CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Forestry and Wood Sciences

Department of Forest Technology and Construction

# Accuracy of double bark thickness estimation methods used in spruce timber production in Czechia

DIPLOMA THESIS

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# CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Forestry and Wood Sciences

# DIPLOMA THESIS ASSIGNMENT

Bc. Dipl.-Ök. Prince Opoku Peseu

Tropical Forestry and Agroforestry

Thesis title

**Accuracy of double bark thickness estimation methods used in spruce timber production in Czechia**

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**Objectives of thesis**

The thesis is focused on the verification of multiple double bark thickness estimation methods commonly used in Czechia. Student will need to: (i) review the current literature on the topic of bark generation by trees and double bark thickness estimations; (ii) develop a methodological framework for measuring double bark thickness and analysing the current estimation methods; (iii) conduct measurements in sufficient quality and quantity to enable a statistical analysis; (iv) analyse the results; and (v) draw logical and sound conclusions from the research conducted.

**Methodology**

Double bark thickness estimation methods currently used in Czechia are based on decades old datasets. As stated by Stangle et al. (2017), climate change, genetics, and other factors caused that trees generate less bark therefore the double bark thickness estimation methods should be recalibrated. It is therefore reasonable to expect similar patterns in the Czech forests. The student will verify multiple double bark thickness estimation methods commonly used in Czechia. These include the polynomial model of double bark thickness, diameter band deduction method, and the newly developed linear model – LinBark. The student will review the current literature, mainly peer reviewed scientific journals, then proceed to measure spruce logs handled by the University forest enterprise over- and subsequently under bark. Through statistical analyses, he will then determine whether the current methods should be recalibrated for the double bark thickness estimation to be accurate.

Schedule:

03/2021 – Development of the methodology; preliminary literature review

08/2021 – Literature review completed; materials gathered

12/2021 – Materials analysis; Results and Discussion sections completed

03/2022 – Conclusions drafting; compiling thesis sections

04/2022 – Thesis submission.

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**The proposed extent of the thesis**

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**Keywords**

double bark thickness estimation methods; diameter band bark deduction; linear bark deduction; polynomial bark deduction; spruce timber production; under bark volume;

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**Recommended information sources**


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Prague on 10. 02. 2022

**Declaration**

I declare that I prepared this diploma thesis " Accuracy of double bark thickness estimation method used in spruce timber production in Czechia " independently and that I cited all relevant sources of information in accordance with Methodical guidelines for producing an academic thesis.

Prague, 12th May 2020

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Prince Opoku Peseu

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## Abstract

Foresters measure diameter over bark (DOB) to determine bark thickness, which they then use to calculate log volume. Poor bucking optimization and out-of-spec logs can diminish returns due to spruce bark thickness estimation errors. Depending on the region, the stand, and the tree, the thickness of the bark varies. Depending on the application, different complexity prediction equations were utilized, such as Polynomial functions and the LinBark function for bark thickness. Growth rate variation appears to be influenced by the site and stands characteristics, which have a significant impact on the thickness of the bark; relative bark thickness decreases with increased site quality. Bark thickness equations customized to local or regional species are used in forestry and forest research to determine the external diameters of bark and diameter measurements of the over bark. To assess a volume of quality timber, foresters must precisely evaluate bark thickness.

The objective of this research was to evaluate methods commonly used to estimate double bark thickness in Czechia, as well as to provide a scientific framework for measuring double bark thickness and analysing current estimation methods. I measured 120 spruce logs at the University Forest Enterprise in Kostelec nad Černými lesy. I measured the nominal length (cm), both the small end and large end, diameter over bark (mm), and midspan diameter for each log with a calliper.

To evaluate the differences, I used descriptive analysis and multivariate analysis to integrate the real DBT with the two estimates approaches (Polynomial function and LinBark).



***Keywords***: Diameter over bark, Polynomial functions, LinBark function, Double bark thickness

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**List of abbreviations**

| | |
|---|---|
| DOB | Diameter over bark |
| VUB | Volume under bark |
| DBT | Double bark thickness |
| dbhOB | Diameter over bark at breast height |
| UFE | University Forest Enterprise |
| CCT | Czech Cubing Tables |
| NFI | National Forest Inventory |
| DCM | Diameter class method |

# 1**. Introduction**

The goal of this research was to verify numerous double bark thickness estimation methods that are regularly used in Czechia, as well as to build a scientific framework for measuring double bark thickness and analysing current estimation methods. At the University Forest Enterprise in Kostelec nad Černými lesy, I measured a total of 120 spruce logs. I took measurements of each log's needed or nominal length (cm), diameter over bark (mm), and midspan diameter. To assess the differences, I combined the real DBT with the two estimation methodologies (Polynomial function and LinBark) using statistical analysis. The bark's physiological role is crucial in maintaining the tree's nutrition and allowing them to produce the stems and leaves of a tree. The canopy's complete leaves and stems were massive and vigorous plant structures. To prevent the stems and trunk from rupturing, effective support is essential. The bark is responsible for the tree's mechanical support (Graves et al. 2014). In both old and young stems, different proportions of bark thickness are observed: tips are covered in more bark, resulting in a reduction in wood production. Early stem bark stiffness is proportional to bark thickness.

Tree bark can defend trees from both abiotic and biotic threats. If the thickness of the bark is vital for defense, independent of the threat, it should increase as the tree grows in girth, because extra thickness above a point gives the tree a survival advantage (Wilson & Witkowski 2003). The bark of the tree is a fire-resistant substance (Adams & Jackson, 1995). Bark thickness, and thus the survival potential of fire resistant, is the most of cambium layer (Paine et al. 2010). Fire-return intervals in some ecosystems, are important most trees will almost likely never be exposed to fire. It can also be used as energy generation or for medicinal purpose. Because roundwood is transported and sold by volume as standard without bark, bark has an impact on realized income. As a result, in today's wood industry, knowing how thick the bark is and being able to make the most precise and critical erroneous assessments, the forest owners could lose up to 11% of its value (Marshall et al. 2006).

