Review of productivity models for harvesters, feller-bunchers, and harwarders published in 2013-2023

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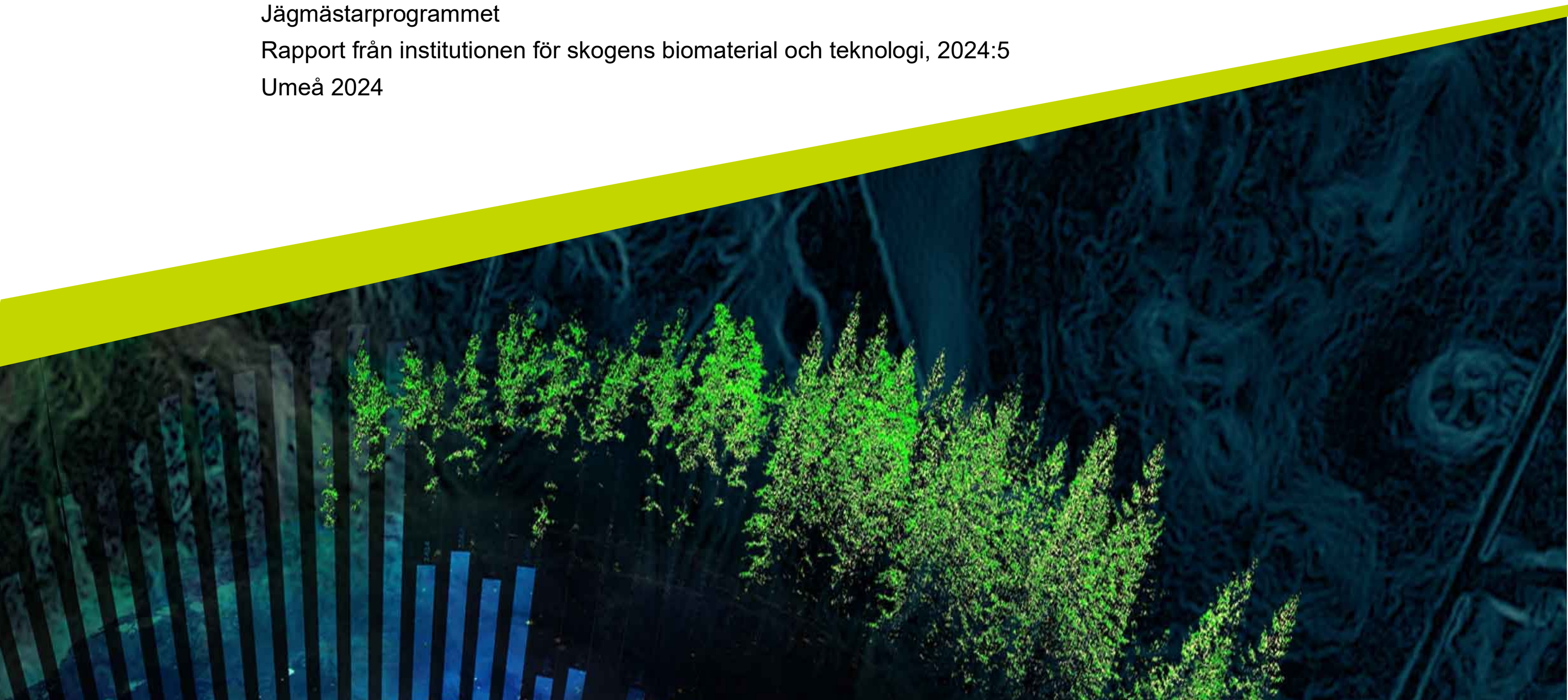

Review of productivity models for harvesters, feller-bunchers, and harwarders published in 2013-2023

Litteraturstudie om produktivitetsmodeller för skördare, fällare-läggare, och drivare.

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Abstract

Accurate predictions of work productivity are crucial for fully mechanized harvesting. Predictive models are thus employed to, for instance, estimate the duration of a harvesting operation. If these predictions are inaccurate, planning failures of forest companies may occur. The employed models are developed based on time studies or follow-up studies, and due to the diverse work conditions and the choices of the modeler, models' characteristics, such as independent variables and predictive capabilities, will differ considerably. Despite the models' significance, there are few publications that have scrutinized models for fully mechanized harvesting in terms of the models' independent and dependent variables, mathematical structures, coefficients of determination, the quantity of operators used for collecting data, the equipment used for time measurement, incorporation of delays, and potential regional or harvesting method-based differences. Therefore, a literature review was conducted to scrutinize productivity models for harvesters, feller-bunchers, and harwarders, aiming to better understand and explain the observed variability in models. One-hundred-and-fifteen publications containing models were identified, and the publications originated from six continents, 22 countries, and covered a wide range of forest types and work conditions. The review identified several differences in terms of equipment type used, with hand-held computers being the most common. However, more than a third of the publications did not specify equipment type. The number of operators studied also varied considerably, where most publications focused on a single operator, but the number of operators ranged from 1-120. In more than a third of publications, the number of operators could not be ascertained. Regarding their experience, it ranged from only a couple of months to several decades of expertise.

