141. Jahrgang (2024), Heft 3, S. 215–240

Austrian Journal of Forest Science
Centralblatt für das gesamte Forstwesen

An assessment of the statistical performance of the horizontal point sampling (HPS) in an open coppice forest

Abschätzung der statistischen Leistungsfähigkeit der Winkelzählprobe für offene Niederwälder

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Keywords: Monte-Carlo simulation; Forest inventory; Open sparse oak forest; Zagros forest, Sampling methods

Schlüsselbegriffe: Monte-Carlo-Simulation; Waldinventur; offener spärlicher Eichenwald; Zagros Wald, Stichprobenmethoden

Abstract

Sampling surveys are broadly employed in forest inventories due to their efficiency in quantifying forest characteristics. To this end, selecting an appropriate sampling method is essential. This study introduces a new application of horizontal point sampling (HPS). We assess the statistical properties of HPS with variations in crown basal area factor (CBAF) and sample sizes (*n*). The study further conducts a comparative analysis between HPS and fixed-radius (FR) plot sampling methods. The study was done in an actual open coppice forest and in a simulated forest, using sampling simulations with a large number of repetitions. In HPS, a greater CBAF for a given sample size lead to a higher relative standard error (RSE %). Multiple regression model showed that both *n* and CBAF influence RSE %. There was an inverse relationship between *n* and RSE%, whereas a positive relationship was found between CBAF and RSE %. A combination of HPS and crown relascope is easily applicable in forest inventories. This combined

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method demonstrates efficiency, when compared to the traditional FR for estimating crown cover area in open coppice forests.

Zusammenfassung

Stichprobenbasierte Untersuchungen werden aufgrund ihrer Effizienz bei der Bewertung von Waldeigenschaften in Waldinventuren eingesetzt. Die Auswahl einer geeigneten Stichprobenmethode ist dabei wesentlich. Diese Studie stellt eine neue Form der Winkelzählprobe (horizontal point sampling, HPS) vor. Die Studie bewertet die statistischen Eigenschaften von HPS hinsichtlich Variationen im Kronengrundflächenfaktor (CBAF) und Stichprobengröße (*n*). Außerdem führen wir eine vergleichende Analyse zwischen HPS und der fixen Probekreismethode (FR) durch. Die Studie wurde in einem offenen Niederwald mittels Stichprobensimulationen einer großen Anzahl von Wiederholungen durchgeführt. Bei HPS führte ein größerer CBAF für eine gegebene Stichprobengröße zu einer höheren relativen Koeffizientenvariation (RSE %). Das multiple Regressionsmodell zeigte, dass sowohl die Stichprobengröße (*n*) als auch der CBAF den RSE % beeinflussen. Es zeigte sich eine umgekehrte Beziehung zwischen *n* und RSE %, während eine positive Beziehung zwischen CBAF und RSE % festzustellen war. Eine Kombination von HPS und Kronenrelaskop ist leicht in Waldinventuren umsetzbar. Diese kombinierte Methode zeigt eine verbesserte Effizienz im Vergleich zur weit verbreiteten FR bei der Schätzung einiger Waldeigenschaften in offenen Niederwäldern.

1 Introduction

A variety of forest inventory methods have been developed to gather quantitative data for forest management planning. The main goal of these inventories is to estimate parameters in cost-efficient way as accurately as possible (Kershaw *et al*. 2016). However, not all methods or instruments are equally effective or efficient in different situations or for different purposes. Forest characteristics of interest, the objective of the survey, and costs influence the choice of the most suitable inventory method and instrument. Schreuder *et al*. (1987) and Leiter & Hasenauer (2023) demonstrated the effectiveness of traditional relascope sampling (horizontal point sampling, HPS) in estimating stand-level basal area. However, its efficacy might vary when estimating other parameters such as tree density and stand volume (Henttonen & Kangas 2015, Häbel *et al*. 2019). Ducey *et al*. (2002) employed a combination of HPS and horizontal line sampling (HLS) to enhance the precision of snag volume estimation. Köhl & Magnussen (2016) demonstrated that FR gave the best results in terms of accuracy for tree number, but not for basal area and the average tree diameter. Jeffrey *et al*. (2011) found that FR can yield an unbiased estimate of the volume of deadwood (DW). However, when it comes to estimating the population density in terms of the number of down coarse woody debris, FR may not always provide precise results. On the other hand, Ritter and Saborowski (2012) found that point transect sampling is superior to traditional methods such as FR, HPS, and line intersect sampling (LIS) when it comes to sampling standing deadwood (DW). However, LIS is more cost-effective than point transect sampling for sampling downed DW. Therefore, it is beneficial to develop new inventory methods or adapt existing instruments to fit various situations. It's always important to choose the most appropriate method based on the specific characteristics of the forest being sampled.

In contrast to high forest (non-coppice forest), which are typically characterized by single-stemmed trees that grow from seeds, a coppice forest (CF) is a very different forest type (Scolastri *et al*. 2017). CF are primarily composed of trees that regenerate from shoots, with only a small fraction originating from seeds (Scolastri *et al*. 2017; Iranmanesh *et al*. 2019). In CFs, the young tree stems are regularly cut down to near ground level, forming a stool. The regeneration of these stands is predominantly through vegetative or asexual sprouting, which is the most common method of regeneration (Vollmuth 2022). These forests serve as a significant renewable resource, offering a variety of products and services including non-timber products, protective services, and heritage ecosystem services. In CFs, trees regenerated from shoots often have short stems (Scolastri *et al*. 2017). A study conducted by Vollmuth (2022) in the coppice forests of Germany concluded that these forests are rich in biodiversity and serve as habitats for many light-dependent species that are currently endangered.

The stem basal area relascope, a widely utilized device in forest inventory, is used to estimate variables like basal area (BA) and volume (Bitterlich 1984; Lynch *et al*. 2021; Leiter & Hasenauer 2023). However, the effectiveness of this inventory tool may be limited in CFs, where trees often lack distinct stems. Additionally, these stems may sometimes be invisible at breast height. To overcome this limitation, the crown relascope (CR, Stenberg *et al*. 2008) could be a feasible alternative. More recently, CR has been used in combination with horizontal line sampling (HLS) in coppice forests to estimate some forest attributes (Ramezani and Nazariani 2023). The authors found that the combination is more cost-effective than line intersect sampling (LIS). Essentially, CR is an extension of the stem basal area relascope. However, in comparison to the stem basal area relascope, CR requires a larger basal area factor, referred to as the crown basal area factor (CBAF).

FR is a commonly used sampling method for inventorying various types of forest attributes (Gray 2003; Ramezani *et al*. 2016; West, P. 2021; Zhao *et al*. 2022; Leiter & Hasenauer 2023). In FR, often all trees within the plot are sampled for various attributes such as tree count, species, diameter, and height. The size of plots used in a forest inventory will vary depending on the desired sampling intensity, average tree size, and tree density. While FR can be cost-effective in many situations, its efficiency can vary depending on factors such as the type of vegetation, spatial distribution patterns, and densities. Other methods might be more cost-effective in certain situations.

