. In the metric system, one are is equal to 100 square meters. One hectare is also equivalent to 2.471 acres.

Land area is necessary information for those who develop management plans for forests. For example, it would be nearly impossible to determine the amount of salable timber in an area without first knowing the amount of surface area or measuring every tree. Once the land area has been determined, and a few of the trees have been measured, the amount of timber in a forest can be estimated with a reasonable degree of accuracy.

One way to determine the land area is to measure it while taking compass readings each time the boundary changes directions. A much easier method for determining land surface area is to prepare a **forest type map** from aerial photographs. The technician uses an instrument called a **stereoscope** to view two different aerial photographs at the same time. Two photographs of the same area taken from slightly different angles are merged by a stereoscope to convert the two views into a single view with three dimensions. Technicians trained to use this instrument are able to prepare maps that accurately record the locations of forests of different types using photographs taken from aircraft or from satellites. A technician skilled in the use of this instrument can even estimate the height of trees with accuracy.

Maps must be prepared proportional to the actual land area they represent. This is known as drawing a map to scale. For example, a map scale of 1:20,000 means that each inch on the map represents 20,000 inches or 1,667 feet in the forest.

A forest type map prepared to scale can be accurately measured to determine land area. This is done through the use of an instrument called a **planimeter** by tracing the perimeter boundary of an area on a map. The instrument accurately measures the area within irregular boundary lines such as those found on a topographical map (showing elevations) or a forest type map.

Another method used to determine land area is the **dot grid** method. A transparent plastic sheet on which dots have been uniformly placed is overlaid on a map. The dots that lie within the boundary lines are then counted. A dot grid with ten rows of ten dots per row (100 dots) for each square inch of surface

area has a conversion factor of 0.638 when a map with a scale of 1:20,000 is used:

1) 20,000 X 20,000 = 400,000,000 square inches forest surface area
2) 400,000,000 / 144 square inches (1 square foot) = 2,777,777.78 square feet
3) 2,777.777.78 43.560 square feet (1 acre) = 63.77 acres per square inch of map surface
4) 63.77 100 dots per square inch = 0.638 acres/dot

If 73 dots are counted within the boundary lines of a timber tract using this grid, the total acreage of the tract is approximately: 73 X 0.638 = 46.57 acres.

The ability to produce aerial photographs of a known scale makes it possible to determine area directly from the photographs. Such photographs are becoming widely used for the purpose of mapping fields and forest lands. This method of measurement is called **photogammetry**. It is used to measure the total area enclosed within boundary lines on the photograph.

TREE DIAMETER AND HEIGHT

The diameter and height of a tree must be known before it is possible to calculate the amount of wood it will produce. These measurements are taken while a tree is still standing. For tree measurements that require a high degree of accuracy, instruments should be used that take direct measurements from the tree, and adjustments must be made to compensate for such things as thickness of bark, and slope.

The diameter of a tree is measured outside the bark of the tree at breast height (4.5 feet). This measurement is called dbh, and is used to estimate timber volume. The dbh measurement can be taken in several ways, with the method of choice determined by the degree of accuracy required. The most accurate instrument for taking this measurement is the tree caliper. It adjusts to make contact on either side of a tree, and the diameter reading is taken directly from the scale on the instrument.

This measurement can also be made using a steel tape calibrated to provide dbh data by measuring the outside distance (circumference) around the tree. This method is accurate when a tree is perfectly round, but since most trees are not perfect cylinders, some accuracy is lost when this method is used. A third method for taking dbh measurements is to use a **Biltmore stick**. The instrument is used by holding the stick against the tree in a horizontal position at a distance of 25 inches (arm's length) from the eye and sighting across it. The left end of the stick is lined up on the outer edge of the tree, and the reading is taken from the instrument at the point where the sighting on the other edge of the tree intersects the stick. This method is not as accurate as the caliper or the tape, but it is quick and easy to use and it is accurate enough to provide reliable information for some forest management purposes. A variety of other devices is available to foresters that can be used to make rough estimates of timber volume. Most of these involve taking sightings through an instrument that is held a fixed distance from the eye.