In the publications, 422 models were identified, and several commonalities as well as differences between models and publications were identified. For example, the majority of publications used piece size (tree volume or diameter at breast height) as a predictor, but there was a large variation in which additional predictors were used. Regional, as well as harvesting method-based differences, were also identified. It was, for instance, more common to model work cycle time and include movement/distances travelled-based and work cycle-based variables in North American publications, as well as in publications focusing on full-tree harvesting, than in other publications. Notable regional differences were also identified regarding models' mathematical structure. Publications from Asia, Eastern Europe, and North America predominantly developed purely linear models, a trend not apparent in other regions. Predictive capabilities of models also varied considerably, where some explained almost nothing, while others explained almost all variation. In terms of delays, most publications excluded them, while, when they were included, several approaches could be observed.

This review identified several regional and harvesting method-based differences in modelling practices for harvesters, feller-bunchers, and harwarders. Not only did this review identify differences, it is also a compilation of productivity models which facilitates easier access and identification of available productivity models published in 2013-2023.

Keywords: performance, efficiency, cut-to-length, regression model, time and motion study

Sammanfattning

Noggranna prediktioner av arbetsproduktivitet är avgörande för fullt mekaniserad avverkning. Prediktiva modeller används därför för att, till exempel, förutsäga hur lång tid en avverkning kommer ta. Om dessa förutsägelser är felaktiga kan planeringen för skogsföretag misslyckas. Modellerna som används är baserade på tidsstudier eller uppföljningsstudier, och på grund av varierande arbetsförhållanden och modellerarens val kommer modellers egenskaper, såsom oberoende variabler och prediktiva förmågor, att skilja sig avsevärt. Trots modellernas viktiga betydelse finns det få publikationer som har granskat modeller för fullt mekaniserad avverkning i form av modellernas oberoende och beroende variabler, matematiska struktur, determinationskoefficienter, antal operatörer som använts för datainsamling, utrustning för tidsmätning, inkludering av uppehåll, och potentiella regionala eller avverkningsmetod-baserade skillnader. En litteraturstudie har därför genomförts för att identifiera och granska produktivitetsmodeller för skördare, fällare-läggare, och drivare, med syftet att bättre förstå och förklara den observerade variabiliteten i modeller. Ett-hundra-femton publikationer som innehöll modeller identifierades, där publikationerna härstammade från sex kontinenter, 22 länder, och täckte ett brett spektrum av olika skogstyper och arbetsförhållanden. I litteraturstudien identifierades flera skillnader angående utrustning för tidsmätning, och att handburna datorer var den vanligaste typen. I mer än en tredjedel av publikationerna specificerades dock inte typen av utrustning. Angående antal operatörer som använts fanns även här en stor variation, där de flesta av publikationerna fokuserade på en operatör men att intervallet sträckte sig mellan 1-120 individer. I mer än en tredjedel av publikationer kunde antalet operatörer inte fastställas. Gällande deras erfarenhet varierade den mellan endast ett par månader till flera årtionden.

I publikationerna identifierades 422 modeller och flera likheter samt skillnader mellan modeller och publikationer identifierades. Till exempel använde majoriteten av publikationer trädstorlek (volym eller brösthöjdsdiameter) som oberoende variabel, men det fanns en stor variation av ytterligare variabler som användes. Regionala såväl som avverkningsmetod-baserade skillnader identifierades också. Det var, till exempel, vanligare att modellera tid för en arbetscykel och inkludera rörelse/distans-baserade och arbetscykel-baserade oberoende variabler i nordamerikanska publikationer, såväl som i publikationer som fokuserade på helträdsmetodsavverkning, jämfört med andra publikationer. Märkbara regionala skillnader identifierades även angående modellernas matematiska struktur. Publikationer från Asien, Östeuropa, och Nordamerika utvecklade i en större grad rent linjära modeller jämfört med andra regioner. En variation observerades även gällande modellernas prediktionsförmåga, där vissa förklarade nästan ingen men där andra förklarade nästan all variation. Angående inkludering av uppehåll i modeller observerades det att majoriteten exkluderade dem, men att när dem väl inkluderades fanns flera variationer på hur de implementerades.