Trees refer to an external tissue as 'bark,' irrespective of its formation (Biggs 1992). The periderm is a secondary bark tissue that replaces the epidermis as a protective layer. Phellogen is the periderm's lateral meristematic tissue; phellem is the phellogen's dead protective tissue; and phelloderm is the phellogen's functional parenchyma (Biggs 1992).

The periderm separates secondary phloem that is still alive from the outer bark, which contains the periderm's newly created dead tissue. The internal bark is the innermost section of the tree play very important role, particularly phloem. As a result, primary assimilates conducting tissue is the inner bark, which is found outside xylem tissue. Outside the tissues, new layer does not survive, while in mature trees' phloem layer emerges (younger trees). When a tree's girth grows and the thickness of its bark thickens, the outer layers of bark may fissure (example: *Albizia adianthifolia*) or shed (example: *A. xanthophloea*). The thickness of a stem's bark grows with age and diameter (Williams et al. 2007).

Other species, on the other hand, have a shaky connection with one another due to varying degrees of bark tissue loss (Williams et al. 2007). Rhytidome features, which influence bark in many species. The weathering processes, tangential strains, periderm growth pattern, phellem organization all influence rhytidome (Junikka 1994). Rhytidome thickness varies as the tree increases or grow and can be genetically altered. Tree bark is typically recognized as an industrial waste product because it is largely used for energy production (Routa 2021). The bark of tree can be utilized and make biomaterials that could replace fossil fuel-based products due to its unique chemical composition. The market for these unique value-added products made from tree bark's rich chemicals is continually growing (Bauhus et al. 2017).

It is critical to precisely identify the quantities of bark, whether it is used as a high-value raw material or processed as a by-product. The inner and outer (bark) barks of most woody plants are the tissues outside of the vascular system. Because calculating the volume of wood without bark necessitates an exact measurement of the bark proportion (Beltrán-Rodrguez et al. 2021), it has a significant cost impact. The ratio of wood to bark biomass can be carefully studied for a variety of reasons, including carbon accounting, and determining the fire resilience of tree species (Hammond et al. 2015).

Bark factors based on bark thickness models are often used to compute the volume of wood by estimating the diameter beneath the bark (Murphy & Cown 2015). The thickness of the bark must be assessed at the species level because the proportion of bark ranges from 4% to 30% depending on the tree species (Wilms et al. 2021). In addition, the growth region must be considered (Stängle et al, 2017). It is difficult to calculate bark allometry tree accurately and consistently or volume due to a variety of bark types (e.g., smooth bark, white bark, fissured bark, and scaly bark) and bark rugosities (ridges and furrows). In forestry, the diameter of the inner bark is an important parameter because it is used to calculate log and tree wood volume as well as to optimize bucking for specific inner-bark sizes. The diameter of a tree or log, on the other hand, is commonly measured outside of the bark, requiring knowledge of the thickness of the bark.  In Czechia, the under-bark volume of timber is typically determined using:

(i) the diameter over-bark,

(ii) the midspan diameter measurement (perpendicularly two measurements), and

(iii) the required log or stem length

## 2. Objectives

The purpose of this thesis was to verify multiple double bark thickness estimate methods that are commonly used in Czechia. The objectives were to:

(i) Conduct a review of the current literature on tree bark production and double bark thickness estimations.

(ii) Create a systematic framework for estimating double bark thickness and evaluating current estimation methods.

(iii) Take measurement of a high enough quality and quantity to allow for statistical analysis.

(iv) Analyse the findings and develop good and logical conclusions from the research.

# 3. Literature review

## 3.1 Geographic Location of Czech Republic

In Central Europe, the Czech Republic shares borders with Poland to the north, Germany to the west, Austria to the south, and Slovakia to the east. Prague is the country's capital and largest city, with a population of 1.3 million people. Since 14th century, an area has been referred to as the Bohemian Crown's territory, but it has also been called the Czech/Bohemian lands, the Bohemian Crown, Czechia, and the Crown of Saint Wenceslaus. After the Austro-Hungarian monarchy fell in 1918, the country was renamed Czechoslovakia to reflect the fusion of Czech and Slovak ethnicities into a single state.

### 3.1.1 Climate

The country's climate is hot in the summer, cold in the winter, and snowy during winter because of change in climatic weather conditions. There is a large temperature difference between summer and winter due to the landlocked location. Temperature is affected by altitude. As one goes higher in elevation, the temperature drops and the pattern of rainfall changes.

## 3.2 Overview of Forestry in the Czech Republic

Forests are both an important component of the ecology and a national heritage. The Czech Republic's forestland covers 2 669 850 hectares, accounting for 33.9 %. Lesy Ceské Republiky manages approximately half of the Czech Republic's forests. For all operations, forests are managed in a sustainable and beneficial manner.

Forest functions are in the following categories:

(i) Production Forest

(ii) Protection Forest and

(iii) Special purpose forest

Production forests are designed to produce timber while simultaneously offering environmental and other benefits. The protected forest's goal is to protect an endangered forest at a high elevation. Wood production is less essential in a protected forest. Producing forests have a longer rotation period and a lower or reduced wood output potential because to poor site quality. Only a fraction of these forests has been designated as forest reserves and the rest have never been logged.

Special-purpose forests address forest degradation due to air pollution, microclimate maintenance, and recreational use. Forests in national parks are classified as special purpose forests. The government owns most of the forest in the Czech Republic (61.5 percent). Private persons own 19% of the forest, while municipalities, forestry commissions, and communities own 17 percent. (The Forestry Commission) oversees 1340.8 thousand hectares of the Czech Republic's 1596.7-thousand-hectare total forest area, while "Vojenské lesy a statky R s.p." oversees 125 thousand hectares. The President of the Republic has power over 6,000 hectares, whereas Správy národnch park has control over 95.6 thousand hectares (National Parks).