Horizontal point sampling (HPS), also known as angle-count sampling, was developed by Austrian forest scientist Walter Bitterlich (1984). It is sometimes referred to as point sampling, variable plot sampling, prism cruising, angle count sampling or angle gauge sampling. HPS is frequently employed in the field of forest inventory to estimate the total basal area of a forest. Moreover, it offers cost-effective estimations for characteristics that are directly related to basal area. For instance, research has demonstrated that the Big BAF sampling (as a two-stage sampling) method, which utilizes two different relascope angles, is an cost-effective approach for estimating both volume and biomass in forest inventories (Marshall *et al*. 2004; Yang *et al*. 2017; Chen *et al*. 2019).

In applications of HPS, the conventional instrument employed was a stem basal area relascope. However, this study introduces a new application of HPS combined with CR in a coppice forest. The research assesses the statistical properties of HPS with variations in relascope angles CBAF and *n*. The primary aim is to estimate forest attributes, including above-ground biomass (AGB), crown cover area (CCA), and stem/tree density (N) in a coppice forest where individual trees lack distinct stems. Additionally, this study conducts a comparative analysis involving HPS at various CBAF (m^2 ha^{-1}) levels (750, 1500, 2000, 2500, 3300, and 4000) and FR, which serves as a traditional sampling method, across different plot radii (5, 10, and 15 meters) and various sample sizes (10, 20, 40, 60, and 70).

2 Material and methods

2.1 Study area

The study was carried out in an open coppice forest (CF) dominated by oak (*Quercus brantii* Lindl) within the Zagros forests of western Iran. Additionally, a similar simulation was conducted on a one-hectare simulated forest. *Quercus brantii* is a significant tree species in the forests of western Iran. Human activities have resulted in only 7% of the oak forests remaining as non-coppice forests, with the rest (93%) are coppice forests (Iranmanesh *et al*. 2019; Mahdavi *et al*. 2020). The Zagros forests, which cover roughly 5 million hectares and are categorized as semi-arid, accounting for 40% of Iran's forests. The elevation in the study area varies from 1860 m to approximately 2070 m above sea level, with an average annual rainfall of 530 mm and an average annual temperature of 18.3° C (Sagheb-Talebi *et al*. 2003). Zagros forests are not only management for timber and offer many other ecosystem services such as water resources, climate regulation or biodiversity conservation. The socio-economic aspects of Zagros forests are intimately tied to the sustainable utilization and management of the forest ecosystem, with activities like ecotourism, handicrafts, and value-added processing of forest products (Salehi 2009; Riyahi 2010). For thousands of years, CFs have been a vital energy source - providing firewood and charcoal - for rural communities. Data were gathered from a single 4-hectare site (plot measuring 200 m × 200 m) located in an open, sparse Oak coppice forest. The global positioning system (GPS) was used to record the coordinate positions of each tree. Figures 1 and 2 present a map of the study area and tree distribution of the real forest and simulated forests, respectively. Table 1 provides descriptive information on the study area (real forest) and the simulated forest.

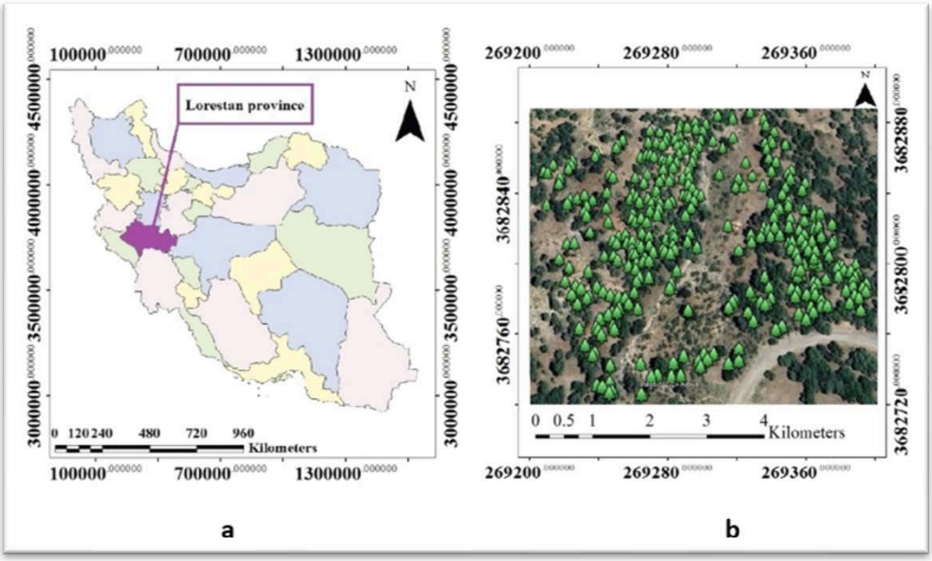


Figure 1: Location of the study area.

Abbildung 1: Lage des Untersuchungsgebietes.

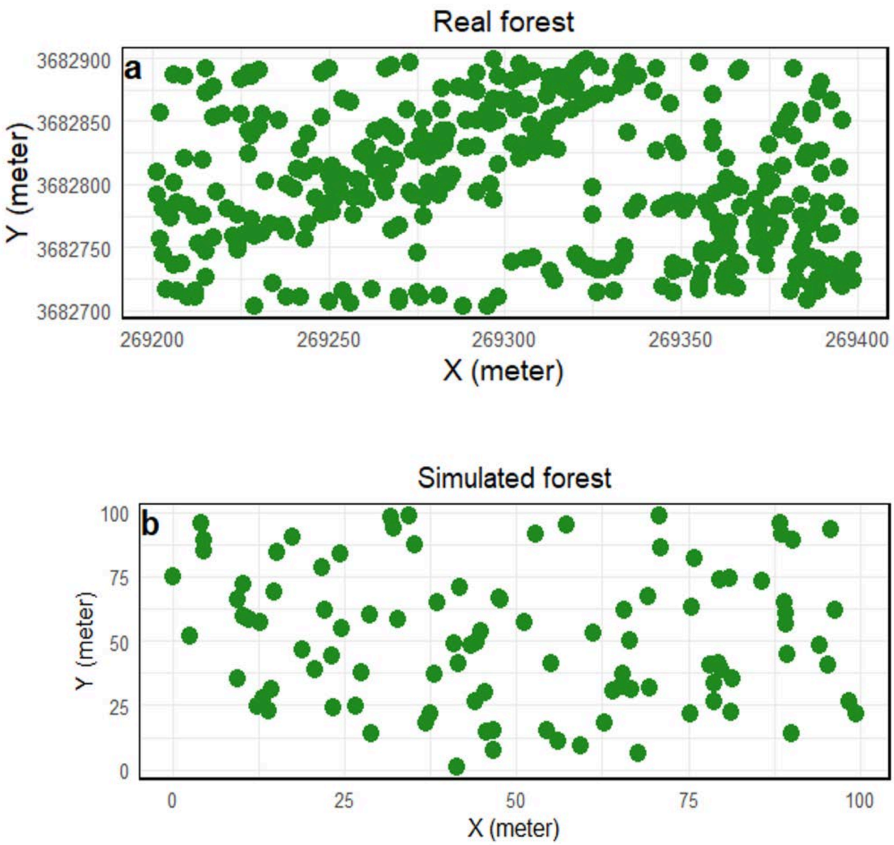


Figure 2: Maps of tree distribution: a) real forest b) simulated forest.

