A Review of Past Research on Dendrometers

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ABSTRACT. The purpose of a dendrometer is to measure tree diameter. Contact and noncontact dendrometers accomplish this task by collecting different metrics, including girth or distance between tangent points on a tree stem. Many dendrometers have been developed in the last quarter century and many have been retired. This article summarizes instrument developments and application results, contains an interpretation of the results, and provides guidance for dendrometer selection. For. Sci. 46(4):570–576.

Additional Key Words: Instrumentation, diameter measurement, forest inventory, mensuration.

Diameter measurement is an important part of most forest analyses. Many types of diameter measuring instruments (dendrometers) exist, possessing widely differing properties (e.g., accuracy, precision, cost, operational simplicity, etc.) Yet considerable time has elapsed since a state-of-the-art assessment of dendrometers has been published. Grosenbaugh (1963) and Brickell (1976) present very thorough coverage of dendrometer history, development and evaluation, published to date of their respective reviews. Since these reviews were published, there have been new dendrometer studies but no summary works. Given this time lapse, the acceleration of technological advances, and new devices being studied, a review is needed. This report provides a summary of more recent studies, introduces cautions about comparing independent studies, and indicates guidelines for dendrometer selection.

Contact Dendrometers

Dendrometers can initially be divided into two categories: those that contact the stem physically and those that obtain measurements remotely. Conventional calipers and diameter tapes [included are dendrometer bands (Keeland 1993) and rubbery rulers (Costella 1995)] are the primary "contact" dendrometers used by foresters. The simplicity of their manufacture, design, and operation have left them immutable since their inception with the only significant technical advances coming in the form of digital recording devices. Arguments about the relative merits between tapes and calipers have gone on for years, and the following conclusions have been affirmed. These instruments acquire two different metrics. Calipers measure the distance between parallel tangents of a closed convex region, while diameter tapes measure the perimeter or girth of this region (Figure 1). Diameter tapes can be said to be more "consistent" (Avery and Burkhart 1994, p. 97) than calipers as the measurement represents an average of all diameters over all directions, thus eliminating variability caused by direction. However, it is now recognized that departures from the assumptions of convexity and circularity impede the simple attainment of the elusive "diameter." If used properly, both tools provide comparable results with the majority of bias caused by mathematical models that do not accurately represent stem cross sections (Brickell 1970, Biging and Wensel 1988). More on cross-sectional geometry and related concepts can be found in Matérn (1990).

The electronic tree measuring fork (ETMF) (Binot et al. 1995) is the only other true contact instrument. The ETMF has two arms, 60˚ apart, that contact the tree. Diameter is computed by measuring the speed of ultrasonic waves from

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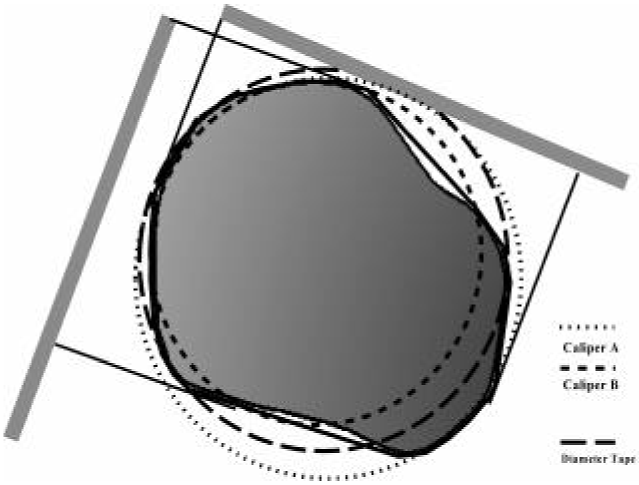

Figure 1. Comparison of caliper versus tape derived cross-sectional area estimates (assuming a circular model). Deviation from an assumed circle will always result in a positive bias ($\hat{D} - D > 0$) when using taped measurements and introduce an unpredictable directional variation in caliper measurements.

