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# A research note on developing a novel method for the estimation of annual volume increment in standing trees

# Ein Vorschlag für eine neue Methode zur Schätzung von Jahresvolumenzuwachs an stehenden Bäumen

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**Schlüsselbegriffe:** Waldökosysteme, Waldbau, Waldmesslehre, Baumwachstum

## Abstract

Measuring tree growth rates is an important requirement in many scientific disciplines and forest production sector. The assessment of annual volume growth rates in standing living trees, under ambient field conditions without destroying the tree has so far only been conducted with model approaches or by repeated measurements of tree dimensions in the field. This research note proposes a novel simple non-destructive method for the estimation of annual volume increment in standing trees, based on tree ring analysis of sampling of the two increment cores for each targeted tree and simple trigonometry rules. The extracted data by the method application can be widely used in many forest disciplines, such as forest ecology, silviculture, and forest management.

## Zusammenfassung

Die Messung der Baumwachstums ist in vielen wissenschaftlichen Disziplinen und im forstwirtschaftlichen Sektor eine wichtige Aufgabe. Die Bewertung der jährlichen Volumenwachstumsraten stehender lebender Bäume unter Feldbedingungen ohne

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Zerstörung des Baumes wurde bisher nur mit Modellansätzen oder durch wiederholte Messungen der Baumabmessungen im Feld durchgeführt. Hier zeigen wir eine neuartige, einfache, zerstörungsfreie Methode zur Schätzung des jährlichen Volumenzuwachses an stehenden Bäumen, die auf der Jahrringanalyse von zwei Zuwachskernen pro Baum und einfachen Trigonometrieregeln basiert. Die mittels dieser Methoden gesammelten Daten könnten in vielen Forstdisziplinen wie Waldökologie, Waldbau und Waldbewirtschaftung verfügbare Datenquellen ergänzen.

## 1 Introduction

Forest tree growth is a complicated biological process depending on the species, as well as on the environmental and ecological conditions (Bowman et al. 2013), tree individual competition, stand tending, *etc.*, and varies annually with climate fluctuations (Duchesne *et al.* 2012). Knowledge on tree growth rates over time is a key basic parameter for population dynamics, species interactions and forest science *e.g.* forest ecology, silviculture, forest management, (Pacala *et al.* 1993; Foster *et al.* 2016; Toochi 2018; Woo *et al.* 2020). Stem volume estimation is commonly based on the measurements of tree diameter and height, two variables that can be easily measured in the field. On the contrary, the assessment of annual volume increment of standing trees is extremely difficult to acquire in the field. Even though diameter annual increment can be accurately measured with the core sampling procedure, and annual ring-analysis, the annual tree height increment is challenging or even impossible (Ganatsas *et al.* 2023). Some efforts to correlate the tree annual height increment with the rate of diameter increment (*e.g.*, Meixner 1978) are generally not widely accepted, since it is no consistent relationship between tree diameter increment and height increment (Hasenauer 2006). For tree volume increment under ambient conditions two basic methods exist:

i) analytical tree measurements after tree felling, and,
ii) repeated diameter and height measurements on standing trees in the field (Hasenauer and Monserud 1997).

The first method concerns the known stem analysis method of the felled trees, which is the most accurate method, but it is a destructive method for the trees, and very time-consuming and expensive method (Dyer and Bailey 1987; Fabbio *et al.* 1994; Hasenauer and Monserud 1997; Kariuki 2002), and thus, it cannot be widely applied. Other methods that have been suggested for the estimation of annual tree volume growth, based on model approaches (Hasenauer 2006; Clark *et al.* 2007), even though they are commonly used, generally contain great uncertainties. This study develops and suggests a new simple and non-destructive method for a reliable estimation of stem volume annual increment in standing trees, in the field. The method is based on the tree annual ring-analysis from two increment cores taken for each targeted tree, and basic rules of trigonometry.

## 2 Material and methods

The execution of the method requires few common forestry scientific equipment, which is usually available in a forestry scientific laboratory: Tree hypsometer, common tape, Pressler's increment borer or similar equipment, Stereomicroscope or an Image analysis system (*e.g.*, WinDENDRO). The estimation of the annual volume increment of a standing tree is performed in five steps, that are described below. However, it can be noted that the method, in fact, consists of an expansion and integration of the method developed by Ganatsas *et al.* (2023) for the estimation of tree height annual increment, and is based on the classical geometry approach that the tree trunk shape (in surface projection) is a triangle (Domke *et al.* 2013). At the first step, a sampling of two increment cores is performed according to Ganatsas *et al.* (2023) (Figure 1). The second step includes the measurements of the two sampling increment cores in the lab.