Abbildung 2: Baumverteilungskarten in (a) realer Wald und (b) simulierter Wald.

Table 1: Descriptive information on the real forest and simulated forest.

Tabelle 1: Bestandskennziffern des realen Waldes und des simulierten Waldes.

	Above ground biomass (AGB, kg ha^{-1})	Crown cover area (CCA, m^2 ha^{-1})	Stem density (N, ha^{-1})
Real forest	17713	1559	74
Simulated forest	7863	1093	100

2.2 Crown relascope (CR)

The crown relascope is a specialized forestry tool used primarily for estimating stand crown cover (Stenberg *et al*. 2008) by counting the number of trees, whose crown diameter exceeds the crown relascope angle. However, to estimate other forest attributes, including tree biomass, the crown diameter of sampled trees can be also used. A CR is an advanced version of the traditional relascope. It can simply be made using wooden pieces and string. A common and practical way to determine the desired the angle θ for constructing a relascope is to use a reach-to-width ratio (R:W). CBAF=10000×k, and $k = (W/2)^2/(R)^2 = \tan(\theta/2)^2$ (Stenberg *et al*. 2008). Several instances of different CBAF (m^2 ha^{-1}, R (cm), W (cm) and relascope angles (θ) are provided in Table 2. The next section provides a brief overview of the inclusion probabilities of trees when using HPS methods, as well as the estimators associated with these sampling methods.

Table 2: Reach (R), width (W), crown basal area factor (CBAF), and relascope angles. R refers to the distance between the eye and the relascope slot and W represents the slot width.

Tabelle 2: R, W, Kronenzählfaktor (CBAF) und Relaskopwinkel. R ist die Distanz zwischen Auge und Relaskopplättchen und W ist die Breite des Relaskopplättchen.

CBAF (m^2 ha^{-1})	R (cm)	W (cm)	Relascope angle (°)
750	40	21.9	15.6
1500	40	31.0	21.4
2000	40	35.8	25.1
2500	40	40.0	28.1
3300	40	46.0	32.0
4000	40	50.6	35.1
750	50	27.4	30.6
1500	50	38.7	42.3
2000	50	44.7	48.2
2500	50	50.0	53.1
3300	50	57.4	59.7
4000	50	63.2	64.6

2.3 Sampling simulation

To investigate the statistical performance of two sampling methods FR and HPS, a sampling simulation (Monte-Carlo simulation) with a large number of replications

(3,000) was conducted on the study site with combinations of five sample sizes (10, 20, 40, 60 and 70 points), three plot radii in FR (5, 10, and 15 m), and six CBAF in HPS (750, 1500, 2000, 2500, 3300, and 4000 m^2 ha^{-1}). We used an independent random sampling design, *i.e.*, the sampling locations were generated independently with uniform distribution over the site. At each sampling location, FR and HPS sampling methods were conducted. The simulation of the sampling process was conducted using the Spatstat R-package (Baddeley *et al*. 2015). The estimators applied in this study are described below. Note that an additional CBAF (*i.e.*, 400) was used in the simulated forest.

a) Fixed-radius (FR) plot sampling

In FR sampling method a fixed circle plot is defined and every tree within the plot is sampled with a probability proportional to its frequency (Avery and Burkhart, 1994). Using FR, the inclusion probability of tree *i* ($\pi_{i,FR}$), is

$$\pi_{i,FR} = \frac{b}{A} \qquad (1)$$

where *b* is the plot area (ha), and *A* is the total area (ha).

The *Horvitz-Thompson* (*HT*) estimator of FR to estimate the total above-ground biomass (*AGB*) for a single sampling unit, *j* is

$$\hat{t}_{AGB,FR,j} = \frac{A}{b} \sum_{i=1}^{m} AGB_i \qquad (2)$$

where *m* is the total number of trees sampled in *j* the sampling location and AGB_i is the above-ground biomass of tree *i*.

To estimate the total number of trees (*N*) the estimator for a single sampling unit, *j* is

$$\hat{t}_{N,FR,j} = \frac{A \cdot m}{b} \qquad (3)$$

To estimate the total crown cover area the estimator is

$$\hat{t}_{CCA,FR,j} = \frac{A}{b} \sum_{i=1}^{m} CCA_i \qquad (4)$$

where, CCA_i (m^2) is the crown cover area of tree *i*, A general *HT* estimator for the population total in a sample of *n* sampling locations (the averaging across *n* sampling units) is

$$\hat{t}_{FR} = \frac{1}{n}\sum_{j=1}^{n} \hat{t}_{FR,j} \qquad (5)$$

b) Horizontal point sampling (HPS)

The basic idea of HPS method is that trees are selected from a chosen sample point in proportion to their BA, as is the case with the traditional relascope sampling (Bitterlich, 1949). This means that each tree has its own inclusion zone and thus a larger tree has a greater probability of being taken as a sample tree. In HPS, a surveyor stands at the sample point and performs a full 360° sweep, counting all trees whose diameter at breast height (DBH) appears larger than the relascope angle applied. This count alone allows us to simply estimate the basal area per hectare.

In this study, however, we used crown relascope (CR) instead of stem basal area relascope and any tree whose crown diameter (CD) appeared greater than the width of the projected angle from the relascope was chosen as a sample tree. Using CR, trees were sampled with probability proportional to their crown basal area (CBA). It should be noted that to estimate other forest parameters such as volume, biomass, and tree density, it is essential to measure CD using the HPS method.

Under the HPS procedure, tree *i*, is selected if the distance from the sample location is within a limiting distance (R_i, see Fig. 3). In HPS, the inclusion probability of tree *i* (π_i) is

$$\pi_i = \pi \times R_i^2 \qquad (6)$$

where R_i (m) is the limiting distance from which a coppice tree appears exactly as wide as the measurement instrument that defines the sighting angle. According to Stenberg *et al*. (2008), R_i for crown relascope can be calculated as

$$R_i = \frac{r_i}{tan(\theta/2)} \qquad (7)$$

where r_i (m) is the tree crown radius of tree *i*, and θ° is relascope angle determined by the measurement instrument and a design parameter that is constant for all trees. Thus, the inclusion probability $\pi_{i,HPS}$ can be expressed with replacing R_i as

$$\pi_{i,HPS} = \frac{CBA_i}{A \times \tan\left(\theta/2\right)^2} \qquad (8)$$

where CBA, is crown basal area (m²) of tree *i* and *A* is total area (ha).

