level). Roots generally vary considerably and are very difficult to model.

As a rule of thumb individual stem volume can be estimated to within $\pm 7.5\%$ of the true value and stand volume to within $\pm 5\%$. Often, the volume of individual trees is calculated to the nearest $0.001\,m^3$ ($0.0001\,m^3$ for very small trees) and at stand level to the nearest $0.1\,m^3\,ha^{-1}$ for research plots and $1\text{–}10\,m^3\,ha^{-1}$ in operational forestry.

Applications

Quantification of wood volume and volume growth is one of the most important forest measurement activities. The wood volume of a tree or a forest stand is an integral measure of solid substance for a major component of the forest ecosystem and a potential basis for estimates of tree biomass, dry matter production, and carbon storage. Furthermore, trading of wood products is often based on their cubic volume, and standing volume and volume growth are significant decision variables in forest management. Importantly, the magnitude and quality of growing stock is closely correlated with the economic potential of the forest as well as with its biological and social value. At the national level, accurate inventory information on volume, volume growth, and their distribution to owner categories, growth regions, forest types, species groups, etc., is a basic requisite for suitable, well-targeted, and efficient forest policies.

As forest management objectives gradually change over time and may vary considerably from place to place, it is becoming increasingly important that forest measurement variables can be used purposefully for a wide range of different aims. It is easy to invent new and unproven variables, but hard to think of any variables that are more robust and less expensive to measure than those from which wood volume is derived. Although dendrometry rarely provides causal models for science or for forestry, it certainly should continue to provide suitable measurements for the sustainable management of our forests.

See also: **Biodiversity**: Biodiversity in Forests. **Experimental Methods and Analysis**: Biometric Research; Design, Performance and Evaluation of Experiments; Statistical Methods (Mathematics and Computers). **Health and Protection**: Diagnosis, Monitoring and Evaluation. **Inventory**: Forest Inventory and Monitoring; Large-scale Forest Inventory and Scenario Modeling; Modeling; Multipurpose Resource Inventories; Stand Inventories. **Landscape and Planning**: Spatial Information. **Mensuration**: Growth and Yield; Timber and Tree Measurements; Tree-Ring Analysis; Yield Tables, Forecasting, Modeling and Simulation. **Plantation Silviculture**: Stand Density and Stocking in Plantations; Sustainability of Forest Plantations. **Resource Assessment**: Forest Resources; GIS and Remote Sensing; Non-timber Forest Resources and Products; Regional and Global Forest Resource Assessments. **Tree Physiology**: Shoot Growth and Canopy Development.

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Timber and Tree Measurements

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Introduction

Trees are complex three-dimensional structures that are very difficult to quantify or measure accurately. To overcome this complexity, the practice of tree measurement is generally to assume that portions of tree resemble simple shapes like cylinders, spheres, etc. A lot is known about these simple or Euclidean shapes, and this knowledge includes relationships between specific variables (e.g., radius of a sphere and the volume or surface area of that sphere). The closeness of the assumed shape to the real shape will partially control the closeness or the errors in estimating the quantity or size of a tree based on measurements of the simple variables. The study of the lengths, areas, and volumes of simple geometric shapes is called *mensuration*.

Forest mensuration is ‘the art and science of locating, measuring and calculating the length of lines, areas of planes, and volumes of solids; and the appropriate application of these calculations to trees and forest stands.’

A tree may be divided into various components that may be quantified in various ways. The most appropriate quantification will depend on the reason why the quantification is required.

Definitions

Bole/Trunk

This is the main woody part of a tree, which is the major source of woody products derived from a tree. It is a three-dimensional object with a cross-sectional area that decreases progressively with increasing height. The bole may be quantified by its volume, height/length, or size at a reference height. The number or volume of standard wood products also often quantifies the bole.

Bark

The bark is the outer sheaf of the bole, branches, and twigs. Bark provides protection for the tree and may be harvested for horticultural, agricultural, or medicinal purposes. The thickness of the sheaf varies with height and position, and whether the bark is persistent or deciduous. Volume or thickness at specific positions may quantify this component.

Leaves/Needles/Crown/Branches/Twigs

The branches and twigs of the crown support the display of the leaves or needles to capture radiant energy for photosynthesis. This component may be harvested as fodder or horticultural products. It is also strongly correlated with growth of the tree. Quantification can include measurements of volume or mass, depth/length of the crown along the bole, and size at a reference height.