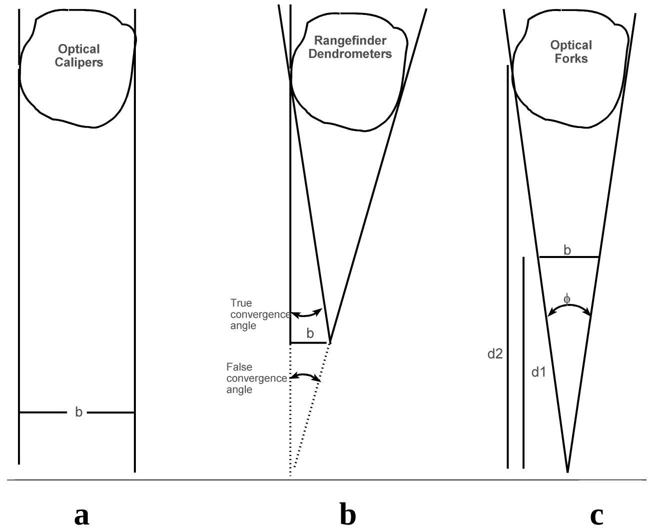

Figure 2. Comparison of principles of three types of optical dendrometers. (a) For the optical caliper, the baseline distance (*b*) is adjusted and substituted as a direct measurement of diameter (distance is not necessary). (b) For the rangefinder, *b* is typically fixed and true and false convergence angles are used to calculate distance and ultimately, diameter. (c) Using an optical fork, two distances (*d*1 and *d*2) and a baseline distance (*b*) are required for diameter.

a transmitter to a receiver. In the study by Binot et al. (1995), diameter results were comparable to calipers and diameter tapes with a 35 to 40% time savings. Concerns were noted regarding bias caused by signal interference induced by bark characteristics of some species.

A plethora of other devices [e.g., the Biltmore stick (Jackson 1911), sector fork (Bitterlich 1998), Samoan stick (Dixon 1973), etc.] are hybrid instruments that must both contact the stem and be interpreted visually. These are based on the optical fork principle, which will be discussed later, with the difference being that the distance from the stem is measured by physical contact. Studies by Matérn (1990) found these instruments all to have a positive bias, increasing proportional to diameter, compared to conventional caliper measurements. Although these tools are very handy and probably the most common instruments among practitioners, their reliability and subjectivity generally preclude their use in scientific or large-scale inventory work.

Noncontact/Optical Dendrometers

Unlike contact dendrometers, optical dendrometers are devices that do not require the stem to be approached. Many styles of optical dendrometers have been designed based on the fork, caliper, and rangefinder principles (Grosenbaugh 1963). To measure a diameter optically, two lines of sight must exist between the observation location and two tangents on the stem lying in the plane representing the desired diameter. Perspective geometry utilizing various angle and distance measurements is then used to calculate the diameter of the stem in this plane. The following sections discuss each type in further detail, and Table 1 shows summary information for some empirical studies using these optical dendrometers.

Optical Calipers

Optical calipers use two parallel lines of sight to view points on a stem that represent the diameter (Figure 2a) making measurement precision distance invariant (disregarding vision restrictions). Direct readings of parallel tangents require only aspect to be controlled when making measurement comparisons with conventional calipers. Some of the early optical calipers were noncoincident (Clark 1913) and experienced difficulties maintaining parallelism, but instruments using pentaprisms (Wheeler 1962, Eller and Keister 1979) or parallel mirrors (McClure 1969) have succeeded in producing excellent results. Diameters are limited to the instrument's length (usually 91 cm), though longer, less portable, versions can easily be constructed (Grosenbaugh 1963).