Using HPS, the *HT* estimator of *AGB* for a single sampling unit, *j* is

$$\hat{\tau}_{AGB,HPS,j} = A \times \tan\left(\frac{\theta}{2}\right)^2 \sum_{i=1}^{m} \frac{AGB_i}{CBA_i} \qquad (9)$$

where AGB_i is the above-ground biomass of tree *i*.

and the estimator of *N* for a single sampling unit, *j* is

$$\hat{\tau}_{N,HPS,j} = A \times \tan\left(\frac{\theta}{2}\right)^2 \sum_{i=1}^{m} \frac{1}{CBA_i} \qquad (10)$$

and the estimator of the total crown cover area for a single sampling unit, *j* is

$$\hat{\tau}_{CCA,HPS,j} = A \times \tan\left(\frac{\theta}{2}\right)^2 \times c \qquad (11)$$

where c denotes tree count at the sampling location *j*.

In the case of HPS, the estimator of the population total in a sample of *n* sample points is

$$\hat{\tau}_{HPS} = \frac{1}{n} \sum_{j=1}^{n} \hat{\tau}_{HPS,j} \qquad (12)$$

The average per hectare ($\bar{\tau}$) for all three attributes was estimated as $\frac{\hat{\tau}}{A}$, where $\hat{\tau}$ represents the total estimated attribute value and *A* is the study area (ha).

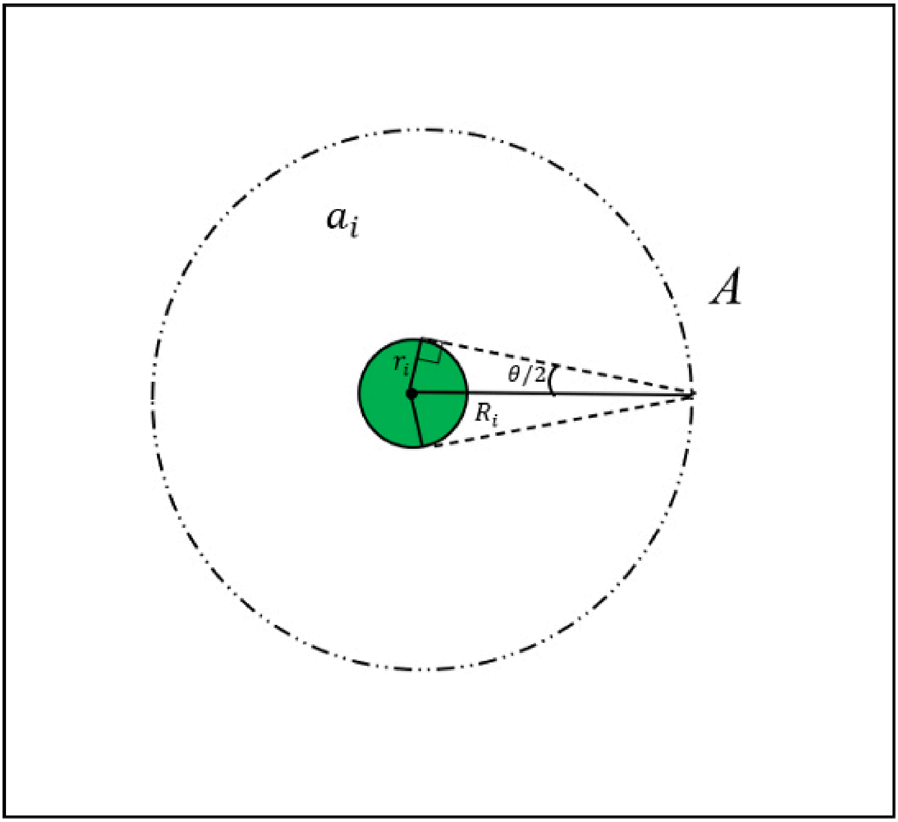


Figure 3: An illustration of the inclusion probabilities, in the case of HPS method. r_i is corresponding crown radius of tree i, R_i is limiting distance of tree i, θ is the fixed sighting angle of the relascope and a_i is the inclusion area of tree i and A is the study area.

Abbildung 3: Darstellung der Einschlusswahrscheinlichkeit in der HPS Methode. r_i ist der Kronenradius eines Baumes *i*, R_i ist der Radius des Grenzkreises eines Baumes *i*, *θ* ist der Sichtwinkel des Relaskops und a_i ist die Fläche des Grenzkreises eines Baumes *i* and *A* ist die Untersuchungsregion.

To avoid bias near the edges of our study area, we used the external peripheral zone method, also known as the buffer method, as described by Gregoire and Valentine (2008, p. 224). This method allows us to place sampling locations not only within the study area but also in a surrounding buffer area. It's important to make sure that the buffer is wide enough so that no part of the population within the study area has a sampling zone that extends beyond the outer boundary of the buffer. In this study, we used a buffer width of 15 meters.

2.4 Efficiency evaluation

In this study, we used the relative standard error (RSE %) to evaluate estimators using a Monte Carlo simulation with a large number of replications (here with 3000 replications). It is commonly employed in various statistical analyses to assess and compare two sampling methods or estimators. To estimate the RSE%, the variance of the estimators should be calculated. In this context, the variance estimator can be represented as the sample mean (Thompson, 2002), allowing the variance to be estimated using the following equation:

$$\hat{v}\left(\hat{Y}_{sim}\right) = \frac{1}{r(r-1)} \sum_{k=1}^{r} (\hat{Y}_k - \bar{\hat{Y}}_{sim})^2 \qquad (13)$$

$$\text{RSE (\%)} = \frac{\sqrt{\hat{v}(\hat{Y}_{sim})}}{Y} \times 100 \qquad (14)$$

Where $\bar{\hat{Y}}_{sim}$ is the average of all the simulations, $\hat{Y}_k$ is the estimate of simulation *k*, Y is the true value of the variable of interest and *r* is the number of replications. Note that in a sampling simulation each replication refers to an observation and sample mean is the average of replications. Variance is measured in squared units of the original data, while standard deviation (and thus standard error) is measured in the same units as the original data.

2.5 Effect of CBAF and n on the RSE (%)

The rate of decrease of the relative standard error (RSE %) with varying CBAF (relascope angle) and sample size (*n*) was studied by the model

$$\gamma = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon \qquad (15)$$

where dependent variable γ is the estimated RSE %, β_0, β_1, and β_2 are parameters. x_1 and x_2 are independent variables CBAF and *n*, respectively and ε is the random error.

In the case of FR, plot radius is also used as independent variable.

3 Results

Table 3 provides the relationship between sample size n and RSE %. Irrespective of plot size or CBAF, increasing the n appears to reduce RSE%. This pattern holds across all three forest attributes. In the case of a given sample size, in FR a larger plot radius results in smaller RSE %, while in HPS, a greater CBAF leads to a higher RSE %. For a certain sample size, using a plot radius of 15 meters and a CBAF of 4000, the smallest and largest RSE % are obtained, respectively.