Denna litteraturstudie identifierade flera regionala och avverkningsmetod-baserade skillnader angående modellutveckling för skördare, fällare-läggare, och drivare. Utöver att denna litteraturstudie identifierade skillnader, fungerar den även som en modellsamling som kan underlätta tillgång och identifiering av tillgängliga produktivitetsmodeller som publicerats mellan 2013-2023.

Nyckelord: prestation, effektivitet, kortvirkesmetod, regressionsmodell, tids- och rörelsestudie

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Table of contents

List of tables

List of figures

1. Introduction

The majority of global roundwood harvest is carried out with the fully mechanized cut-to-length (CTL) and full-tree (FT) methods (Lundbäck et al. 2021). In CTL, the trees are felled, delimbed, and bucked in the forest stand, whereas in FT, the trees are only felled. Approximately 1.38 billion m^3 of roundwood was harvested in 2016, and it was reported that fully mechanized CTL and FT constituted 37% and 33%, respectively (Lundbäck et al. 2021). However, the utilization of the harvesting methods differed greatly depending on the country. For example, in Sweden and Finland, almost all harvesting is carried out with the fully mechanized CTL method while, for example, in the United States, 70% is carried out with the fully mechanized FT method (Lundbäck et al. 2021).

Numerous machine types and models are applied in fully mechanized harvesting and the choice of machine can affect work productivity. Different machines will yield different productivities under various work conditions (e.g. Eriksson & Lindroos 2014; Ackerman et al. 2018). Consequently, it is essential to correctly choose the most suitable machine and accurately predict its productivity for efficient planning, control, and cost management. This can be achieved by applying precise productivity models (Lindroos & Cavalli 2016).

1.1 CTL and FT-machinery

Several types of machines can be utilized in fully mechanized harvesting. Machines commonly used are harvesters, feller-bunchers, and harwarders (Figure 1). The machines are similar in their construction, sharing common design elements. One of the most prominent features is a crane (the so-called swing-boom), which enables the machines to reach several trees from the same position. However, the ”drive-to-tree” feller-buncher type is not equipped with a crane (Figure 1). Consequently, this type of machine drives up to each tree and cuts it (Anon 2023b; d). Furthermore, to actually cut the tree, some kind of felling device is required, and these devices are often called *heads*. These can broadly be categorized into two types: processing heads and felling heads. In addition to a bar saw, processing heads are equipped with delimbing knives and feed rollers. These feautures enable the head to fell the tree, delimb it, and buck it into multiple logs (processing), which means that it is able to perform all the steps in the cut-to-length method. Felling heads lack this processing capability, thus they operate according to the full-tree harvesting method (Anon 2023c). Additionally, both head types can be equipped with accumulator arms, which enables the heads to accumulate multiple trees in the head in one cutting work cycle before processing or bunching (Anon 2023c). This can, in turn, increase productivity as the time spent per tree can be substantially lower (Johansson & Gullberg 2002).

When it comes to the base machines used, there are some distinct categories in terms of whether or not it is purpose-built for forestry, and whether it is wheeled or tracked (Figure 1). Even though harvesting machines might share similar features across categories, there are notable differences between them that can impact productivity. For example, Ackerman et al. (2018) studied a tracked Volvo EC-210-BF excavator and a tracked TimberPro TL-725B harvester in thinning. Even though the machines were relatively similar in appearance, the TimberPro harvester was specifically tailored to forestry, whereas the Volvo excavator was not. Consequently, the two machines exhibited different productivities when working in varying terrain. Ackerman et al. (2018) concluded that for every 1% increase in slope, the productivity of the excavator-based harvester decreased by 0.048 m^3 per productive machine hour, while the purpose-built harvester's productivity remained constant. Ackerman et al. (2018) noted that the disparity in productivity was likely due to the purpose-built harvester's self-levelling and stabilizing capabilities, which were absent in the excavator-based machine. Furthermore, the mobility of excavator-based harvesters is considered to be inferior to that of purpose-built harvesters. This may pose challenges when traversing in forests with bigger obstacles, such as stones and stumps (Bergroth et al. 2006).