The height of a standing tree can be measured in different ways. The most accurate method for measuring height is to use a sectioned or telescoping height pole extended upward through the foliage to the top of the tree. This instrument is used in forest research plots, but is useful only on small and moderate sized trees. Tree heights of more than 60 feet must be measured another way.

Indirect measurement of trees can be done using a type of measuring device called a **hypsometer**. This instrument is available in two types. One of these uses trigonometry to calculate tree height based on angles and known distances. The other type of instrument is based on geometry, and is calibrated to use ratios of known fixed distances on similar triangles to calculate the height of the tree. Most hypsometers are designed to be held at arm length (25") at a distance of one **chain** from the tree. A surveyor's chain for measurement is 66 feet long, and this is the unit of measurement used in the forest.

CAREER OPTION: TIMBER CRUISER

A timber cruiser is a person who estimates marketable timber volume by taking sample measurements from sites throughout a stand of trees. These measurements o predict the total volume of timber in the designated area. Estimated losses are subtracted from the total volume to determine the total volume of marketable timber. A cruiser also gathers data about forest conditions that can be used to make forest management decisions related to logging timber sales, sustained yields, land use and many other purposes.

A timber cruiser spends a great deal of time in the forest, and must be skilled in sampling techniques, use of various measuring instruments, and mathematical calculations. Skills in careful observation are required in order to notice such things as symptoms of decay or insect infestations.

MEASUREMENT OF AGE

The determination of age in an individual tree can be made either before or after it has been harvested, by counting the annual rings in the woody xylem tissue at the tree base. Environmental and physiological changes that accompany the different seasons of the year produce wood of slightly different color and different density. These changes can be distinctly seen in the wood that is deposited beneath the cambium of the stem each year.

The age of a standing tree can be measured using an **increment borer** to extract a core of wood from the cross-section of a living tree. The data obtained using this instrument is used to determine age, growth rate and soundness in a tree. The instrument is equipped with a cutting tip, and the wood is deposited in the center of the hollow bit as it bores into the center of the tree. The wood cores obtained must be carefully removed from the tube to avoid disturbing the alignment of the tissue in the wood core, and the annual rings are counted. A single annual ring of new growth is deposited each year.

Determining the age of harvested trees is easily done by counting the annual rings in a cross section of the base of a tree. Wood deposited during a favorable growth season is generally much thicker and lighter in color than the wood deposit from a year when the tree was subjected to drought conditions or other stressful effects.

MEASURING TIMBER STANDS

Timber stands are measured for a variety of reasons. They are measured regularly to determine timber volume. Timber volume for a single tree can be expressed as **basal area**. This is the area of the cross section of a tree in square meters or square feet. Basal area can also describe timber volume in an entire forest when expressed as square meter per hectare or square feet per acre. The timber volume in a forest on a particular date is expressed as **timber yield**, an inventory used to measure how quickly forests are renewed in comparison with the rate forest products are used. Forest managers need to know how much timber can be harvested each year to maintain a sustained yield.

A common method used to estimate timber yield is to cruise or survey timber in an area. Cruising is the activity of gathering forest data from sample plots. It is seldom necessary to measure every tree in a forest to determine timber yield because measuring sample plots similar to the rest of the forest and applying their yields to the entire area will usually provide data very close to actual measurements of all the trees. A 100% cruise is used only in cases where a high degree of accuracy is required. A forest research plot may require this degree of accuracy, but in most instances a partial cruise is adequate. Some basic assumptions apply to partial cruises to ensure the accuracy of the results: (1) the sample must be representative of the entire forest; (2) enough samples should be tallied to reduce the chance that errors will occur; and (3) the plot size should be large enough to tally 15-20 trees per plot

Establishing the sample site for a partial cruise is important in determining the accuracy of the measurements taken. One method

used to establish the sample sites is random sampling This sampling procedure selects sample sites in each stand using a process that allows every possible site to have an equal chance of being selected. Random sampling is considered to be a fair way to select data collection sites.