Figures 4 and 5 illustrate the relationship between plot size and crown basal area factor in conjunction with the average number of trees per plot/point. As expected, in FR plot sampling method, the average number of trees per plot trend to increase with increasing plot size, while in HPS the average number of trees per point decreases as CBAF increases. Figure 6 presents the distributions of the average number of trees per plot/point across varying plot sizes and crown basal area factors. The plot with a 15 m radius shows the largest variation.

Table 3: Estimated relative standard error (RSE x 1000) for above ground biomass (AGB), crown cover area (CCA), and stem density (N/ha), across a range of plot sizes denoted by different radii (R) and crown basal area factors (CBAF).

Tabelle 3: Relativer Standardfehler (RSE x 1000) der Kronenfläche (CCA), oberirdischen Biomasse (AGB) und Stammzahl (N), für eine Vielzahl von Probekreisflächen mit unterschiedlichen Radii (R) und Kronenzählfaktoren (CBAF).

	AGB (kg/ha)								
Sample size	R 5 m	R 10 m	R 15 m	CBAF 750	CBAF 1500	CBAF 2000	CBAF 2500	CBAF 3300	CBAF 4000
10	9.6	5.9	4.6	5.3	6.7	7.5	7.9	9.1	9.9
20	6.7	4.0	3.2	3.9	4.7	5.0	5.6	6.1	6.5
40	4.7	2.8	2.4	3.3	3.8	3.5	4.3	4.3	4.8
60	3.7	2.3	1.9	2.3	2.7	2.9	3.1	3.7	3.8
70	3.4	2.2	1.7	2.0	2.5	2.7	2.9	3.1	3.6
	CCA (m^2/ha)								
Sample size	R 5 m	R 10 m	R 15 m	CBAF 750	CBAF 1500	CBAF 2000	CBAF 2500	CBAF 3300	CBAF 4000
10	8.1	5.2	4.2	5.2	6.7	7.5	7.3	9.5	8.9
20	5.8	3.6	3.0	3.9	4.6	4.9	5.3	6.1	6.3
40	4.0	2.6	2.2	3.3	3.7	4.6	4.2	4.2	4.6
60	3.2	2.1	1.8	2.2	2.6	2.8	3.0	3.6	3.6
70	3.0	1.9	1.6	1.9	2.4	2.6	2.8	3.1	3.5
	N (ha^{-1})								
Sample size	R 5 m	R 10 m	R 15 m	CBAF 750	CBAF 1500	CBAF 2000	CBAF 2500	CBAF 3300	CBAF 4000
10	7.7	4.9	4.0	5.6	7.0	8.0	8.5	9.6	10.6
20	5.2	3.5	2.9	5.2	4.9	5.3	5.9	6.5	7.1
40	3.7	2.5	2.1	3.5	4.0	3.8	4.5	4.5	4.9
60	3.1	2.0	1.7	2.4	2.8	3.0	3.3	3.9	4.0
70	2.9	1.8	1.5	2.1	2.6	2.9	3.0	3.4	3.8

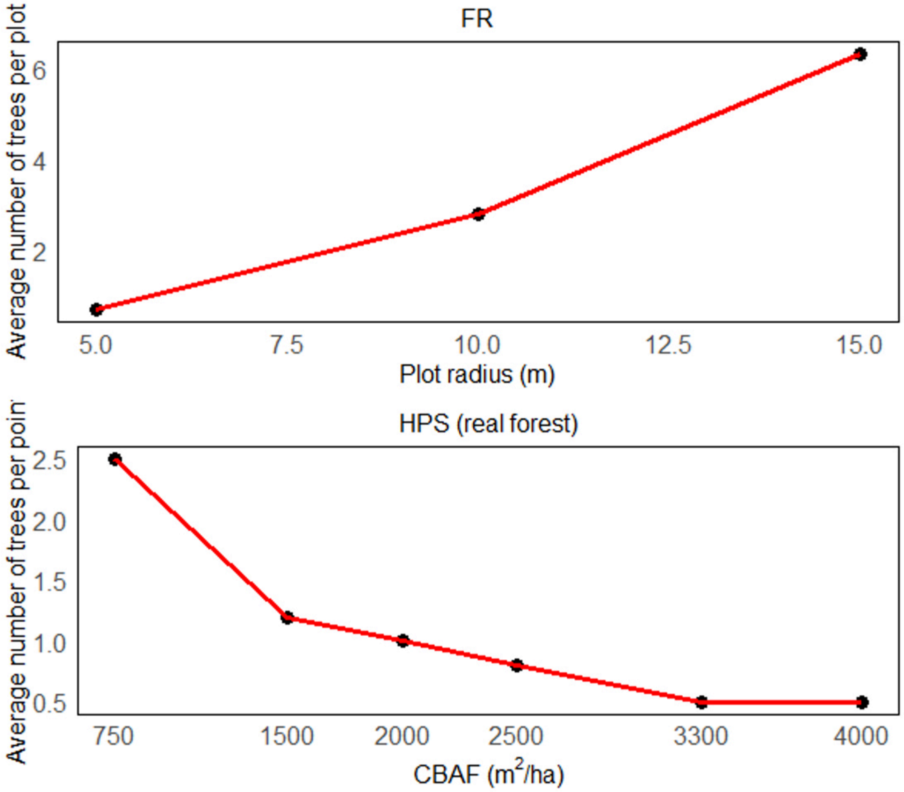


Figure 4: The relationship between the average number of trees per plot and radius of fixed area plot (top) and between the average number of trees per plot and crown basal area factor, CBAF (bottom) in the real forest.

Abbildung 4: Zusammenhang zwischen durchschnittlicher Anzahl Bäume pro Plot und Radius des fixen Probekreises (oben) und zwischen durchschnittlicher Anzahl Bäume pro Plot und Kronenzählfaktor, CBAF (unten) in dem realen Wald.

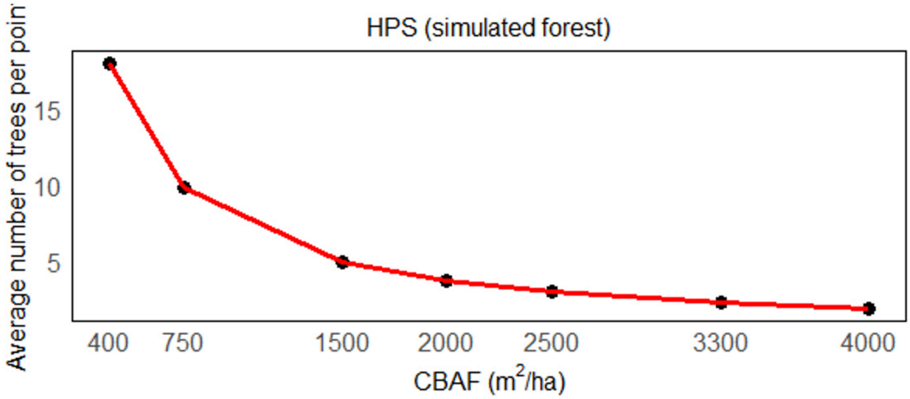


Figure 5: The relationship between the average number of trees per point and crown basal area factor CBAF in the simulated forest.