Forest regulations govern the forest's products. Any forest with a size of more than 50 hectares must have a ten-year Forest Management Plan, according to this Act. Harvesting is an important aspect of the management plan. The Forest Management Guidelines have been endorsed by regional offices (for holdings of less than 50 ha). There are three prerequisites that must be fulfilled. In state or municipal forests, the maximum harvesting volume - In stands younger than 40 years, a minimum area of thinning is required. Regional forest agencies and the Czech Environmental Inspectorate oversee enforcing the Forest Act.

In the Czech Republic, illegal logging from public forests is a low-risk activity. Government-managed public forests account for more than 60% of all forest land and are governed by the government on a regular basis.  Risk Assessment of Timber Legality in the Czech Republic because private woods vary in size, there are insufficient rules governing them, and government monitoring is impracticable due to the huge number of forest owners, they pose a greater risk.

### 3.2.1 Species Composition of the Czech forests

The principal coniferous trees, spruce, and pine, continue to shrink in size, while the percentage of fir continues to rise. The proportion of deciduous trees, particularly beech and oak, is also increasing. This is the result of foresters' long-term efforts, which have been assisted by the state's targeted subsidy policy to produce an optimal forest species composition.

Figure 1. Standing trees of Norway spruce (*Picea abies*)

Source: https://www.borregaard.com

Figure 2. Oak species in Czech forest

Source: https://www.borregaard.com

Figure 3. Larch tree species in Czech forest

Source: https://www.borregaard.com

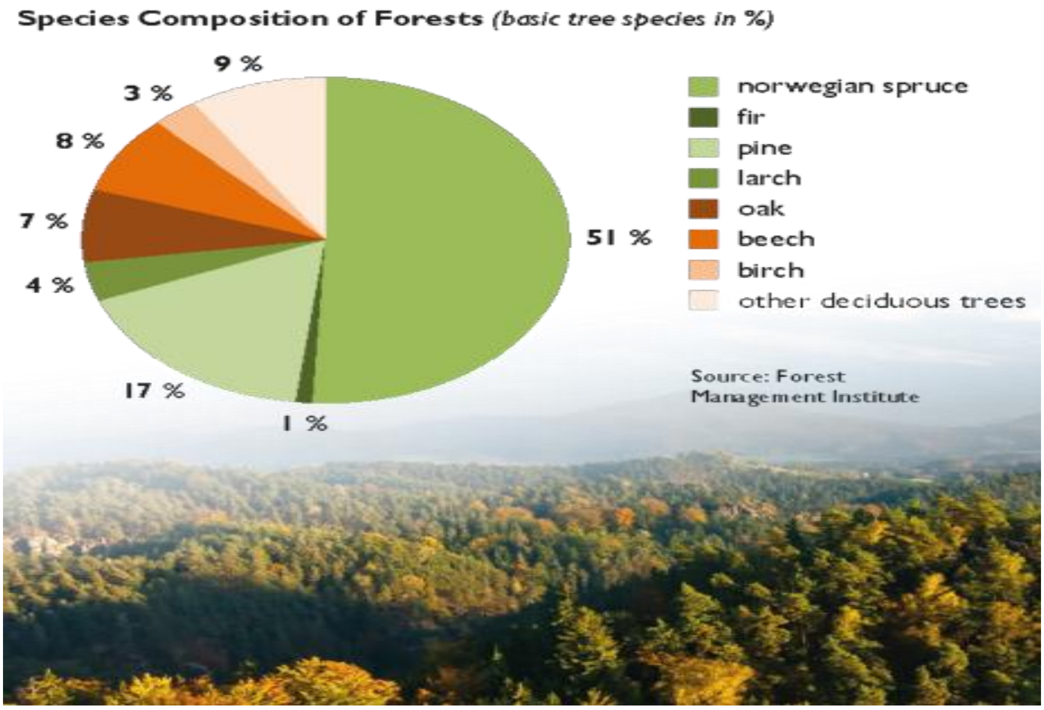


Figure 4. Pie chart showing species composition

Source: Forest Management Institute

### 3.2.2 Spruce Species in Czech Republic

In the Czech Republic, spruce species have a total wood supply of 589,700 hectares accounting for 16.1%. The research was conducted from 2001 to 2004 (NFI CR), the spruce inhabited 1,38424 hectares of spruce tree species in the Czech Republic. The plant is popular among forest owners since it is simple to care for, grows quickly, and can be used for a variety of tasks. As a result, the spruce's native range has expanded significantly. In Europe, the spruce is an economically and environmentally significant tree (especially in Czech Republic). It has the potential to grow to a height of over 40 meters and a diameter of over one meter under ideal conditions. The bark appears to be thin and grey. Young branches and trunks have smooth bark at first, but in different ways depending on the ecosystem. Spruce is used to make Christmas trees and musical instruments.

Figure 5. Spruce logs showing bark thickness.

Source: https://megawoods.com.ua

Figure 6. Spruce logs showing bark thickness

Source: https://www.globalsources.com

Figure 7. Log debarking machine debarking spruce log

Source: https://en.wikipedia.org

Figure 8. Log debarking machine debarking log

Source: https://en.wikipedia.org

### 3.3 General Overview of Bark Thickness

Flurry conducted investigation on the thickness of the bark in Switzerland around the turn of the century, linear models was predicted as fraction based on dimension factors were used to develop bark thickness equations (Flurry 2007). Stängle et al. (2017) developed equations for calculating the thickness of the bark as a function variety of predictor parameters, many of which may be measured simply on the stem. A series of research from a variety of tree in different countries marked the start of a series of research from a variety of tree species in different countries with the goal of establishing criteria that would allow the volume of a trunk with bark to be converted to volume without bark. Furthermore, earlier research (Musi et al. 2019) primarily measured bark.

The thickness with bark at breast height can be used to estimate the volume. However, in recent years, scientists have focused more on the impact of other factors on tree bark thickness, such as trunk height, habitat, and so on. Rusu et al. (2006) conducted the first significant investigation on bark thickness in Baden-Württemberg. A 35.752 km2 area with a diverse variety of habitat and stand characteristics is included in the sample. In Slovenia, (Holzleitner & Kanzian 2022) looked at the thickness of spruce bark. His results were quadrupled when he used a larger sample with a more common tree species, spruce, but his estimates of bark thickness were significantly higher.