A number of empirical studies have been performed with pentaprisms since their resurgence in the early 1960s. Wheeler (1962) measured ten trees at two heights (1.4 and 5.3 m) using a Wheeler's pentaprism caliper. Measurements were within ±13 mm of wooden caliper measurements using a 95% chi-square test. Robbins and Young (1968) compared three dendrometers to conventional calipers: the Wheeler pentaprism, an early version of the McClure pentaprism (that only permitted direct readings to the nearest 13 mm), and a diameter tape. Twenty stems were measured, containing marked diameters at 6 heights (from 1.5 to 10 m). The ranges of errors relative to conventional calipers were –18, 33, –18, 20, and –20, 25 mm for diameter tape, McClure, and Wheeler pentaprism, respectively. All instruments studied had a slight positive bias between 3 and 5 mm. In a second study on ten trees at eight heights (1.5 to 10 m), Robbins and Young (1973) found the McClure pentaprism produced greater average differences than the Wheeler pentaprism and the Barr & Stroud[1] dendrometer. The Wheeler pentaprism demonstrated a time savings over both of the other instruments and has

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 1. Details of selected empirical dendrometer studies.

Investigator/s	Instrument	Accuracy results	# stems	# obs	Genus	Distance (m)	Diameter range (cm)	Height range (m)	Location method
Optical calipers									
Wheeler (1962)	Wheeler pentaprism	13 mm[1]	10	40	*Pinus*	NA	16–41	1.4–5.3	NA
Robbins & Young (1968)	Wheeler & McClure pentaprisms	(–17.8, 33.0) mm[2]	20	120	4 spp.	NA	10–43	0.2–9.9	Pole/paint
Robbins & Young (1973)	Wheeler & McClure pentaprisms	(–15.2, 33.0) mm[2]	10	80	*Pinus*	NA	25–42	1.5–9.9	Tape
Garrett et al. (1997)	Wheeler pentaprism	(–16, 37%)[3] 10% on ave	25	300	*Pinus*	NA	19–56[12]	1.4–NA	Paint
Parker & Matney (1999)	Wheeler pentaprism	–4.16 ± 0.56%[4]	96	96	*Pinus*	NA	15–62	5	Line
Rangefinder dendrometers									
Jeffers (1955)	Barr & Stroud FP-7	15 mm[5]	NA	408	NA	NA	NA	NA	NA
Grosenbaugh (1963)	Barr & Stroud FP-9	4.1%[5] (vol)	8	56	NA	11–42	24–91	0.3–14.9	Tape
Mesavage (1969)	Modified Zeiss Teletop	–0.4 / 0.5[6]	12	12	Hardwoods	12–32	25–69	1.4	Nails
Sandrasegaran (1969)	Barr & Stroud FP-12	(–0.5, 2.5) mm[2]	7	7	*Pinus*	NA	13–28	1.4	NA
Bell & Groman (1971)	Barr & Stroud FP-12	7.7 mm[1]	12	81	*Pseudotsuga*	25 & 35	13–48	1.4–27.5	Pole/nails
Bower (1971)	Zeiss Telemeter Teletop	1.28% ft^3 vol[7]	10	~90–180	*Pinus*	NA	33–47	0.2–16	Clearly
	Barr & Stroud FP-15	1.04% ft^3 vol[7]	10	~90–180	*Pinus*	NA	33–47	0.2–16	Clearly
Robbins & Young (1973)	Barr & Stroud	(–22.9, 25.4) mm[2]	10	80	*Pinus*	NA	25–42	1.5–9.9	Tape
Brickell (1976)	Barr & Stroud FP-12	6.4 mm[5]	87	261	*Pinus*	"Reason-able"	13–79	1.4	Tape
Eller & Keister (1979)	Breithaupt Todis Dendrometer	7 mm[1]	38	38	*Pinus*	NA	5–29	1.9–19.2	Bullethole
Garrett et al. (1997)	Barr & Stroud	(–15.5, 29.7%)[3] 7% on ave	25	300	*Pinus*	NA	19–56[12]	1.4–NA	Paint
Williams et al. (1999)	Barr & Stroud FP-15	8.8 mm[8]	369	1,187	*Pinus*	NA[9]	NA	1.5–11	Paint

(Table 1 continues on next page)

finer graduations and greater magnification than the McClure instrument. A range of differences between –16 and 37% was presented by Garrett et al. (1997) for breast height and undefined upper stem diameters on 25 stems. Parker and Matney (1999) experienced a standard error of 0.56%, about a mean percentage difference of –4.16% for diameters at 5 m heights using a Wheeler pentaprism. Efficiency and ease of use are the consistently noted advantages of optical caliper instruments.