One way to ensure that sample plots selected are similar to all other sample plots is to establish straight lines that extend across the entire area from which forest measurements are taken. The lines are spaced evenly and sample units are identified at equal intervals along each line. Lines should be oriented to run up and down slopes instead of around slopes because timber of similar quality tends to be located in similar positions on a slope. Trees representing the different quality and type characteristics found in the entire forest are most likely to be encountered in the trees that are tallied when lines are oriented in this manner. This sampling method is called **systematic sampling**.

When systematic sampling methods are used, the process of gathering data is known as **line-plot cruising**. Two cruisers usually work together in teams with one team member taking measurements and the other recording data on the tally sheet or in a small portable computer. They also refine field maps and make adjustments to type lines located on aerial photographs that identify forest types. Experienced cruisers also learn to make minor adjustments in values as they work. This may be necessary when one sample site includes a pocket of old growth timber not typical of the stand being measured. Cruisers must keep in mind that the purpose for doing a partial cruise is to gather data for the purpose of making an accurate estimate of the forest yield for the entire stand.

Several other methods of sampling a forest are used to determine the amount of marketable timber. One of these is to determine the average number of trees in each dbh class per acre of forest. This is done by tallying the number and dbh of all the trees located in sample sites. Sample sites are distributed in different locations throughout the stand, and data from these sites is used to predict the forest yield for the entire stand. Another method is to use a cruising instrument that gauges the dbh of trees by sight. While standing at the center of the selected site, record only those trees that are larger than a certain dbh while turning slowly through a full circle. Values derived from these and similar sampling techniques can be used to estimate the amount of timber in the stand.

DETERMINING FOREST GROWTH

Forest growth is defined as the increase that occurs in the volume of wood in a forest over a specific period of time. Data used to determine forest growth are obtained by doing forest surveys. At least two surveys must be conducted at the same site following an interval of several years to determine forest growth. The difference in volume between the original survey and the second survey represents growth.

Conditions at a particular survey site in a forest tend to change during the time interval between forest surveys. New trees not present when an earlier survey was conducted, plus trees not big enough to be tallied in the original survey, add forest volume to the total that inflates forest growth beyond the amount of growth that occurs in individual trees during the same time period. This growth is known as **ingrowth**. Ingrowth is partly offset by the loss of trees measured during the first survey that were dead when the second survey was conducted. The data collected from these trees is recorded in a category of losses called **mortality**, and attempts are made to determine what caused their deaths.

Trees harvested prior to the second forest survey are tallied using data from their stump measurements. This category is called **cut**. Trees measured in both surveys for the time interval during which growth is evaluated are **survivor trees**. The total difference in volume of these trees between the two surveys is called **survival growth**. The net forest growth is calculated according to the following formula:

Ingrowth - survivor growth - mortality - cut = forest growth

The growth rate of a tree or group of similar trees can be measured by using an increment borer to remove a core of wood from the tree and measuring the width of the most recent growth rings. The average width of the annual rings multiplied by 2 is equal to the annual increase in the diameter of the tree.

MEASURING FOREST PRODUCTS

The final and most accurate forest measurements are those taken after the timber has been harvested. Raw timber products include sawlogs, bolts and chips. Each of these is measured in a different way. For example, sawlogs are sold by the board foot. Bolts sold for firewood are usually measured in stacks and sold by the cord, while bolts sold for pulpwood are measured by the cord or by weight. Most pulpwood and paper products are sold by net weight. Measure-ment of forest products to determine the quantity or amount of product is called **scaling**.

Sawlogs include logs that are at least 8 feet long with a small-end diameter not less than 6 inches. These logs are scaled by first measuring the diameter of the small end of the log inside the bark. This value in combination with the log length is used to determine the number of board feet in a log. This value is usually obtained from a table constructed for this purpose. The tables in most common use are the **Scribner rule** and the **Doyle rule**.

LOG SCALING SYSTEMS: SCRIBNER, DOYLE AND INTERNATIONAL RULES

Three common methods for measuring logs are used in North American forests. The Doyle method tends to favor the buyer of logs that are less than 28 inches in diameter because more lumber can usually be cut from trees of this size than the formula indicates. The Scribner rule is quite accurate in its estimates, and a modified version called the Scribner decimal C is used to measure timber sales by the U.S. Forest Service.