It is essential to note the difference between conventional harvesters and feller-bunchers to harwarders (Figure 1). Harwarders are similar to purpose-built harvesters and swing-boom feller-bunchers, however, a fundamental difference is the harwarders' capability to both cut and forward logs/trees, which is possible due to load carriers (Jonsson et al. 2023). Yet, when only harvesting is concerned, the difference in productivity is minimal compared to conventional harvesters (Jonsson 2021).

Figure 1. Various types of machines utilized in timber harvesting, A: purpose-built harvester (Billingsley et al. 2008), B: excavator-based harvester (Mcewan et al. 2016), C: purpose-built swing-boom feller-buncher (Rocha et al. 2022), D: purpose-built drive-to-tree feller-buncher (Anon 2023a), E and F: purpose-built harwarder (Laitila & Väätäinen 2020)

1.2 Productivity models

Productivity models are used to predict harvesting machines' productivity and the development of these models has been carried out for many decades (Brewer et al. 2018). In this review, the terms productivity (output/input) and time consumption (input/output) are used interchangeably. Therefore, "productivity" refers to both aspects.

Productivity models serve many purposes. For example, accurate predictions of productivity are required to effectively deliver the correct volume of timber at the correct time and at a reasonable price (Eriksson & Lindroos 2014; Lindroos et al.

2024). Additionally, models can be used to determine salaries, payments, and calculate costs of harvesting (Nuutinen et al. 2008). Models can also be utilized for evaluation of new machines and entire new systems (Liski et al. 2020). In addition to this, operators can be evaluated, and comparisons can be conducted to explore the effect of age and training on productivity (Malinen et al. 2018). Similarly, stand and terrain parameters' effect on productivity can be studied by analyzing the relationship between these and productivity with models (Visser & Spinelli 2012). To develop productivity models, data is needed which is usually collected by performing studies dedicated for this purpose (e.g. Eriksson & Lindroos 2014; Bergström et al. 2016, 2022)

1.3 Work studies, time studies, and follow-up studies

The purpose of a work study is to determine the relationship between input variables and output variables, while also assessing the influence of other variables on the relationship (Acuna et al. 2012). Work studies in forestry have been conducted for more than a century and their primary objective in forest work, improving operational effectiveness, have been largely unchanged since they originated (Koŝir et al. 2015). However, Koŝir et al. (2015) also emphasized that the scope of work studies has widened, and site impact assessment are often included today.

In forest research, work studies can typically be categorized into two types: comparative studies and correlation studies. In comparative studies, comparisons are made between, for instance, two or more methods or machines. Other influencing factors, such as work conditions, remain the same. In comparison, correlation studies assess the relationship between productivity and changes in influential factors, such as tree size (Lindroos 2010). Conducting time studies is one common way to study the relationship between productivity and influencing factors (Björheden et al. 1995).

A time study aims to study the relationship between inputs and outputs under a relatively brief period (Eriksson & Lindroos 2014). It is the predominant method for assessing work time in forest operations (Szewczyk & Sowa 2017). Depending on the detail desired in the time study, the output variable can be measured in different levels, i.e. having different observational units. Productivity can be evaluated on plot, shift, work cycle, or work element level. When evaluating productivity on plot level, the time needed to harvest the entire plot and the total outcome is noted. For shift level, the time and output for the entire shift is noted. When more detailed results are desired, researchers may study a machine's performance on work cycle or work element level. A work cycle is comprised of several repetitive work elements (Acuna et al. 2012). This can be illustrated with the publication by Bergström et al. (2022), where they studied a Valmet 901.4 harvester's productivity in boom-corridor thinning. The harvester's work cycle was comprised of seven unique repetitive work elements, many of which were executed for every tree, excluding miscellaneous elements and delays.

Several types of equipment can be used to measure time in work studies. In the survey of the role of work studies by Koŝir et al. (2015), handheld computers and mechanical study boards with stopwatches were the most common equipment, while video recordings, data loggers, company records, or combinations of these were less common. Moreover, while several types of equipment can be used, there is limited knowledge regarding what equipment type is most commonly used to measure time for modelling purposes. There is, however, literature that describe what the most common types are for work studies (Koŝir et al. 2015). However, since the survey by Koŝir et al. (2015) was conducted, nearly a decade has passed, and changes in equipment preferences might have occurred. Additionally, a bias towards European researchers was exhibited in the study caused by, for instance, personal connections. Furthermore, the Hawthorne effect suggests a great probability that a worker will change their behavior when aware of being observed. This change in behavior can significantly skew the results in a shorter time study (Acuna et al. 2012). The equipment type can therefore be connected to different levels of bias-risk.