Rangefinder Dendrometers

The remaining two types of optical dendrometers have lines of sight that intersect. This means that diameters are not direct measurements, but rather calculations of diameter with trigonometric formulas. This is an important consideration when evaluating results. If the cross-section is not circular, the points being measured represent different diameters with any change in view angle (including distance). Measurement precision is variable with these instruments based on distance and in some cases diameter. Rangefinder dendrometers use either a fixed baseline distance or viewing angle and the ability to accurately measure the alternate variable to obtain true and false coincidence angles (Figure 2b) from which the radius of the stem at that location is calculated.

There have been many studies done with varying models of the Barr & Stroud—a short-based, split-image, coincident, magnifying dendrometer. Jeffers (1955) obtained a 95% confidence interval of ±15.2 mm in field tests with an added caveat that standard deviations three times larger may be common where visibility is obscured. Also, with the model FP9, Grosenbaugh (1963) found that volumes of individual trees would be within 4.1% of taped volumes two-thirds of the time. The FP12 performed very satisfactorily in several tests (Sandrasegaran 1969, Bell and Groman 1971, Robbins and Young 1973, Brickell 1976) before modifications (Mesavage 1967) were implemented in the last model—the FP15 (Mesavage 1969a). This unit was found to be more precise (Bower 1971) than another instrument modified by Mesavage (1969b), the Zeiss Telemeter Teletop. Now out of production (Ferguson et al. 1984), the Barr and Stroud continues to be a means of comparison to other instruments (Garrett et al. 1997, Williams et al. 1999). The Breithaupt

Table 1. (continued)

Investigator/s	Instrument	Accuracy results	# stems	# obs	Genus	Distance (m)	Diameter range (cm)	Height range (m)	Location method
Optical forks									
Marsh (1952)	35 mm camera	(20.3–63.5) mm[9]	NA	NA	NA	NA	NA	NA	NA
Vaux (1952)	Meterscope	9.2 & 10.4 mm[10]	100	100	NA	NA	ave 76	1.4–5.8	NA
Bradshaw (1972)	35 mm camera w/ 135 mm lens	9.9 mm[5]	1	26	*Pinus*	~20	30–76	1.2–26.2	Bullethole
Qazi (1974)	Forestmeter	(–22.9, 20.3) mm[2]	NA	22	NA	NA	21–83	NA	NA
Qazi (1975)	Sathi	(–45.7–38.1) mm[2]	22	22	*Dalbergia*	NA	21–102	1.4	NA
Crosby et al. (1983)	35 mm camera w/ 200 mm lens	2%[5]	20	60	*Pinus*	10	?–50	5–10	Paint
Fairweather (1994)	Criterion laser instrument	8 mm[11]	50	300	*Quercus*	8–15	ave 33	1.4–5	Tape
Liu (1995)	Criterion laser instrument	(–77, 22.9) mm[2]	2	>250	Metal pole	10–40	9–44	1–21	Paint
Garrett et al. (1997)	Tele-relaskop	(–10.3, 30.3%)[3] 10% on ave	25	300	*Pinus*	NA	19–56[12]	1.4–NA	Paint
	Relaskop	(–28.6, 20.9%)[3] 11% on ave	25	300	*Pinus*	NA	19–56[12]	1.4–NA	Paint
	Criterion laser instrument	(–31.7, 22.7%)[3] 8% on ave	25	300	*Pinus*	NA	19–56[12]	1.4–NA	Paint
Takahashi et al. (1997)	Minolta MC-100 camera	4.9 mm[5]	NA	~70–80	*Cryptomeria*	15–24	13–35	1.2–5.2	NA
Clark et al. (In Press)	Kodak DC120 Digital Camera	40 mm[1]	20	669	*Quercus*	9–15	4–66	1.4–20	None
Parker & Matney (1999)	Tele-Relaskop	1.54 ± 0.66%[4]	96	96	*Pinus*	NA	15–62	5	Line
	Criterion laser instrument	–1.92 ± 0.60%[4]	96	96	*Pinus*	NA	15–62	5	Line
Williams et al. (1999)	Criterion laser instrument	14.3 mm[8]	369	1,187	*Pinus*	NA[13]	NA	1.5–11	Paint