Many different rules for scaling logs have been used in the past, but the most accurate is the **International log rule**. Unlike the Scribner and Doyle rules for log measurement still widely used in the timber industry, the International log rule takes into account the amount of wood in the taper of the log from the small end to the large end. This system was developed by Judson Clark, a forester who mistrusted the log rules in use at the time. Using the International log rule, the volume of a log is determined by calculating the value of each 4 foot section of the log and adding them together.

Doyle -- $V = (D = 4)^2L/16$

Scribner -- $V = (.79D^2 - 2D-4)\ L/16$

Scribner decimal C -- Round Scribner value to nearest 10 board feet; drop the last 0

International -- $V = 22D^2 - 71D$; calculate each 4' section separately, then add them all together for final total (adjusts for 1/2" taper per 4' section of log)

The unit of measurement known as the board foot (BF) is equivalent to the volume of wood in a board that measures 1' long X 12" wide X 1" thick. A more useful way to calculate a board foot is to express the formula as BF = L X W X T / 12 where L (length) is expressed in feet, and W (width) and T (thickness) are expressed in inches. Board feet may be more easily calculated in odd-size lumber by changing the formula to express all measurements in inches.

Another log scaling method that has proven to be dependable is **Smalian's formula**. This measurement estimates the volume of solid wood in a log. Measurements are taken from both ends of the log to determine the area of the cross-section surface inside the bark. These measurements are combined with the length of the log to determine the volume of solid wood. Despite its high degree of accuracy, the wood industry continues to use board feet as the most common unit of measurement instead of converting to a volume system of measurement. This is probably because more time is required to make the measurements that are needed to use this system. In comparison, the Doyle and Scribner methods are faster and easier to use. The formula for calculating total volume of solid wood in a log using Smalian's formula is:

$V = (A1+A2)L/2$

V = volume; A1 & A2 = Areas of log ends; L = Length

Pulpwood and firewood scaling is usually done using a unit of measurement known as a **standard cord**. One cord of stacked wood

measures 4' X 4'X 8', or 128 cubic feet in volume. The following formula can be used to calculate the number of cords in a stack of wood when each measurement is expressed in feet:

(Length X Height X Width) / 128 = Number of Cords

ESTIMATING BIOMASS

Wood has long been used as a form of energy. Even in the modern world, more wood is used for fuel than for all other uses combined. Biomass is deemed as the weight of all of the material in a tree that can be used as a source of energy. In more realistic terms, it is the portion of the tree above ground that can be used as fuel. Intensive culture of fast growing trees has the capability of producing high tonnages of biomass when trees are planted in dense stands and harvested after twenty or thirty years of carefully managed growth.

Biomass production is measured as net weight of dry matter. One contributing factor to its potential as an energy crop is that whole-tree harvest methods convert the entire tree into biomass. This includes the branches, bark and even the leaves. All this plant material is used, and none is wasted. The trees are usually harvested mechanically and chipped in the field. In most instances, they are hauled to electrical power plants where they are dried and burned for fuel. Wood chips can even be converted to gas for more efficient generation of electricity.

Most of the biomass used for power production today comes from waste products. Biomass is now the second leading renewable source of energy for power production behind hydroelectric power. The production of biomass is a rapidly growing industry. As the production of biomass as an energy crop increases, it is estimated by the U. S. Department of Energy that up to 50,000 MW of electricity will be produced in biomass powered generating plants by the year 2010. This industry is also expected to create 120,000 new jobs in rural areas during the same period of time.

The weight of biomass available in a stand of trees can be very difficult to estimate because it involves several variables. Examples of these are differences in tree varieties (hardwoods tend to be higher in density than softwoods), and maturity of the trees (immature wood tends to be higher in water content than mature wood). Biomass yield can be estimated by first measuring the volume of wood in a similar manner to the way cruising is done in a stand of timber. These weights must be adjusted upward, however, because the entire portion of the tree above the ground contributes to the yield of a biomass crop. Adjustments must also be made to convert the weight of the biomass available to a dry matter basis.