#### 3.3.1 Bark Deduction

Previously, bark thickness was calculated using simple or multivariate linear regression models. (Jankovský et al. 2019), which correctly predicted the outcome. Modelling techniques, on the other hand, have advanced at a breakneck pace as computational power has increased. Tables and polynomial functions are used in the Czech Republic to estimate the volume of logs under bark. They are based on the historical forestry development of each location. In the Czech Republic, the volume of wood beneath the bark is generally calculated by taking two perpendicular measurements of the midspan over-bark diameter, rounding down the results of each measurement, and then rounding down the mean of the measurements to the nearest millimetres (regardless of whether the measurements are performed by machine or by man).

The volume of the under-bark is then estimated using the ŠN 48 009 technical standard's Czech cubing tables (CCT) (ŠN 1977). To estimate the under-bark volume, timber producers and log buyers currently employ a polynomial function rather than the CCT. Using CCT data, the polynomial function calculates the double bark thickness, which is then subtracted from the over-bark diameter using Huber's approach. With the least amount of error, the function fits CCT data.  Log purchasers who use log scanners use this method to deduct the double bark thickness because of its advantages, such as the capacity to apply precise midspan diameter over bark or the ease with which it can be used with timber measurement software programs. Regardless, Dvorak et al. (2020) suggests rounding down the diameter measurement results for calculating the volume of the under-bark log.

$$\mathrm{DBT} = p_0 + p_1 \times d_{OB}^{p2}$$

$$V_{\mathrm{UB}} = \pi/4 \times (d_{OB} - \mathrm{DBT})^2 \times l \times 10^{-4}$$

The parameters p0, p1, and p2 have the following definitions: VUB stands for volume under bark ($m^3$), and l stands for log length. dOB represents for diameter over bark (mm), VUB stands for volume under bark ($m^3$), and l stands for log length. The following are the definitions for the function parameters p0, p1, and p2: VUB stands for volume under bark ($m^3$), and l stands for log length. dOB represents for diameter over bark (mm), VUB stands for volume under bark ($m^3$), and l stands for log length. The function parameters p0, p1, and p2 are defined as follows: dOB represents for diameter over bark (mm), VUB stands for volume under bark ($m^3$), and l stands for log length. p0, p1, and p2 are function parameters; dOB stands for diameter over bark (mm); VUB stands for volume under bark ($m^3$); and l stands for log length.

DBT stands for double bark thickness (mm); p0, p1, and p2 are function parameters; dOB stands for diameter over bark (mm); VUB stands for volume under bark ($m^3$); and l stands for log length (Double-check diameter measurements to get an accurate estimate of under-bark volume, as a one-centimetre error in stem volume forecasts can result in a 19% error (Bottero et al. 2021). Given this data, both current under-bark volume estimation algorithms suffer from the issue of rounding down the mean midspan diameter, resulting in consistent log volume underestimation. Rounding down to the nearest millimetre while taking manual measurements reduces the impact of rounding errors.

However, to estimate the volume beneath the bark, a new statistical method known as linear modelling was developed. In the Czech Republic, machines collect a substantial amount of wood, accounting for around 30% of the annual budget (Ministry of Agriculture of the Czech Republic 2015). If harvesters' equipment is properly calibrated, they can measure the diameter of logs they process to a precision of 2 mm and the length to a precision of 2 cm (Dvorak et al.2020b).

The StanForD standard allows users to simply keep track of how much wood is generated above and below the bark. If under-the-bark data are collected, it is critical to record the bark thickness values, which will be subtracted from the measured over-bark diameter. (GPS) (113 t4), parametric (linear) deduction, parametric (linear) deduction, parametric (linear) deduction parametric (linear).

### 3.3.2 Band Deduction

On the stem diameter band, the user can enter the number of millimetres to be deducted as bark (113 t2, 3) as well as the suitable diameter interval with the mean double bark thickness found for each. The forest machine can be used to specify the double bark thickness values (e.g., Timber Matic 300, Dasa Forester, and so on). The bark would be deducted twice otherwise. At diameter intervals ranging from 1 to 4 inches, the value of double bark thickness was computed. Using TaP and FCR 2015, the value of double bark thickness was calculated for diameter intervals of 1 to 70 cm, because the TaP polynomial was designed for diameters in centimetres, the resultant values must be numerically converted to full millimetres. These parameters in DBT values should be in millimetres. After deduction bands with an interval of 70 mm, the mean for each band will determined with an accuracy of 100th millimetre. Because bark deduction band records vary by kind of wood acquisition and forest machine system, specific features, such as DBT values in the software machine, are recorded.

They can estimate the log's under-bark volume using either linear modelling or the diameter class bark deduction method (DCM), both of which are detailed in the StanForD standard (Stängle et al. 2017a). It's extensively used by harvester producers in data processing systems for harvester control and wood purchase.

The double bark thickness deductions in DCM are determined by the log's midspan diameter class. Using this strategy has two disadvantages. Because double bark thickness is constant for each diameter class, the estimate's error grows when the actual over bark diameter deviates from the class's centre point. Second, variables for different diameter classes for each tree species must be set independently into the machine's wood procurement system to forecast how much bark is removed from the over bark log volume. Each major tree species in the Czech Republic has ten different diameter classes. Another option is to use a linear function, such as the ones shown below.

DBT = b0 + b1dOB + 1

DBT = b0 + b1dbhOB + b2dOB + 1

dOB stands for diameter over bark at that position (mm); dbhOB denotes diameter at breast height which is 1.3 m; and b0, b1, and b2 are function parameters. This procedure is straightforward to implement because operators only need to enter two or three parameters per species into the machine's wood procurement systems. Canton studied at or investigated the process of creating spruce bark thickness tables. The results of the study are based on a variety of factors, including bark thickness. Only trees with a normal shape or no visible deformations on the trunk will be included in the sample several diameters will be measured on each trunk.