Roots

Tree roots provide anchorage and storage (large roots) and access to water, minerals, and other elements in the soil (fine roots) and may be harvested for agricultural or medicinal purposes. Quantification is relatively rare, but is normally mass.

The following sections outline the issues and practices involved with measuring these tree components.

Bole/Trunk

Reference Height (Breast Height)

To allow measurements of bole size to be compared, a standard point on the trunk is defined. It is important that this point is at a convenient height near the ground and that it can be reliably located (and relocated) by different measurers. This standard height is termed *breast height*.

The actual location of breast height varies slightly between some countries. In continental Europe, South Africa, Australia, the UK, Canada and some former members of the British Commonwealth, breast height is defined as 1.3 m above the ground. The breast height convention in the USA, New Zealand, Burma, India, Malaysia, and some other countries is measured at 1.4 m (or 4′ 6″) above ground.

Breast height is a convention with a long history of use within forestry practice. However, other standard heights are also used. Some researchers in grazing and agriculture use bole size at 0.3 or 0.7 m above the ground as their standard height. This reference height is used because it has a strong relationship to the grass/crop/tree competition measurements. Researchers studying tree volume have also found very strong relationships between volume and the size of the bole at a relative height (e.g., 5% of the total tree height up from the ground). However, while 5% of a 30-m tall tree is only 1.5 m above the ground and therefore easily within reach, it is difficult to reach the same relative height on a 60-m tall tree.

Measurement at breast height (or other nominated height) may not always represent the appropriate size of a tree. For example, the volume of the tree bole may not be correlated with a measurement at a height that corresponds to a fork in the tree or a fire scar. Typical causes of unrepresentative points include:

- branches or forks
- nodal swellings
- malformations of the trunk due to genetics or disease
- wounds
- insect attacks.

Special rules apply where a tree forks near breast height. For example, if a fork is below breast height, the tree should be treated as double- or multi-stemmed (i.e., more than one tree). If the fork is above breast height, treat the tree as a single stem with multiple leaders. When swelling at breast height occurs due to multiple leaders, the breast height measurement is conventionally taken where the bole diameter is smallest below the swelling.

Special instructions are also necessary where buttressing and fluting are common. Measurement is commonly made above the influence of the buttress or fluting. Where this influence extends well up the bole, an arbitrary height is specified.

When repeat measurements on the bole are expected (e.g., permanent samples), the actual height of measurement should be clearly marked.

The representative size of the bole at a nominated height may be estimated by two common techniques:

1. Take two measurements equally distant above and below the nominated height. If there is little difference between these measurements, take the mean value as the representative size. If the difference in bole diameter at these two heights is relatively large, then a quadratic mean may be more appropriate.
2. Subjectively select a representative point and take measurements at this point. Although quicker than the above method, this approach may lead to bias.

Consistent definition of ground level is essential to maintain precision of measurements. Ground level generally excludes loose leaves and litter that is not incorporated into the soil. Clear this loose material away before taking measurements of height. Sloping ground presents another problem for consistency of measurement. Conventionally, ground level on sloping ground is taken to be the uphill side of a vertical tree, however the mid-point between the uphill and downhill side is used in some countries. If a tree is leaning, imagine which would be the uphill side if the ground were rotated to make the tree vertical. Thus, on flat land, ground level would be defined from the underside of a leaning tree.

Size at a Specified Height

Measurement of a tree bole at a specified height would be easy if the bole corresponded to a simple geometric shape. For example, if we could assume that the bole cross-section was like a circle, then we could measure the radius (r), diameter (d), circumference (c), or area (a). We can calculate all the other variables once we measure any one of them.

$$c = \pi \times d = 2 \times r \times \pi$$

$$d = c/\pi = 2 \times r$$

$$a = \pi \times r^2 = \pi \times d^2/4$$

where $\pi = 3.14159265\ldots$

However, the tree bole is rarely circular (or any other simple geometric shape) and the use of the above equations will only provide approximate estimates. The selection of which parameter to measure will depend on: (1) the use of the measurement; (2) the resources and tools available; (3) tradition; and (4) the acceptable error.

Radius (r): length from the center to the outside of the bole The radius is rarely measured in forestry. Radius cannot be measured on standing trees because the center of the tree needs to be accurately located. Because a bole is not circular, different measurements of radius are possible.

Diameter (d): length from the outside of the bole, through the center, to the opposite side Diameter is commonly measured in forestry. Again, because tree boles are not circular, different measurements of diameter are possible.

Diameter at breast height (dbh) is probably the most common measurement made on a standing tree.