1 95% confidence (chi-square distribution).
2 Range of deviations.
3 Range of percent differences for four groups of measurements.
4 Mean percent difference and standard error (mean diameter 320 mm).
5 67% confidence.
6 Percent bias/coefficient of variation (percent).
7 Percent error.
8 67% confidence after removal of bias (e.g., standard deviation assuming normal distribution).
9 Range for horizontal and oblique photos, respectively.
10 Average deviation ($|x\text{-}y|/n$) of 10 groups at 1.4 and 5.8 m heights, respectively.
11 No statistical information ave. range from –10.7 to 17.3 mm.
12 Personal communication.
13 Variable radius plots.

Todis dendrometer (Eller and Keister 1979) and other teletop instruments (Mesavage 1969b, Grosenbaugh 1963, Brickell 1976) differ from the Barr and Stroud in that the convergence angle is fixed and range is measured by varying the baseline distance. What differentiates these instruments from optical calipers, also having two pentaprisms mounted on a scale, is the use of a deflecting prism to define a convergence angle. The advantages of these instruments compared to other similar contemporary instruments are instrument costs and direct measurement readings. Reduced weight is an advantage in Mesavage's (1969b) modified teletop as opposed to the greater weight of the Breithaupt Todis (Eller and Keister 1979). Mesavage (1969b) reported a coefficient of variation of 0.5% with a percent bias of –0.4% for 12 breast height diameters using a modified teletop instrument. Breithaupt Todis measurements were unbiased within ±7 mm of the actual 95% of the time (Eller and Keister 1979).

Optical Forks

Optical forks use the principle of similar triangles to determine the angle between two intersecting tangents of the stem at the desired diameter location (Figure 2c). Distance from the line of sight intersection to the point of measurement (range, $d2$) needs to be obtained as well as the distance ($d1$) to a baseline (b) measurement.

Some of these dendrometers work with a fixed fork angle where $d1$ and b are defined by the "apparatus"—whether it be a wedge prism alone (Rennie and Leake 1997), a wedge prism mounted to one lens of an ordinary pair of binoculars (Bitterlich 1984), or any other object of set dimension (thumb, coin, etc.) placed at a set distance (e.g., arm length) from the eye. Any number of devices have been used with distance measuring methodologies ranging from contact (Stoehr 1960, Qazi 1975), to pacing alone, to taped measurements using an inclinometer for horizontal distance and height calculation (Vaux 1952, Rennie and Leake 1997). The observer must adjust the range (*d*2) to the stem until the limiting distance of the apparatus is achieved. Although the components of these "instruments" are inexpensive, implementation is challenging.