In all position of the stem (segment) was measured for the following:

• measured in centimetres with millimetre precision outside the bark (in the centre of the segment) and crossed (largest and smallest).

• measured of bark thickness where the diameter measuring equipment meets the trunk (two measurements).

During the measurement, the incision was made in proportion to the wood's trunk, allowing the bark thickness to be easily visible and correctly quantified. Mobile measuring equipment was used for the actual measurements (vernier callipers). In general, using a Swedish bark gauge to measure thickness overestimates thickness because it enters the wood partially during the measurement and is especially susceptible to sampling season. Furthermore, because assessing bark thickness needs a high level of skill to detect whether wood penetrates, the measurement expert's subjective assessment is particularly important.

Many woody species in South Africa have non-linear bark thickness–stem diameter correlations above a certain stem diameter threshold, making relative bark thickness estimates dependent on the range of stem diameters. The diameter of the stems was investigated which aimed at understanding the negative impact fire on tree species ecosystems, bark thickness has emerged as a significant characteristic (Midgley & Lawes 2016).

(1) A set of input data for minuscule stem diameters indicated by the breakpoint chosen for each species was fitted to two linear regression models. (2) with the origin confined ('raw-origin model'); (3) with a term for the intercept ‘raw-intercept model'). A third linear regression model a, 'log-intercept model) was fitted to the log-transformed full data set for each species.

(3) The log-transformed full data set was fitted with a third linear regression model referred to as the "log-intercept model") for each species.

### 3.4 Linear Regression Analysis of Bark Thickness

Linear regressions are used to calculate bark thickness. The range of minuscule stem diameters for which the relationship is generally linear, identified using a three-step approach, and raw data analysis which limit the range. After dividing the data into two linear portions, an abrupt transition piecewise linear regression is performed to find the stem diameter breakpoint that reduced the overall residual sum of squares (Hempson et al.2014). Low sampling density across a section of the stem diameter range, or a strong linear link at large stem diameter, could lead to poor model fit for microscopic stem diameters, hence the breakpoint will be visually inspected. A second visual estimate of the probable breakpoint produced by the raw-intercept model and the forecast from the best-fitting model to the complete data set.

The parameter estimates for both the allometric and modified exponential models is highly significant for all species, indicating that both models fit the data well. The allometric model better captured the information for the tree species, while the exponential model was chosen for four species (based on values). The parameter estimates for both the allometric and modified exponential models were highly significant for all species, indicating that both models fit the data well.

### 3.4.1 The Linear Models of Bark Thickness

The data used to create linear models that describe bark distribution patterns at the diameters of stems where woody plants are most vulnerable to fire. Because non-linear correlations, as well as fluctuating maximum stem diameters, can dramatically distort any relative bark thickness metric, the bark allocation pattern is derived from the early linear phase of the relationship. The problem is not overcome by linearizing the relationship using data log transformation, and slope estimations from the log-intercept model for the linear subset of stem diameters should not be expected to correlate with the raw-intercept model slope. The majority of coniferous tree bark research has focused on Silver Fir (Mederski et al. 2022) investigated the thickness of spruce bark in Slovenia (Musi et al. 2019) discovered slightly greater bark thickness estimations than (Mederski et al. 2022) but advised that the findings needed to be confirmed with a bigger sample and in areas with more spruce trees.

The diameter of the trunk with bark, the overall height of the trunk, and measuring height have all been found to be good indicators of bark thickness for a variety of coniferous species. The thickness of spruce bark, which is influenced by the tree's age, height, and shape, determines the diameter of the bark and the relative height of the trunk. All the different scientific areas' studies into bark thickness have resulted to the well-known fact that

(i) The diameter of the trunk is proportional to its thickness

(ii) Thickness diminishes by the stump to the top.

(iii) As the wood increases its thickness, its volume decreases.

# 4. Methodology

## 4.1 Study area

The University Forest industry in the Czech Republic's Kostelec nad Černými lesy municipality. It has a population of approximately 6000 people. The University Forest Enterprise (UFE) was founded in 1935 by the Czech Technical University's College of Agricultural and Forestry Engineering in Prague. The educational enterprise was formed on Kostelec nad Černými lesy's state forest management, which arose from Liechtenstein's property in 1933. Because of its rich natural surrounds and good forests, the Kostelec n. C.1forest was chosen (Sramek 1985).

The University Forest Enterprise is a self-sustaining enterprise that is one of two comparable facilities. The University Forest Enterprise manages a total of 5,700 hectares of forestland. In the Czech Republic's municipality of Kostelec nad Černými lesy, the University Forest enterprise is located.

### 4.1.1 Climate Conditions

Winters in the climatic district are mild, and annual precipitation of 650 mm. With average temperatures of 8.5-9°C and mean annual precipitation 650 mm, the area is described as a moderate climatic region with a moderately mild, slightly humid upland climate district and a pleasant winter. 150 to 160 days pass during the growth season. In recent years, though dry periods have affected the forest's health. In 2014, there was only 563 mm of rain, 451 mm in 2015, and 509 mm in 2016.

### 4.1.2 Natural Conditions

This region's geology is extremely diversified. The most prevalent Perm and Carbon rocks include conglomerates, arkoses, sandstone, bone coal, shale, and breccia. The

Central-Bohemia pluton, which is the bedrock of the University Forest Enterprise's south-western part, can also be found elsewhere. The granodiorite is dominated by biotite-porphyric granodiorite. The massive orthoclase grains in this rock are well-known. Pleistocene clays, particularly loess, are less important in bedrock soil development despite their relevance.