Direct measurement of diameter commonly measures two different axes:

- the diameter of the maximum and minimum axis of the bole on trees that are clearly elliptical
- the diameter of the maximum axis and the axis at 90°
- the diameter of any two axes at 90° to each other.

The two diameter measurements are averaged using an arithmetic mean (most common) or a geometric mean (for highly elliptical boles).

The measurement of diameter on one axis is often acceptable when the data are only being used to group trees into diameter classes for a stand table.

Circumference (c): the length around the outside of the bole Circumference, also known as girth, is commonly measured in forestry, but usually it is then used to estimate bole diameter. If the bole were circular, diameter can be estimated as circumference divided by π. However, if the bole deviates from this ideal shape, then this calculation will overestimate the diameter. The size of this bias is not constant and will vary with the degree and type of deviation. However, this bias is rarely considered significant.

An advantage of measuring the bole girth is that there is no sampling error involved. Unlike diameter measurements, the result does not depend on which axis was selected to measure. This leads to an increase in measurement precision. In addition, if a tree bole changes by 1 cm in diameter, the girth measurement changes by 3.1415... cm (π). Thus, finer readings of the change can be read.

Sectional area (a): the area of the cross-section of the bole This parameter is very important in forestry. The sectional area at breast height is used in many relationships and is called basal area (g).

Sectional area could be directly measured using a planimeter, but this is rarely done. Instead, sectional area is calculated from diameter after assuming that the bole has a circular shape. If the diameter is estimated from a measurement of circumference, then the basal area estimate will be an overestimate (positively biased). If the diameter is estimated from the mean of measurements on one or two axes, then an over- or underestimate of the sectional area is possible. The geometric mean of the maximum and minimum axes is less biased than other approaches.

Height

Total tree height may be defined as the distance along the axis of the bole of the tree from the ground to the uppermost point (tip). In trees with a single, straight stem, this corresponds to the total length of the stem.

The total height (or potential height) of a woody plant is used to distinguish shrubs from trees. For example, a woody plant, usually with a single stem, that is more than 5 m tall may be classified as a tree. Tree height is also well correlated with other important tree and stand parameters.

On leaning trees, height may also be expressed as the:

- vertical component – the vertical distance from the ground to the uppermost point of the tree
- slope or linear component – the length from the base of the tree along the axis of the bole to the uppermost tip of the tree.

The linear component will always be greater than the vertical component for leaning trees. However, unless the lean is severe, the difference is rarely critical. The tree must be leaning by more than 18° off vertical before the difference exceeds 5%. A lean in excess of 15° looks severe.

The vertical component (V) can be calculated from the slope (S) height (and vice versa) if the horizontal distance (H) from the base of the tree to the point directly beneath the tip is known.

$$S = \sqrt{H^2 + V^2}$$

Merchantable height Merchantable height may be defined as the distance from the base of the tree to the first occurrence of either:

- the highest point on the main stem where the stem diameter is not less than some specified value or
- the lowest point on the main stem, above the stump, where branching or other defect limits utilization of the stem.

Merchantable height is used to predict conventionally merchantable woody material. Unfortunately, it is a variable quantity that depends on the specification of the merchantable products at the time of measurement.

Shape (Form)

The diameter of a tree bole generally decreases or tapers from the base to the tip. The way in which this decrease occurs defines the bole form. This taper can occur at different rates and in different ways or shapes. Tree form is complex; however, portions of the tree bole may approximate general geometric shapes like cylinders, conoids, and truncated paraboloids and neiloids. The base of the tree tends to be neiloid while the tip tends to be conoid. The main part of the bole tends to be paraboloid. The points of inflection between these shapes however are not constant. Species and genotype predispose the bole to certain forms, but a wide range of environmental and contextual factors will influence this form.

There is a complex interaction between the bole form and the tree crown. Thus, any factor that influences the crown may also influence the bole form. Different parts of the bole grow at different rates as environmental and other factors affect the crown and the way photosynthates are distributed. The major theories that attempt to explain the shape of the bole may be grouped into three general types:

1. Mechanical: argues that the bole shape corresponds to the most economical shape of a beam of uniform resistance to bending anchored at the base, and functioning as a lever arm. If the tree were firmly anchored, the most economical shape for this beam would be a uniform taper similar to a truncated cubic paraboloid. However, if the tree stem were not firmly anchored to the ground, a quadratic paraboloid shape would be more consistent with the mechanical needs imposed by this assumption.
2. Transportation: based on ideas that deal with the movement of liquids through pipes – tree bole shape is related to the need of the tree to transport water or nutrients within the tree (water-conducting theory and nutritional theory of stem form respectively).
3. Hormonal: growth substances, originating in the crown, are distributed around and down the bole to control the activity of the cambium. These substances would reduce or enhance radial growth

at specific locations on the bole and thus affect bole shape.