Abbildung 5: Zusammenhang zwischen durchschnittlicher Anzahl Bäume pro Plot und Kronenzählfaktor, CBAF (unten) in dem simulierten Wald.

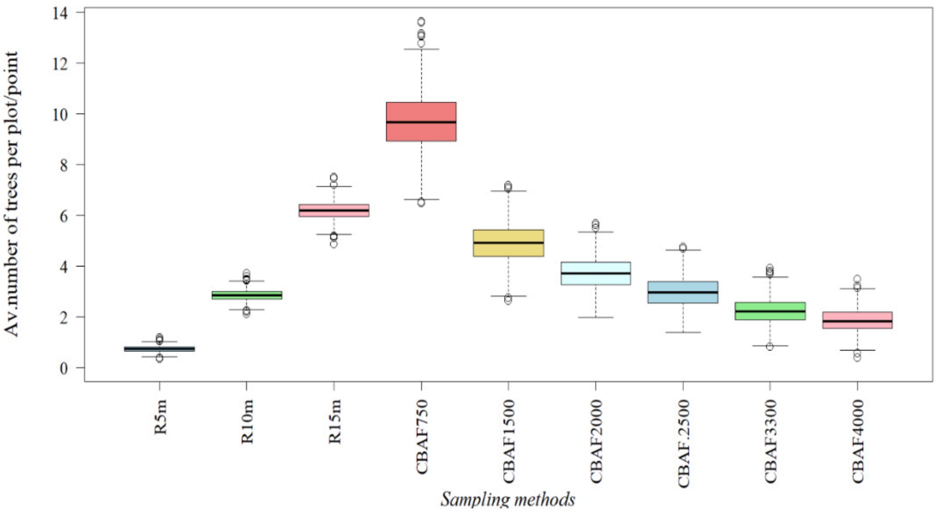


Figure 6: Distributions of average of trees per plot/point in the real forest across varying plot sizes and crown basal area factors (CBAF).

Abbildung 6: Verteilung der durchschnittlichen Anzahl Bäume pro Plot/Punkt in dem realen Wald für verschiedene Probekreisflächen mit unterschiedlichen Radii (R) und Kronenzählfaktoren (CBAF).

A multiple regression analysis was conducted to explore the impact of sample size (n) and crown basal area factor (CBAF) on the relative standard error (RSE%). The regression models for three forest attributes based on sample size (*n*) and crown basal area factor (CBAF) are presented in Table 4. All six regression models exhibit statistical significance at a 95% confidence level ($p < 0.05$). These models collectively indicate that *n* and CBAF have an influence on RSE %.

Specifically, in FR, a reverse relationship was observed between sample size and plot radius in relation to RSE %. Conversely, in HPS, a positive relationship was detected between RSE % and CBAF. Overall, the models explained about 98% of the variation in RSE %. In HPS and for CCA and AGB, a unit increase in ln(n) leads to ln (SE) decreases by 0.49, whereas a unit increase in ln (CBAF) leads to ln (SE) increases by 0.29.

Table 4: Regression models, with P-values, and R-squared values, for estimating RSE based on sample size (n) and crown basal area factor (CBAF) or fixed plot radius (R) for three forest attributes (see Tab. 1) and HPS and FR methods.

Tabelle 4: Regressionsmodelle, mit P-Werten und Bestimmtheitsmaß, für Schätzungen von RSE basierend auf Stichprobenanzahl (n) und Kronenzählfaktor (CBAF) oder Radius des fixen Probekreises (R) für drei Bestandeseigenschaften (siehe Tabelle 1) und HPS und FR Methoden.

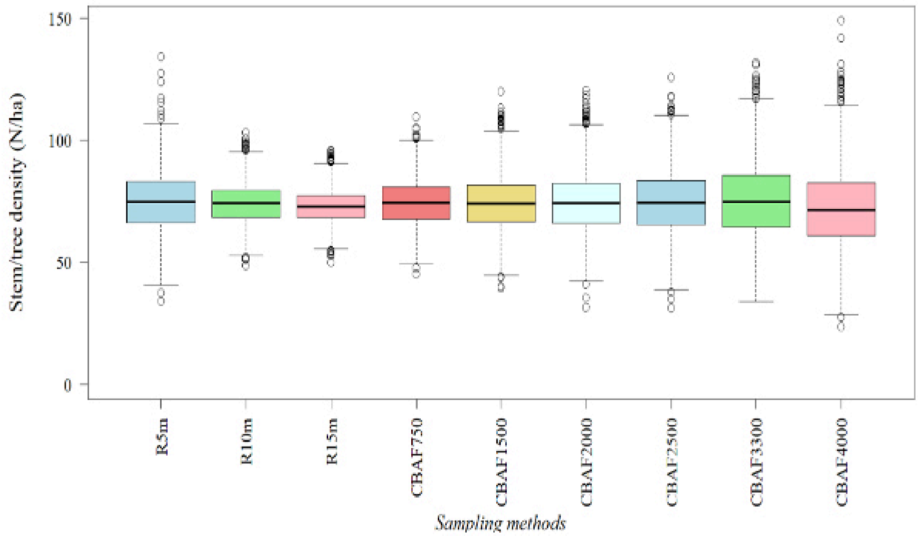
	Model	P-value	R-sq(adj)
HPS			
AGB	$\ln(\text{RSE}) = 2.6 - 0.49 \ln(n) + 0.29 \ln(CBAF)$	0.003	0.98
CCA	$\ln(\text{RSE}) = 2.5 - 0.49 \ln(n) + 0.29 \ln(CBAF)$	0.001	0.98
N	$\ln(\text{RSE}) = 2.5 - 0.50 \ln(n) + 0.31 \ln(CBAF)$	0.002	0.98
FR			
AGB	$\ln(\text{RSE}) = 6 - 0.50 \ln(n) - 0.62 \ln(R)$	0.001	0.99
CCA	$\ln(\text{RSE}) = 5.7 - 0.46 \ln(n) - 0.55 \ln(R)$	0.001	0.99
N	$\ln(\text{RSE}) = 5.7 - 0.50 \ln(n) - 0.57 \ln(R)$	0.002	0.99