Table 1. Species composition in percentage at UFE

| Species | Percentage |
|---|---|
| European beech | 11.65 |
| Black alder | 1.4 |
| European larch | 4.35 |
| Silver fir | 1.64 |
| Norway Spruce | 49.78 |
| Oaks | 8.86 |
| Hornbeam | 1.12 |
| Pine | 18.15 |
| Other species | 3.41 |

Source: https://www.agriculturejournal.cz

## 4.2 Data Collection

The present methods for determining double bark thickness in Czechia are based on data from decades ago. Climate change, genetics, and other factors, according to (Stängle et al. 2017), have caused trees to produce less bark. As a result, it's time to re-calibrate the techniques for determining double bark thickness. As a result, similar trends could be expected in Czech forests. Spruce bark deduction bands are used to calculate roundwood volume beneath bark based on midspan diameter measured over bark utilizing tables and polynomials. Using the value of double bark thickness, the diameter was computed (hence "DBT").

Because the TaP polynomial was designed for diameters in centimetres, the final number must be numerically rectified to complete millimetres. To test the LinBark function on the data, I used the mean (the average difference between the predicted value and the real

DBT number). The double bark thickness (dependent variable mm), while the continuous variable was diameter section (cm) - mean diameter of the section. I used a measuring tape to measure the nominal length (cm) and measured the small end and the large end as well as the diameter of the midspan with a calliper. I followed the guidelines for sorting and measuring diameter stated by (Wojnar et al.2007).

I remeasured the midspan diameter under the bark after peeling the bark. I waited for the logs to be mechanically debarked and remeasured the midspan diameter of the debarking. Using descriptive analysis and multivariate analysis, I determined the differences that between the two estimation methods for evaluating double bark thickness. To compute the volume of the cut-off measured after debarking or for the cut-off with bark applied during measurement, the following parameter functions are used.

Table 2. Parameter functions of individual wood section volume (P0 P1 P2 are parameter functions)

| Wood | P0 | P1 | P2 |
|---|---|---|---|
| Spruce | 0,57723 | 0,006897 | 1,3123 |
| Pine -bark | 0,24017 | 0,001915 | 1,7866 |
| Pine | 1,7015 | 0,008762 | 1,4568 |
| Beech | -0,04088 | 0,16634 | 0,56076 |
| Oak | 1,2474 | 0,042323 | 1,0623 |

Source: (Wojnar et al.2007)