Then, at the third stage, the tree rings for both cores are dated, and pair the two radiuses corresponding to the same year (*e.g.*, last year, the year before, *etc.*) at the two sampling height points. The differences between the tree radiuses at the two sampling heights (0.5 and 2.0 m) are computed for each year, *e.g.*, AB for the last year $t$, A1B1 for the year before $t_{-1}$, etc. (Figure 1) (values in meters). By considering the triangle created by the distance between the two sampling points of the tree trunk (1.5 m) as one vertical side (distance BC in Figure 1) of the orthogonal triangle ABC and the difference between the paired tree radiuses (corresponding to the same year) as the second horizontal side of the triangle (distance AB (in m) for the current tree height), we compute the angle ($\boldsymbol{\alpha}$) of the triangle, using the typical formula, $\boldsymbol{\alpha}$ equals to opposite side of a triangle divided by the adjacent side, which in our case, for a year $t$ corresponds to:

$$\boldsymbol{\alpha} = 1.5/(RAD - RCE) \qquad (1)$$

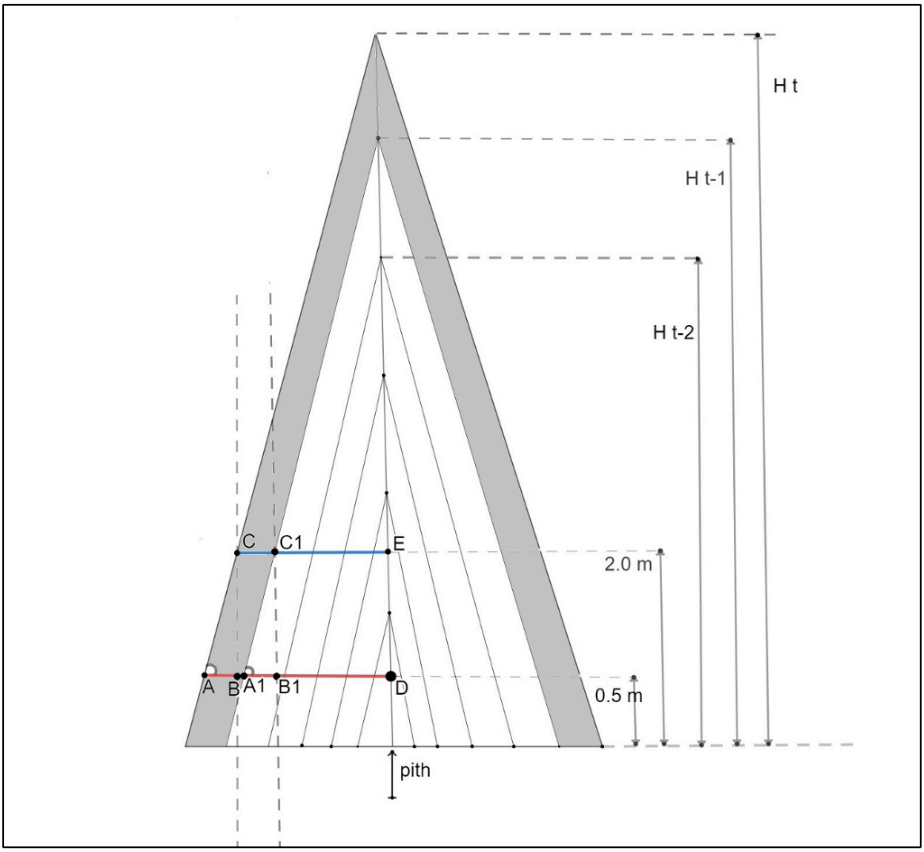


*Figure 1: Tree stem simulation showing the procedure of sampling the two increment cores at two different tree trunk heights (0.5 and 2.0 m). Red line AD shows the tree radius at 0.5 m (RAD), Blue line CE shows the tree radius at 2.0 m (RCE). $H_t$ = current tree height, $H_{t-1}$ = tree height at one year before, etc. Shaded area indicates the stem volume increment (in two dimensions) for the current year.*