Overall or average shape is in some cases quantified as an index of a nominated bole dimension to a reference shape or dimension. Two common indices include:

1. Form factor: the volume of the stem compared to the volume of a standard geometric solid of the same diameter at the base and total height. The most common form factor is the breast height form factor, which is defined as the ratio of the bole volume to a cylinder of the same height as the bole and with a sectional area equal to the sectional area of the stem at breast height. Specific breast height form factors suggest general stem shapes: 0.25 neiloid; 0.33 conoid; 0.50 quadratic paraboloid; 0.60 cubic paraboloid; and 1.00 cylinder.
2. Form quotient (FQ): the ratio of the diameter at some point above breast height to the diameter at breast height. The absolute FQ is used to group trees into form classes. This quotient is calculated by measuring the diameter at a height halfway between breast height and total tree height. This diameter is then divided by the diameter at breast height and expressed as a decimal. Absolute FQs also suggest general stem shapes: 0.325–0.375 (FQ class 35) neiloid; 0.475–0.525 (FQ class 50) conoid; 0.675–0.725 (FQ class 70) quadratic paraboloid; 0.775–0.825 (FQ class 80) cubic paraboloid.

More precise quantification of bole shape is now commonly achieved through the development of mathematical equations that predict the diameter or sectional area of the bole at any height up the tree. These mathematical equations, called taper equations or taper models, use polynomial, exponential, and other types of mathematical structures to relate diameter or sectional area at nominated points up the bole to a reference diameter (diameter at breast height), total tree height, and the relative height where the prediction is required.

Volume

Stem volume is a function of a tree's height, basal area, shape, and, depending on definition, bark thickness. It is therefore one of the most difficult parameters to measure, because an error in the measurement or assumptions for any one of the above factors will propagate to the volume estimate.

Volume is often measured for specific purposes, and the measurement and interpretation of the volume estimate will depend on the units of measurement, standards of use, and other specifications. For example:

- Biological volume is the volume of stem with branches trimmed at the junction with the stem, but usually excluding irregularities not part of the natural growth habit (e.g., malformation due to insects, fungi, fire, and mechanical damage).
- Utilizable or merchantable volume excludes some volume within irregularities of the bole shape caused by normal growth in addition to those irregularities not part of natural growth. For example, the volume contained in the swelling around a branch node may be excluded because this volume could not be utilized (by a nominated user).
- Gross volume estimates would include defective and decayed wood.
- Net volume estimates would exclude defective and decayed wood.

Thus, the type of volume measured must be reported for reliable interpretation. For example, the net merchantable volume of sawlogs in a tree will be significantly different from the gross biological volume.

Calculations of merchantable volume may also be based on true cubic volume or product-oriented volume. Product-oriented volume is the volume of a nominal product that could be cut from the log or stem under specified conditions and assumptions.

Direct and indirect methods for estimating volume are available. The direct methods tend to divide the stem into theoretical or actual sections and measure the volume of these sections:

- Fluid displacement: essentially, the tree stem is cut into manageable sections and immersed in a bath. The amount of water displaced equals the volume of the section. Also called xylometry, this approach most accurately measures gross biological volume.
- Graphical method: measurements of sectional area are made every 1–2 m up the tree bole and then plotted against height (in meters) on a scaled graph. Freehand lines join the plots, and then the area under the curve is equivalent to the cubic volume of the bole.
- Standard sectional method: the main stem, up to merchantable height, is theoretically divided into a number of (mostly) standard length sections. The standard length is normally 3 m (10 ft). The exception to the standard section is the odd log – a section less than the standard length that fits

between the last standard section and the merchantable height. These sections are assumed to be second-degree paraboloids in shape. The bole from the merchantable height to the tip is assumed to be conoid in shape. Equations to predict the volume of second-degree paraboloids and conoids from measurements of length and sectional area are then used to estimate the volume of each section.