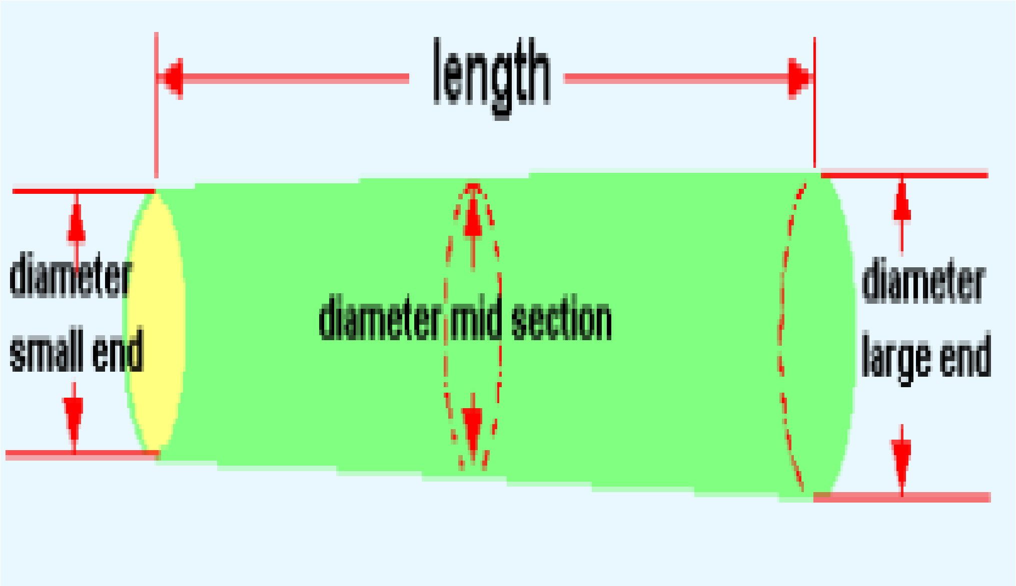


Figure 9. Nominal length of a log with small end, large end and midspan diameter

Source: https://www.spikevm.com

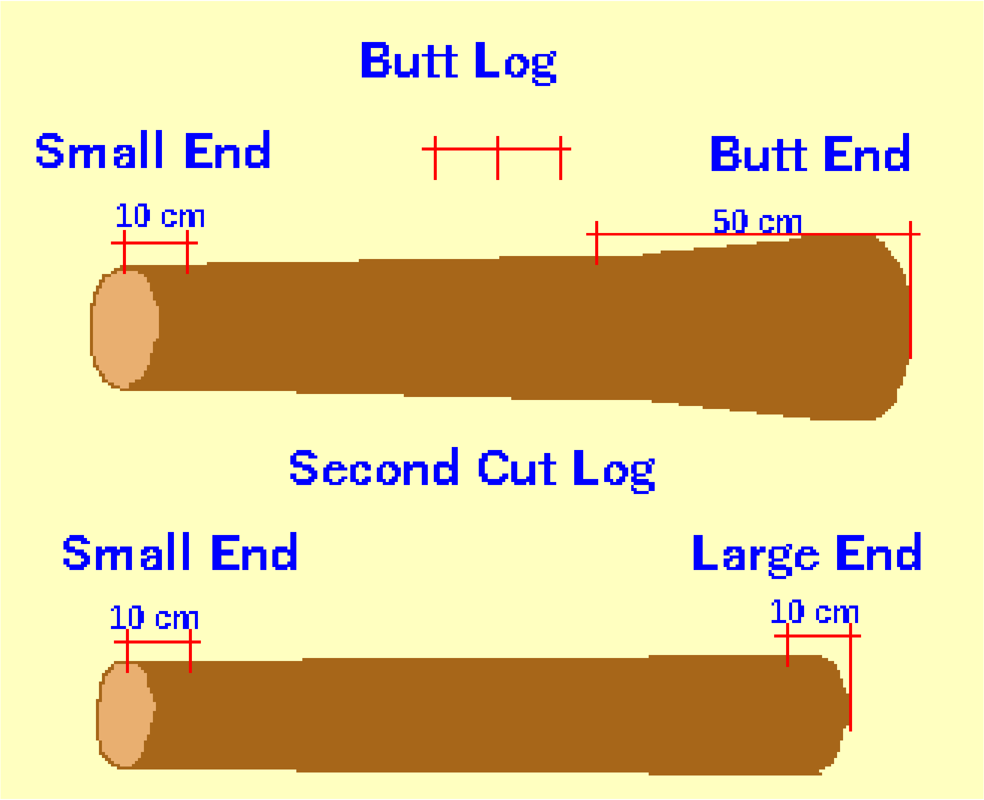


Figure 10. Measurement location for log small end and large end diameter

Source: https://www.spikevm.com

Figure 11. Debarking scraper used for manual debarking

Source: https://www.krumpholz.cz

Figure 12. Track log puller

Source: https://www.canstockphoto.com

Figure 13. A calliper used for diameter measurement of a log

Source: https://www.bahco-naradi.cz


Figure 14. Measuring tape used for measuring the length of a log

Source: https://www.obi.cz

Figure 15. Diameter measurement of small end of a spruce log with a calliper

## 5. Results

### 5.1 Double Bark Thickness Estimation

Bark thickness is assumed to be dependent on the point of measurement on the trunk, or the distance from the stump to its top, in addition to the diameter of roundwood, according to the findings or results of studies on double bark thickness. Table 3 compares Real DBT with Polynomial DBT and shows the variance of the model,residual deviation (model error), and overall variance of data on bark thickness.

The correlation shows that there is a weak and negative correlation between Real DBT and Polynomial DBT on the variables as shown in table 4 below**.** It can be concluded that the independent variables chosen to have a statistically significant impact on the change in the dependent variable's value and the correlation table 4 shows a significant level of 0.328 which is greater than 0.05 which implies that the analysis is not statistically significant.

The diameter of the trunk section (Dm section) has the biggest impact on bark thickness, as expected, based on the findings of the source of variation study on Real DBT and Polynomial DBT, variations recorded in Table 3. It's also possible to establish that the variable (a section of the trunk) has a big influence on bark thickness. That is, double bark thickness is not comparable at different relative heights of the trunk at the same diameter of the section (part of the trunk). As a result, to remedy these weaknesses, a polynomial function was created.

Table 3. Comparison of Real DBT and Polynomial DBT

| Units (mm) | Mean | Standard Deviation | Number |
|---|---|---|---|
| Real DBT | 290.7989 | 63.17139 | 174 |
| Polynomial DBT | 15.07 | 16.031 | 174 |

Table 4.Correlation the difference between Real DBT and Polynomial DBT

| | Units (mm**)** | Real DBT | Polynomial DBT |
|---|---|---|---|
| Pearson Correlation | Real DBT<br>Polynomial DBT | 1.000<br>-0.34 | -0.34<br>1.000 |
| Sig.(1-tailed) | Real DBT<br>Polynomial DBT | 0.328 | 0.328 |
| N | Real DBT<br>Polynomial DBT | 174<br>174 | 174<br>174 |

The correlation table shows that there is a weak and negative correlation between Real DBT and Polynomial DBT variables**.** The Pearson correlation implies that there is a weak correlation between the two variables. The model summary shows that the analysis is statistically significant. The difference between double bark estimation is significantly different. Polynomial provided different double bark thickness.

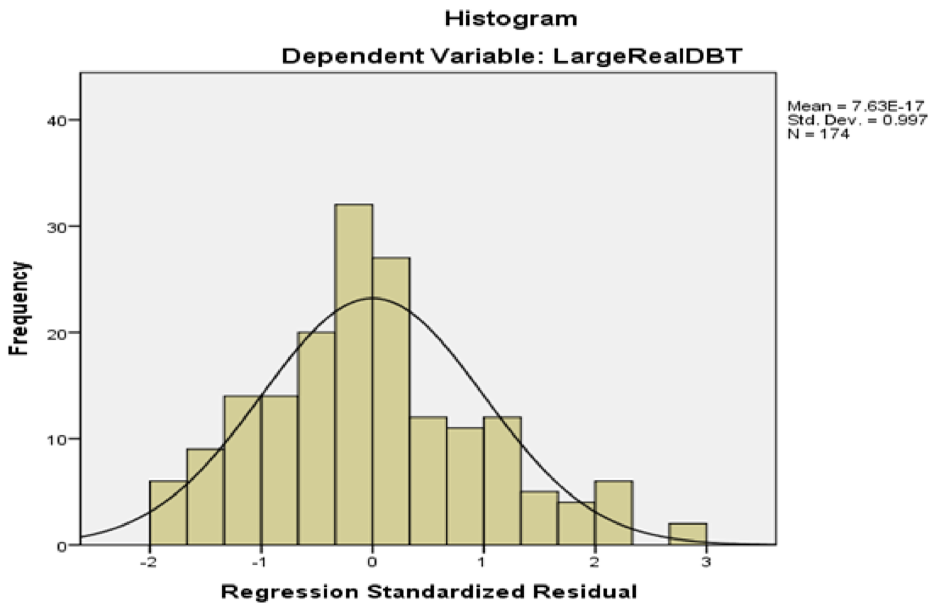


Figure 16. A histogram showing the distribution of Real DBT and Polynomial DBT

LinBark was able to achieve a mean double bark thickness of 13.2920 from table 5 and showed that there is a strong positive correlation between Large Real DBT and Large Lin Bark. The function, however, underestimated the double bark thickness for spruce logs and overestimated it for roundwood logs due to the unequal distribution of the midspan diameter across bark among the grade groups. Nonetheless, the LinBark function was more accurate as compared to the polynomial function.