Abbildung 1: Schematische Darstellung eines Baumes mit zwei Zuwachsbohrkerne entnommen an zwei Positionen (0.5 und 2.0 m). Rote Linie AD zeigt den Baumradius in 0.5 m Höhe (RAD), blaue Line den Radius in 2.0 m Höhe (RCE). $H_t$ = aktuelle Baumhöhe, $H_{t-1}$ = Baumhöhe ein Jahr zuvor. Schraffierte Fläche zeigt den Volumenzuwachs (in zwei Dimensionen) für das aktuelle Jahr.

Based on the equation (1), the size of $\alpha$ is computed. Then, based on the size of $\alpha$, we compute the total tree height, as the opposite side of the triangle formed by the total dimensions of the tree, named total height for the year *t* (in m), as vertical side ($H_t$ in the Figure 2), and total tree radius at 0.5 m (RAD, in m), as horizontal side. Thus, the total tree height in *t* time ($H_t$ in m) equals to total tree radius (in m) at the point 0.5m multiplied by $\alpha$, plus 0.5:

$H_t = (RAD \times \alpha) + 0.5$ (2)

For avoiding any decline in the estimation of total tree height, we simultaneously measure the total tree height by a common tree hypsometer, and we check if any correction (- or +) is required in the current method, in relation to the real total tree height.

Current volume calculation is performed at the fourth stage. Generally, tree trunk treated as paraboloid, cylinder or conoid (Cruz de León 2010; Kushwaha *et al.* 2021). Thus, based on the radius *RAD* and the estimated $H_t$ form the equation (2), we compute the current tree volume at year *t* using the general equation for the cone volume (in $m^3$) (both parameters' values in the equation are in m):

*Current tree volume* $V_t = 1/3 \times H_t \times \pi \times RAD^2$ (3)

The same procedure is followed for the next inner annual ring pairs, corresponding to the previous years, towards the interior (pith) of the two increment cores, computing the angles at years $t_{-1}$, $t_{-2}$ … $t_{-n}$. Tree height estimation at each year is estimated with the same way as the equation (2) as tree height of the year $t_{-1}$ ($H_{t-1}$) equals to tree radius at the year $t_{-1}$ multiplied by $\alpha 1$ (at the year $t_{-1}$) plus 0.5:

$H_{t-1} = (RA1D \times \alpha 1) + 0.5$ (4)

Thus, similarly to equation (3), tree volume one year before is:

$V_{t-1} = 1/3 \times H_{t-1} \times \pi \times RA1D^2$ (5)

At the fifth stage, the Annual Tree Volume Increment (ATVI) for the last year is computed as follows (in $m^3$):

$ATVI_t = V_t - V_{t-1}$ (6)

which is indicating by the shaded area (in two dimensions) in Figure 1.

Similarly, the annual tree volume increment for the year before (ATVI t-1) is (in $m^3$):

$ATVI_{t-1} = V_{t-1} - V_{t-2}$ (7)

Following the same procedure for each paired of annual rings (last year, the previous year *etc.*), we reconstruct the whole tree development during its life, similarly to the results extracted by the complete stem analysis method, without destroying the tree. The two sampling points at tree trunk heights of 0.5 m and 2.0 m are suggested because at these two heights the core sampling is feasible for a human from the ground. If there are opportunities and appropriate facilities, this distance (1.5 m) can be modified as suggested by Ganatsas *et al.* (2023). In that case, the equation that gives the value for $\boldsymbol{\alpha}$ takes the form:

$$\alpha = X / (R_{t-1} - R_{t-2}) \qquad (8)$$

where $X$ is the distance (in m) between the two sampling points at year $t_{-1}$ and $t_{-2}$, and $R_{t-1}$, $R_{t-2}$ are tree radiuses (in m) from the two sampling points respectively.

## 3 Limitations of the method

This method assumes that:

i) the tree volume of standing trees can be estimated using the cone basic equation, and

ii) the tree diameter's reduction rate with height is relatively uniform throughout the tree life span.

Field testing for the method validation for different tree species would help to provide additional evidence of the accuracy and reliability of the method.

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## Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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