The indirect methods include:

- Volume tables: a tree volume table is a statement of the expected volume of a tree of nominated dimensions in a particular stand or population. The number of measurements or dimensions determines the number of entry points or ways into the table. For example, a one-way table normally uses dbh or basal area as the only measurement; a two-way table may use dbh and height; while a three- or more way table would include measurements that correspond to bark thickness or taper.
- Volume equations: volume equations are a mathematical statement of the expected volume of a tree of nominated dimensions in a particular stand or population. The input variables to the equations can also include diameter (at breast height and other heights), height, taper, and interaction terms.
- Integrating taper equations: where a taper function is continuous and able to be integrated, the volume of the bole can be determined by integration. Where this is not feasible, the equation can be used to predict the sectional area at 1- or 2-m intervals up the tree, and volume can be calculated as for the graphical method.
- Variance reduction methods (e.g. importance sampling and centroid sampling): variance reduction methods use the knowledge contained in taper functions to improve the precision and cost of estimating sample tree volume. Essentially, a taper model predicts tree shape and hence sectional area and cumulative volume at any height up the tree. A sample height on the tree is selected and the bole measured. The difference between the measured and predicted size at that height is used to correct the volume estimated from the original taper equation. Various methods differ in the way the sample height is selected and the way the original estimate is corrected.

The volume of wood contained in a tree bole is of primary interest to sawmillers and these millers are interested in the quantity of product they can extract from the bole or logs cut from the bole. Therefore, product-oriented volume definitions rather than the true volume estimates of the three-dimensional shape are of more direct interest. Log rules are a common attempt to estimate volume that is of direct interest to these wood-processing industries.

A log rule is a table or formula showing estimated volume, in standard units, for various log diameters and lengths. During the 1900s, at least 100 log rules were devised. Several sets of these rules are widely adopted throughout the USA, but have not become common in other regions of the world.

The major log rules in the USA predict the production of the board foot. A board foot is equivalent to a plank 1 in. (2.5 cm) thick and 12 in. (1 ft: 30 cm) square; it contains 144 cubic in. (900 cm^3) of wood. However, none of these rules can accurately predict the mill output of boards, except when near-cylindrical logs are sawed according to rigid assumptions on which the rules are based.

Bark

Bark is the outer sheath of the tree. Some trees annually shed bark, while others have persistent bark. The inner bark transports photosynthates from the crown, while the outer bark has a major protective role. The bark protects the bole from insects and damage from physical abrasion. It is also important for fire resistance. Bark thickness normally decreases from the ground to the tree tip. This decrease may be related to the rate of taper of the bole, but there are often irregularities and anomalies. Bark thickness varies with species; genetic constitution; site; tree age, health and size; rate of growth; bark persistence; and position along the bole.

On felled trees and logs, bark thickness can be directly measured at the cut ends. A small chip of bark can also be cut and the thickness measured. However, cutting the chip with an axe may compress the bark and provide biased estimates. Where a ring of bark can be removed, the diameter overbark and diameter underbark can be measured. Bark thickness is one-half of the difference between overbark and underbark diameter.

On standing trees, bark thickness is measured indirectly. A probe is pushed through the bark to meet the wood interface and the length of penetration is measured. Because bark varies around the bole, an average of four measurements (evenly spaced or where the caliper arms contact the bole) is normally required.

Bark sectional area is normally calculated as the difference between overbark and underbark sectional area. Similarly, bark volume is the difference between overbark and underbark volume, where volume is by the standard sectional or other technique. Thus diameter overbark and bark thickness, at a number of heights up the bole, needs to be determined.

Many hardwood trees maintain a reasonably constant ratio of diameter underbark to diameter overbark along the tree bole. Thus diameter underbark at any point along the tree may be calculated by multiplying overbark diameter by the ratio of under- to overbark diameter at breast height.

For many other tree species, particularly conifers, the under- to overbark diameter ratio increases with increasing height along the bole. That is, the relative bark thickness decreases. A few rare species have a decreasing ratio of under- to overbark diameter.

Where the ratio of under- to overbark diameter is not constant, statistical equations may be developed to predict bark thickness from measurements at ground level.

Leaves/Needles/Crown/Branches/Twigs

Crown Diameter

The width of a crown can be measured by projecting the edges of the crown to the ground and measuring the length along one axis from edge to edge through the crown center. Unless the crown has a regular shape, the width measured will depend on the axis selected for measurement. If the crown width is being used to estimate sectional area (used in crown surface area and volume calculations), two axes are normally selected and averaged.

Crown Depth (Length)

Crown depth is the length along the main axis from the tree tip to the base of the crown, where the base of the crown is defined by:

- the lowest complete branch whorl or major branch that forms part of the canopy (used in calculating upper crown length) or
- the lowest live branch, excluding epicormics or water shoots (used in calculating lower crown length).