Table 5. Comparison of Real DBT and LinBark DBT

| Unit (mm) | Mean | Std.Deviation | N |
|---|---|---|---|
| Real DBT | 290.7989 | 63.17139 | 174 |
| LinBark | 13.2920 | 3.53906 | 174 |

Table 6. Correlation the difference between Real DBT and LinBark DBT

| | Unit (mm) | Real DBT | LinBark |
|---|---|---|---|
| Pearson correlation | Real DBT<br>LinBark DBT | 1.000<br>0.968 | 0.968<br>1.000 |
| Sig.(1-tailed) | Real DBT<br>LinBark | 0.00 | 0.00 |
| N | Real DBT<br>LinBark | 174<br>174 | 174<br>174 |

The correlation table above shows that there is a strong positive correlation between Large Real DBT and LinBark DBT. The significance table shows that the analysis is statistically significant**.**

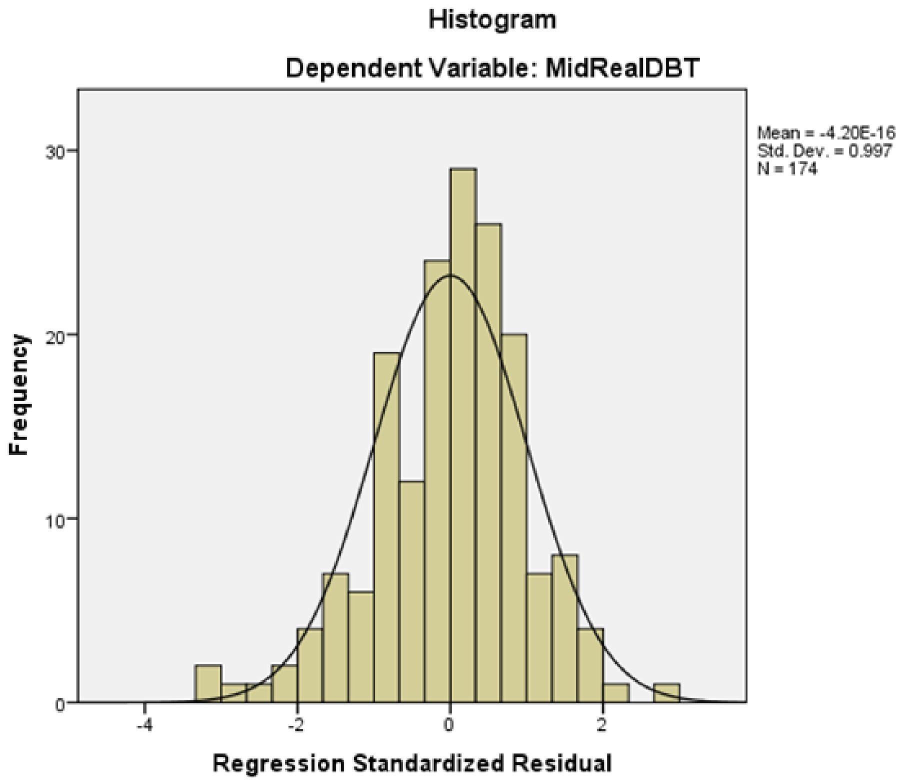


Figure 17. Distribution of Real DBT and LinBark DBT in the midspan diameter.

## 6. Discussion

The relationship between Real DBT and Lin Bark DBT measured at the large end of the logs was correlated. They have a 0.968 correlation which shows a strong and positive correlation between the two variables. The analysis between the two variables is also statistically significant of the variance has been explained in the two variables. Therefore, all the double bark thickness estimation methods used in Czech Republic should be recalibrated apart from large Real DBT and large Lin Bark DBT. Real bark thickness was estimated and compared with Lin Bark DBT linear regressions of both the raw and log-transformed data. Statistical investigations were confined to the scope of little stem distances across for which the relationship was roughly straight, which was resolved utilizing a three-venture process.

It was found that any increase in the measurement of Lin Bark, there is a positive change in Real DBT. Initially, a sharp progress piecewise straight relapse was utilized to distinguish the stem measurement breakpoint that limited the general leftover number of squares while dividing the information into two direct parts. Second, the place of this breakpoint was outwardly checked, as at times low examining densities across a piece of the scope of stem measurements or a solid direct relationship at large stem widths brought about an unfortunate model fit for little stem breadth.

Generally, there was nearer arrangement between bark thickness expectations made utilizing the algometric and outstanding models than between the log block and algometric models. Stängle et al. (2017) could not find a significant link between geographical factors and bark thickness variability although, the effects of factors such as latitude, climate, and others can lead to trees with significantly varied bark thickness. This could be as results of the influence of these factors on site productivity, as well as variations in tree growth (Kahriman et al., 2016).

Different authors (Jankovský et al., 2019) have stated that genetic and other factors have a substantial impact in the thickness of bark the tree generates during its growth.

## 7. Conclusion

The relationship between Real DBT and LinBark DBT is correlated. They have a 0.968 correlation which shows a strong and positive correlation between the two variables. The analysis between the two variables is also statistically significant of the variance has been explained in the two variables. The mean over-bark log volume computed showed a significant difference of double bark estimation. The thickness and structure of the bark, as well as the surface and tapering of the stem, might alter the measured characteristics of each tree species. The total volumes of the tested logs displayed relative variances in midspan diameter and necessary length distribution. It is very vital to note, however, that the available double bark thickness estimation methods evaluated are based on dated data. Stängle et al. (2017) discovered that tree bark formation has decreased, the underlying data set should be examined for validity. The difference between double bark estimation is significant different the polynomial provided different double thickness from LinBark DBT.

Timber producers aims to estimate the volume of merchantable timber as precisely as possible while employing the most effective methods.  Therefore, all the double bark thickness estimation methods used in Czech Republic should be recalibrated apart from large Real DBT and large Lin Bark DBT. For foresters, the mean of the statistical results will predict lower revenues for the price category in which they sell their timber.

The sample size was small, minimum 20 cm on the small end, and I therefore recommend further studies on a larger sample size on the significant differences between double bark estimation on polynomial DBT and LinBark DBT.

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