Other optical forks vary or measure the line of sight angle. Military binoculars having a mil-scale (Forbes 1955), a transit fitted with a reticle (Robinson 1962), and other handmade instruments (Qazi 1974) have been used to accomplish this purpose. The Spiegel Relascope (Rennie and Leake 1997) and the Tele-relaskop (Parker 1997) are two commercially available units that use pendulous relative unit scales from which heights and diameters are determined given one known height, diameter, or distance. The multipurpose Relascope has not fared well when used to measure upper stem diameters (Garrett et al. 1997, Ashley and Roger 1969, Rennie and Leake 1997). Relascope errors are sometimes attributed to a lack of magnification, which is improved with the 8× magnification of the Tele-relaskop. The latter instrument has been shown quite capable for diameter measurements (Garrett et al. 1997, Parker 1997), but not very useful for height determination (Williams et al. 1994). Cameras also fit into the optical fork category. Rather than measuring the angle at a point between the intersection of the lines of sight and the diameter being measured, a measurement is taken from an image. Marsh (1952) provided some of the first results of using terrestrial photogrammetry to measure tree diameters. His reported results were not very good: ±63.5 mm for oblique photos and ±20.3 mm for horizontal photos. Ashley and Roger (1969) designed a device and procedure that placed the camera in a set orientation to the stem. They did not present any field test results for this device, but reported an accuracy of ±7.6 mm for laboratory measurements of fixed targets (every 5 ft up to 100 ft on a flat surface). Bradshaw (1972) used a camera with a 135 mm lens and a basic scaling formula to obtain 26 diameters from a single stem with an accuracy of ±9.9 mm. Another study using a 200 mm lens and a scale of known length was conducted by Crosby et al. (1983). Average errors reported by this study were 0.063% and 0.089% for black and white photos and slides, respectively, with standard deviations of 1.91 and 2.40% on diameters less than 50 cm. In a study by Takahashi et al. (1997), a prototype range-finding camera with a 500 mm lens produced results with mean error of +0.15 mm and standard deviation of 4.9 mm, after corrections for false diameter and distance. In another experiment, 29 diameter measurements of hinoki (*Chamaecyparis obtusa*) stems produced a mean error of +1.6 mm and standard deviation of 4.6 mm, after corrections for bark and systematic errors. Most recently, Clark et al. (in press) used a nonmetric digital camera to measure diameters within 40 mm at any heights to 20 m and within 25 mm at heights below 5 m.

The most recent advancement for dendrometers is the use of laser instruments (Carr 1992) to measure distance finally eliminating concerns about tree lean (Grosenbaugh 1980, 1981, 1991). This is accomplished by measuring the time lag between emission and reception of precisely directed energy pulses from the unit. Diameter accuracies as reported in some empirical studies range from 8 mm (Fairweather 1994) to 14.3 mm (Williams et al. 1999). Some criticisms of current instruments include: understory obstructions interfering with distance measurement, parallax effects, and difficulty viewing through the reticle (used to measure the angle between the lines of sight).

Comparing Independent Studies

Table 1 is shown for summary purposes with a caution about the examination of the results. The numbers alone should not be interpreted apart from the conditions of the study or the experimental design since results can be affected more by the experimental conditions than the effects of manufacture or design (Bruce 1975). Careful attention should be paid to the description of the experimental procedures and conditions. Measurement conditions (e.g., low light conditions, terrain, species, morphology, understory, wind) may affect the performance of some instruments more than others. Experimental procedures (e.g., marked observation points, control for aspect, range of diameters, heights, distances) and statistical analysis (e.g., paired observations vs. mean error, standard deviation vs. 95% chi-square, percent vs. absolute units) can influence results or prohibit side-by-side comparison between studies.

Dendrometer Selection

Despite the great variation among users and applications, the primary goal of dendrometer selection is universal—to select an instrument that will produce results of specified accuracy at the lowest cost. Often either cost or accuracy is fixed and adjustments are required to meet the alternate objective. The definition of desired results should include an element to be estimated and the quality (accuracy, precision, reliability) of that estimation. In the case of dendrometers, an arbitrary "diameter" is estimated from a length measurement between two or more points. This "diameter" can then be used for anything from classifying individual stems by size category to intricate mathematical modeling of large population characteristics.

Data acquisition cost should be evaluated in relation to the cost of an incorrect assessment. Data acquisition cost can be broken down into the cost of time and equipment. In addition to being one of the specifications of a project, time also incurs cost in the form of salaries in the usual case.

Accuracy is proportional to cost whether in the form of the quality of instrumentation or care in data collection. Accuracy for a measurement is broken down into bias and precision (Bruce 1975). Calibration may be performed to reduce systematic bias (Ferguson et al. 1984) caused by the instrument or modeling. Observer bias is often unpredictable and may factor into dendrometer selection. Precision can also vary among observers, though more commonly an effect of instrumentation or methodology.