The depth of the crown is often expressed as:

- crown length ratio (crown length divided by total tree height)
- green crown percent (crown length ratio expressed as a percentage of total tree height).

Crown Surface Area

Crown surface area is a surrogate for the area available for leaves to capture radiant energy from the sun or atmospheric gases and pollution. As the most actively photosynthetic leaves are the young leaves near the crown periphery, crown surface area is a useful index of growth. Crown surface area is calculated by assuming the crown is a solid geometric shape (e.g., conoid, paraboloid, or hemisphere) with a measured crown depth and crown width.

Crown Volume

Crown volume is calculated in a similar way to crown surface area. It is normally estimated from the crown width and crown depth after assuming a regular geometric shape.

Crown Mass

The only direct way to determine crown mass is to fell the tree. Once felled, the leaves, twigs, and branches are separated into discrete pools and the fresh or green weight of these components is determined. The dry weight (and mineral content if required) of a subsample of components is also determined. The ratio of dry-to-fresh weight is used to estimate the original crown's total mass. A variety of sampling approaches has been designed to estimate an unbiased ratio of dry-to-fresh weight.

Indirect approaches to estimating crown mass include the development of statistical equations of the correlation between the expected mass of a tree crown or branch of nominated dimensions in a particular stand or population.

Roots

The measurement of mature tree roots is difficult and rare. The mass of smaller, pot-grown roots is determined by washing away the potting material and direct measurement. The mass of the large roots for mature trees may be estimated by digging a trench around the tree and then pushing the tree over. Many of the major roots will stay attached to the pushed bole. These roots can then be detached and weighed.

Indirect approaches to estimating root mass include the use of estimated root : shoot ratios and the development of statistical equations of the correlation between the expected mass of the roots and dbh or basal area.

See also: **Mensuration**: Forest Measurements; Growth and Yield; Yield Tables, Forecasting, Modeling and Simulation. **Resource Assessment**: Non-timber Forest Resources and Products. **Solid Wood Products**: Lumber Production, Properties and Uses.

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Growth and Yield

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The Purpose of Forest Mensuration

Forest mensuration (the study of measurement) is the research discipline that develops and evaluates both the theoretical basis and practical application of systems for assessing the growth and yield of trees and forest stands. Originally subjective assessments and qualitative systems were used for characterizing the productivity of forest stands; however, methods of mensuration developed over the past 200 years have allowed the adoption of a strictly quantitative approach.

Forest inventory techniques are underpinned by a substantial body of research on measurement methods, and on approaches for the processing of measurements to derive summary results that provide an indication of current and potential future yield. Often the term mensuration is also used to describe the conventions adopted in standardized procedures used by forest industries for quantifying forest resources and as part of production forecasting.

A comprehensive forest mensuration research program involves developing and evaluating:

- measurement instruments and conventions for their use
- procedures for quantifying the structure and yield of forest stands
- descriptions and analyses of tree and stand growth patterns
- relationships between potential stand yield and site factors
- mathematical models of forest structure, growth and yield.

Measurement Variables, Instruments, and Conventions

The essential endeavour of mensuration involves working out how to measure variables relevant to the growth of trees and forest stands. Traditionally measurements are taken of external physical characteristics of a tree or sample of trees that are easy to measure and obviously related to growth. Notable examples of tree growth variables include:

- total height
- stem diameter, circumference, or cross-sectional area
- stem volume
- gross dimensions of the crown.

Sometimes more complex measurements are included as part of mensuration procedures, for example involving detailed assessments of tree and stand architecture. A variety of methods exists for measuring and describing the architecture of individual trees or stands, such as based on:

- the shape and size of crown(s)
- the detailed disposition of branches, foliage, and roots
- the distribution of tree species and size classes in a stand.

A wide range of instruments has been applied to the measurement of growth variables of trees as illustrated in **Table 1**.

Conventions and standards for the measurement of growth and yield variables are very important in order to ensure consistency. These need to cover not only the typical trees in a population but also give clear rules for the measurement of unusual trees (**Figure 1**). Conventions are also required for the measurement of felled trees and any cut produce such as roundwood. Consistency is important if measurements and derived results are to be repeatable. This is essential in the forest industries when buying and selling of quantities of wood. It is also important in a research context when the growth of trees or stands needs to be monitored over time, for example to find out if production is consistent with growth.

An important function of measurement conventions is to prescribe levels of accuracy for measurement. For