LOOKING BACK

Forest management for sustained yields requires the ability to measure living forests and forest products. Land surveys are used to define property lines and to describe locations of timber stands on maps. Maps are also used to record forest types. Timber cruisers refine maps derived from aerial photographs, and measure timber stands to determine the management practices needed. They do this by measuring representative samples of the trees in the stand and calculating volume estimates based on data obtained from the sample sites. Timber yield charts are used to calculate timber yields. The Scribner decimal C rule is the method adopted by the U. S. Forest Service to measure timber sales. Timber stands are measured and marked using measuring devices of several types to estimate forest yield. Timber products are measured after the trees have been harvested by using direct measurements on the trees. Timber products are mostly sold on the basis of volume and weight.

QUESTIONS FOR DISCUSSION AND REVIEW

Essay Questions

1. Explain the management concept of sustained yield, and identify the kinds of information needed to develop a sustained yield forest management plan.
2. What are the two types of land surveys used in the United States? What are the key differences between them?
3. How is the rectangular survey system organized to identity the locations of property lines and boundaries?
4. Describe how instruments such as the stereoscope and planimeter are used to create a forest-type map.
5. How does a timber cruiser determine the height and diameters of live trees?
6. How does a forest worker determine the age of a live tree?
7. What is the difference between a 100% timber cruise and a partial timber cruise? When is each method appropriately used?
8. Suggest some sampling and measuring practices that can influence the accuracy of a partial timber cruise.
9. Explain the formula for determining forest growth, and describe each of the formula components.
10. List the steps and explain the procedures used to scale logs.

Multiple Choice Questions

1. The type of land survey system used in most areas of the United States except in some areas of the southeast is:
   a. Metes and bounds
   b. Rectangular survey
   c. Scribner's rule
   d. Gannet survey

2. Which of the following is a survey line that runs east-west?
   a. principal meridian
   b. section
   c. guide meridian
   d. baseline

3. Each section of land has a surface area of approximately how many acres?
   a. 640
   b. 320
   c. 160
   d. 40

4. A tract of land approximately six miles square is called a:
   a. Section
   b. Township
   c. Quarter-section
   d. Range

5. A procedure called the dot method uses a clear plastic sheet with evenly spaced dots to:
   a. Measure land area
   b. Measure tree heights
   c. Make forest-type maps
   d. Calculate forest basal area

6. A method that uses aerial photographs to make field maps to scale is:
   a. Photogammetry
   b. Altimetric scaling
   c. Planimetery
   d. Fotometry

7. An instrument used to measure the circumference of a tree is called:
   a. Biltmore stick
   b. Steel tape
   c. hypsometer
   d. timber cruiser

8. The age of a living tree is determined using an instrument called a:
   a. Increment borer
   b. Planimetery
   c. Biltmore stick
   d. Stereoscope

9. The activity of gathering data for the purpose of estimating the volume of standing timber is called:
   a. Slumming
   b. Scaling
   c. Cruising
   d. Scribner's rule

10. The timber volume table that is used by' the U. S. Forest Service to measure timber sales is:
   a. Doyle's rule
   b. Scribner's decimal C
   c. Scribner's rule
   d. International log rule

11. The activity of measuring piled logs to determine their yield in board feet is called:
   a. Slumming
   b. Scaling
   c. Cruising
   d. Scribbing

12. The standard of measurement that is used to express biomass production is:
   a. Cubic feet
   b. Board feet
   c. Cubic meters
   d. Net weight

LEARNING ACTIVITIES

1. Cut some cross-sections 2-3 inches in width from several cut trees of different sizes. Assign students to work together in small groups with each group receiving one of the cross-sections of a tree. Assume that the tree was harvested last year. Determine the age of the tree at the time it was harvested. Determine some years when drought or other stressful factors affected the tree, and determine some years when growth conditions were favorable. Use pins to mark the annual ring deposited when significant events occurred, such as the end of World War II, or the year men walked on the moon.

2. Obtain some aerial photographs or maps of agricultural fields or timber sales areas from a government agency such as the Farm Service Agency or Forest Service. Also obtain some dot grid sheets from the same agency or purchase some from a forestry supply catalog. Invite a professional forester or soil conservation officer to instruct the class on the methods and purposes for measuring land area. Make sure each student successfully calculates the land area on his or her field photograph or map.