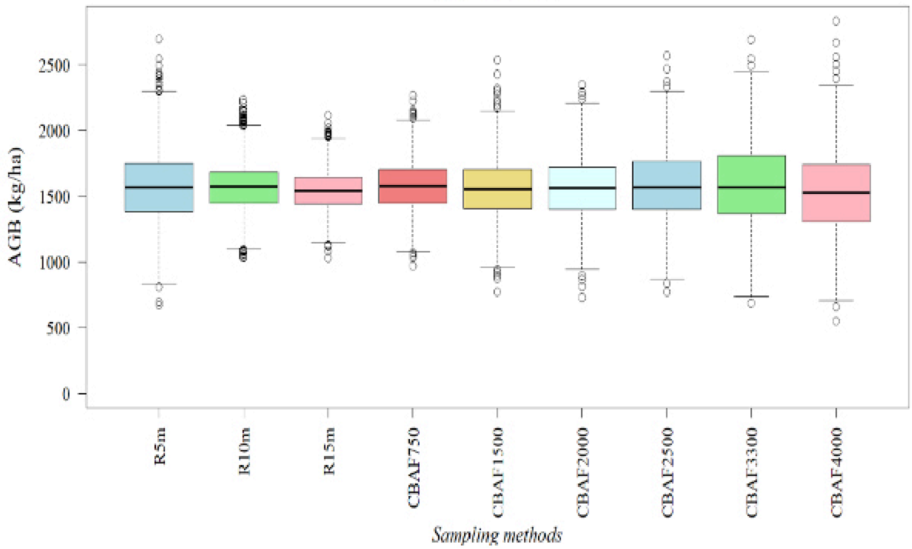
We also utilized boxplots to compare the mean and distribution of the estimates across various plot sizes and crown basal area factors. Fig. 7 presents distributions of three forest attributes from the real forest across varying plot sizes and crown basal area factors, with a constant sample size of 60 sampling locations. In FR, variability rises with smaller plot sizes, while in HPS, variability increases with higher CBAF. The same behavior of variability was observed with the other sample sizes used, although those results are not shown here. Fig. 8 presents the distributions of CCA from the simulated forest across varying plot sizes and crown basal area factors. It exhibits the same behavior as the CCA of the real forest. Similar behavior was observed for other forest attributes, although those results are not shown here. The corresponding simulation bias (%) for three forest attributes is presented in Table 5. As the results indicate, the simulation bias is minimal.

Table 5: The simulation bias (%) for three forest attributes, for sample size 60 and for three plot radius and six CBAF.

Tabelle 5: Simulationsbias (%) von drei Bestandeseigenschaften für Stichprobenanzahl von 60 und drei fixen Probekreisradien und sechs CBAF.

	R 5	R 10	R 15	CBAF 750	CBAF 1500	CBAF 2000	CBAF 2500	CBAF 3300	CBAF 4000
AGB (kg/ha)	1.3%	-0.4%	-0.3%	-0.4%	-1.5%	0.5%	2.2%	1.5%	1.6%
CCA (m²/ha)	0.4%	0.9%	-1.2%	0.9%	-0.2%	1.2%	1.7%	1.7%	-1.7%
N (ha^{-1})	1.3%	0.1%	-1.5%	0.7%	0.5%	0.7%	1.2%	2.0%	-2.5%





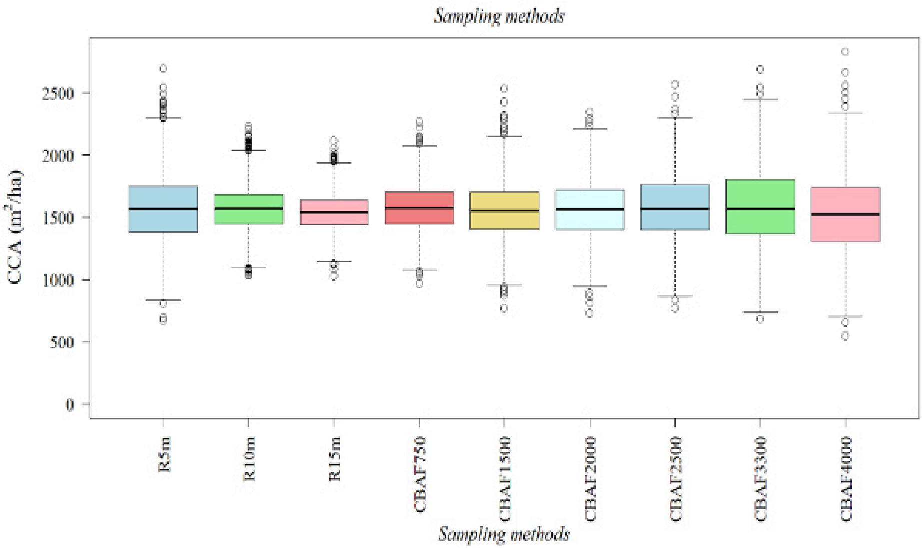


Figure 7: Distributions of three forest attributes across varying plot size radii (R) and crown basal area factors (CBAF), with a fixed sample size of 60 in the real forest, showing the stem density (top), above-ground biomass (middle) and canopy cover area (bottom).

Abbildung 7: Verteilung der drei Bestandskennzahlen für unterschiedliche Probekreisradien (R) und Kronenzählfaktoren (CBAF) für Stichprobenzahl von 60 in dem realen Wald für Stammzahl (oben), oberirdische Biomasse (mitte) und Kronenfläche (unten).

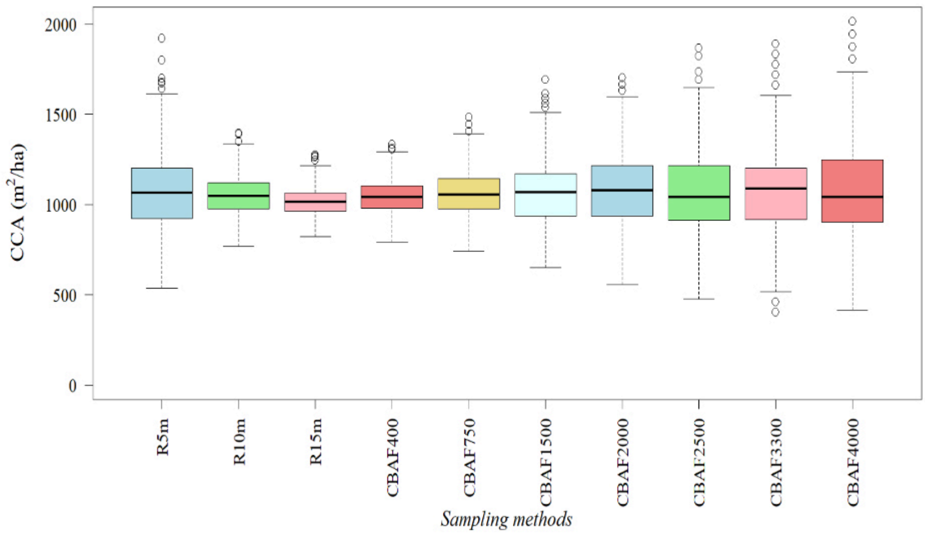


Figure 8: Distributions of CCA from the simulated forest across varying plot sizes and crown basal area factors (CBAF), with a fixed sample size of 60 sampling points in the simulated forest.

Abbildung 8: Verteilung von CCA für den simulierten Wald für unterschiedliche Probekreisradien (R) und Kronenzählfaktoren (CBAF) für Stichprobenzahl von 60 in dem simulierten Wald.

4 Discussion

In this study, we present a new approach that integrates HPS and CR for estimating stand properties in coppice forests. This innovative combination was compared with the traditional FR. Stenberg *et al*. (2008) discovered that CR is not only efficient but also suitable for forest stands characterized by low density and absence of crown overlap. These conditions are consistent with our research carried out in an open coppice forest. Ramezani and Nazariani (2023) suggested that combining CR with HLS could serve as a viable alternative to LIS. However, drawing a direct comparison between the findings is difficult due to the use of different sampling units.