Contact dendrometers allow the greatest accuracy for the lowest cost, although generally, due to time constraints and safety issues, these are limited to measurements of the lower bole. Diameter tape, calipers, and ETMF are all comparable in accuracy, with the ETMF having a greater instrument cost but lower labor cost if many trees are to be measured. The hybrid optical/contact instruments are least accurate, but convenient and inexpensive. Contact dendrometers are ideal for inventory situations where a large proportion of stems can be visited and adequate prediction models are available for the variable of interest.

Precision instruments such as the dial gauge dendrometer (Brown et al. 1947, Tryon and Finn 1949) are necessary for short-term studies of growth response or diurnal change. A portion or the entire instrument is left in place to eliminate location error for sequential measurements. If the measurements are not required more than once in a growing season, diameter tape and caliper readings of carefully marked locations may be sufficient (Bower and Blocker 1966).

If diameters are out of reach, labor costs usually favor the use of optical/noncontact instruments. Due to the specialty and rare use of optical dendrometers, many of the instruments found in the literature are no longer available (Table 2). This is an obvious impediment for the selection of those dendrometers. Highly magnifying, coincident instruments such as the Barr and Stroud dendrometer are the most precise, but also among the most expensive in terms of time and instrument expense (if it were available). Laser instruments are the most precise and also the most expensive instruments currently available. The Relaskop, pentaprism, and meterscope are comparable in accuracy and expense. Cameras, wedge prisms, or handcrafted optical forks are the least expensive instruments, and likely the least accurate due to lack of magnification and care in determining the range from instrument to measurement point.

In situations where the labor rate is high and a large number of samples is required, instrument expense would be minor compared to labor costs. For noncontact dendrometers, there can be significant variation in the time required to capture and record measurements. The pentaprism instrument is the most expedient, as no distance is required for diameter measurement, and the user receives a direct diameter measurement. Despite this fact, upper-stem diameters are usually referenced by a height measurement that requires the use of a hypsometer or scaled rods. If a hypsometer is used, a distance measurement may still be required, as well as correction for tree lean (Grosenbaugh 1980, 1981, 1991). These same tree lean and distance determination problems are evident in all of the optical forks, excepting the laser instruments and range-finding cameras. The drawbacks of many of the electronic instruments are durability, reliability, and power requirements; however, the benefits of time savings, error reduction, and the increased ability to collect, manipulate, and extract more information make these instruments the most promising for future advancements in individual stem data collection.

Conclusions

A variety of dendrometers exist; some have been tested and utilized for centuries and some only years. New tools are being developed to help biometricians collect more data at a faster rate. Careful consideration should be exercised before purchasing the latest and greatest gadget on the market, and conversely, to losing productivity and accuracy by using traditional equipment when there are better instruments available. Users should evaluate their project needs thoroughly before selecting a dendrometer to ensure that it will provide a reliable answer to the questions asked, and for a reasonable cost.

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Table 2. Ranking[1] of dendrometers by accuracy, speed, price, availability, and restrictions.

	Commercially available	Practical restrictions[2]	Accuracy	Speed[5]	Price
Dial-gauge dendrometers	Y	h	1	5	2–4
Diameter tapes	Y	d h	2	1	1
Conventional calipers	Y	d h	2	1	2
ETMF	N	d h	2	1	NA
Wheeler pentaprism	Y	d HN	4	1 or 3[3]	3
McClure pentaprism	N	HN	5	1 or 3[3]	NA
Barr & Stroud	N	b p	3	4	NA
Teletops	N	b p	3	4	NA
Meterscope	Y	p DN	5	3	2
Tele-relaskop	Y	p DN	4	3	NA
Relaskop	Y	DN	5	3	4
Criterion laser instrument	Y	b	4	2	7
35 mm camera	Y	p HN	5	6	5[4]
Minolta MC-100 camera	N	p AN	3	2	NA
Kodak DC120 Digital Camera	Y	p HN	6	6	6

1 Lower numbers more favorable.
2 d—diameter limit, h—height limit, b—bulk/weight of instrument, p—post-processing required, separate angle (AN), distance (DN), or height (HN) required.
3 Slower if heights needed.
4 Plus variable costs (film, developing, etc.).
5 Single observation.

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