For a given sample size, RSE % tends to increase when using larger CBAF (Table 3), because more trees are sampled the lower the CBAF. When estimating the stand basal area in a non-coppice forest using a stem basal area relascope, the traditional relascope proves to be more efficient compared to other sampling methods like FR (Piqué *et al*. 2011; Leiter & Hasenauer 2023). The results, as shown in Table 3, also reveal that FR, using a radius of 15 meters, is the most efficient in terms of RSE %. Conversely, HPS with CBAF of 4000 is the least efficient. This study presents only the statistical performance in terms of RSE % of different combinations of sample sizes, CBAFs and plot sizes. Therefore, there is a need for a time study to determine an optimal, cost-efficient scenario.

From Husch *et al.* (2003) and Becker and Nichols (2011), the expected number of in-trees is proportional to the reciprocal of BAF when using stem based relascope in non-coppice forest, as we observed in our use of CBAF in coppice forests. For case AGB, Fig. 4 and Table 3 illustrate that, on average, 6.3 trees were measured within a 15-meter radius to achieve a relative standard error of 4.6 across 10 sampling locations. In contrast, with a CBAF 4000, an average of 0.5 trees were measured to attain a relative standard error of 9.9. Using CR, a similar result was obtained when the simulation study was conducted on a simulated forest.

Without conducting a time study, selecting the most cost-effective method becomes infeasible. In other words, our choice of a cost-effective method is constrained by our inventory resources. While this study did not conduct a time study, it is anticipated that HPS will be more efficient in terms of time-precision than FR in estimating the crown cover area (CCA). This is because the CCA is the product of the average tree count in the sample location and a predefined CBAF.

The results displayed in Table 4 reveal that all three factors, namely CBAF (relascope angle), plot size, and sample size, influence the relative standard error (RSE %). In the case of HPS, the impact of sample size on RSE % is more pronounced compared to the influence of the relascope angle. Conversely, when utilizing FR, the effect of plot size is more significant than that of sample size. This aligns with the findings of Ramezani and Nazariani (2023), who also observed that a larger relascope angle can contribute to a higher coefficient of variation. Our conclusion is that in forest inventory planning with HPS, it is more crucial to consider the sample size rather than the relascope angle.

The findings obtained from our randomly positioned sampling locations align with sampling theory, demonstrating that inventory means were essentially consistent regardless of plot size or CBAF. Meanwhile, the variance exhibits a decrease with increasing plot size and an increase with rising CBAF, as illustrated in Figs 7 and 8. These findings are consistent with the observations made by Becker and Nichols (2011) and Leiter and Hasenauer (2023) when assessing FR and BAF (basal area factor) methods in a non-coppice forest.

In an actual forest inventory, we frequently work with various variables of interest, such as biomass, tree density and basal area. It's important to recognize that a single plot design (either size or type) or a given relascope angle (in the case of HPS), may not be equally effective for all these variables (Henttonen & Kangas, 2015). To overcome this problem, one approach is to combine different CBAFs and/or combine FR and HPS methods. For instance, HPS can be employed to estimate crown cover area, while FR can be utilized to assess attributes like biomass and tree density. This flexible approach allows for more accurate and comprehensive forest attribute estimations. A combination of FR and HPS is also recommended by Leiter and Hasenauer (2023) for continuous cover forests (also known as multi-aged forests).

This study operated under the assumption that tree crowns are circular in shape. However, tree crowns often deviate from a perfect circle, introducing a certain level of bias. Recently, Iles (2023) developed an unbiased method to overcome non-circularity of tree crowns when using a crown relascope (CR). When using Iles (2023) method, there are certain measurements, and the shape of the virtual inclusion area looks like a Voronoi polygon. Certain measurements refer to the distance between the border of the inclusion area and the tree.

Given the new application of crown relascope and horizontal point sampling in coppice forests (CF), there is a need for further research to explore the most effective CBAF. Brooks and McGill (2004) found that estimated variance was influenced by the forest structure for both HPS and FR methods. Therefore, it would be interesting to carry out a comparable study in coppice forests characterized by distinct structural and density characteristics.

Another interesting research topic in CF is the investigation of HPS with a double sampling approach as a potential alternative to the traditional FR and HPS sampling methods. With point double sampling it is possible to maintain acceptable precision of volume/biomass estimate with a reduction in field data collection time (Yang *et al*. 2017; Chen *et al*. 2019). In point double sampling, at the first phase, using a smaller relascope angle, many samples are measured to calculate the mean of an auxiliary variable (for instance, tree crown cover area), which is easier and cheaper to collect. Simultaneously, during the second sampling phase, a larger relascope angle is employed to collect data on the variable of interest from a subsample of trees initially sampled.

Our findings suggest that combining HPS with CR can be highly effective in estimating crown cover area (CCA). Since HPS seems to be more time-efficient than FR sampling for CCA estimation, it's recommended to prioritize HPS when CCA is a key variable of interest in the inventory.

Our results indicate that while larger CBAFs might be less efficient, they can still be beneficial, if combined with an appropriate sample size. Therefore, fieldwork should involve balancing the relascope angle with the sample size to optimize the sampling effort. For instance, in areas where the tree density is low, using a smaller CBAF with a larger sample size might yield more precise estimates without requiring excessive field time.

A significant limitation of this study is the assumption that tree crowns are circular in shape. In reality, however, tree crowns often deviate from a perfect circle, which introduces bias into the CCA estimates when using CR. While this assumption simplifies data collection and analysis, it can lead to inaccuracies, especially in forests with irregularly shaped crowns.

5 Conclusion

This study demonstrates the potential of integrating HPS and CR techniques in the inventory of open coppice forests. By comparing these innovative methods with traditional FR sampling, we have highlighted the strengths and limitations of each approach. The findings suggest that while FR sampling is more efficient for estimating above ground biomass and tree density, HPS combined with CR offers significant advantages in estimating crown cover area (CCA), particularly in terms of time efficiency.

Our results underline the importance of selecting appropriate sampling methods based on the specific attributes of interest in forest inventories. For instance, HPS, with a focus on sample size rather than relascope angle, provides more accurate CCA estimates, making it a valuable tool in certain forest structures. Conversely, FR sampling remains preferable for variables such as biomass and tree density, especially when larger plot sizes are used to reduce the coefficient of variation.

The study also emphasizes the need for further research, particularly in exploring the most effective CBAF for various forest structures. Additionally, addressing the bias introduced by the assumption of circular tree crowns is crucial for improving the accuracy of CR-based measurements.

In conclusion, the combination of HPS and FR sampling methods offers a flexible and comprehensive approach to forest inventory, especially in complex or heterogeneous forest environments. By tailoring the choice of sampling techniques to the specific needs of the inventory, practitioners can achieve more precise and efficient outcomes, ultimately supporting better forest management and conservation efforts.

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