Koŝir et al. (2015) pointed out the significance of the technological advancements of machines and sensors, which facilitates monitoring work for longer periods of time by utilizing sensors instead of manual collection of data. Additionally, modern harvesters are equipped with sophisticated on-board computers (OBC) that automatically capture production data (Brewer et al. 2018). For instance, if a harvester is equipped with an adequate OBC, each harvested log's diameter, length, and assortment are collected along with other production data. In some regions of the world, such data has been collected for several decades from regular forest operations (Kemmerer & Labelle 2021).

The data is collected from OBCs' with standards such as StanFord (Brewer et al. 2018). The StanFord report is an extensible markup language (XML) file, which allows easy extraction and analysis of data in a structured manner (Kemmerer & Labelle 2021). The introduction of automatic data collection has facilitated the analysis of machines' productivity with follow-up studies (Brewer et al. 2018), as it is possible to use existing data collected from regular production activities. An example of a publication that utilized an extensive amount of automatically collected data is by Eriksson and Lindroos (2014), who used data created by over 700 harvesters that harvested more than 20 million m^3 of roundwood to develop productivity models.

Notably, harvesting machines that utilize FT harvesting, such as feller-bunchers, most often lack OBC's and sensors that capture real-time productivity data. Therefore, the harvested volume can only be determined at landing. This will, in turn, limit follow-up studies to machines with processing heads and OBC's (Lahrsen et al. 2022).

Whether a time study or a follow-up study is conducted could impact the results of, for instance, productivity. As mentioned previously, automatic data collection facilitates collection of data for longer periods of time (Koŝir et al. 2015). Consequently, factors that only seldom occur (such as delays (e.g. Spinelli & Visser 2008)) might inadvertently be missed in a shorter time study but could be identified in a longer follow-up study. Additionally, the collection of data over extended periods of time increases the chance of covering a more extensive array of work conditions and operator skills. The probability of producing valid general inferences is, therefore, increased (Eriksson & Lindroos 2014). Additionally, the Hawthorne effect will not occur if direct observations in the field are not performed (Acuna et al. 2012).

The advantages of follow-up studies may facilitate wider use of them when developing productivity models, and there has been some debate whether conventional work studies are outdated (Kanzian 2023). There is, however, uncertainty whether follow-up studies have indeed become a more common method for developing productivity models or if most researchers still prefer conventional time studies. Currently, no literature exists that investigates whether researchers have increasingly adopted follow-up studies when conducting work productivity studies to develop productivity models. If, however, no shift has occurred, it could be beneficial to understand why to improve model development in the future, and whether the negative aspects of follow-up studies have discouraged researchers from conducting them for modelling purposes.

There are negative aspects to follow-up studies, such as the possible lack of certain data. OBC's do not gather data on certain stand characteristics that could influence productivity, such as ground roughness, tree form, branch size, weather conditions, and the presence of trees with multiple stems (Olivera et al. 2016). Furthermore, the level of detail in the two types of studies varies. The data is, in general, of higher detail in time studies than when data has been collected from regular production activities (Eriksson & Lindroos 2014). However, the level of detail acquired in time studies may also differ. To determine the effects of manual ways of collecting data in time studies, Szewczyk & Sowa (2017) compared work cycle time using both a handheld computer and video recordings. Szewczyk & Sowa (2017) studied a CTL harvester, and a statistical difference was observed in work cycle time between the two types of equipment. This difference was attributed to variations in timing measurements for the delimbing and bucking work elements. In addition, Nuutinen et al. (2008) emphasized the importance of experience of the observer collecting time study data. In their controlled data collection via simulator screens with handheld computers, 62% of experienced researchers' timing errors were within 0.5 seconds of the data loggers' time measurements for the processing work element. While no productivity models were developed in the study, the difference in timing measurements may lead to different productivity models when derived from such data. In this study, they deemed researchers who had previously performed time studies in the field as experienced. In contrast to this, the proportion of students with only 15 and 30 minutes of experience whose timing errors were within 0.5 seconds, were 33% and 47%, respectively.

1.4 Model development and structure

When the data has been collected, regression analysis is often the methodology used when developing models. In regression analysis, the relationship between a dependent variable and one or multiple independent variables is depicted. The most widely used regression method is ordinary least square (OLS) (Acuna et al. 2012). In OLS, it is also common that dummy variables are utilized in the models to incorporate discrete factors, such as type of machine. OLS works well when there is a limited number of independent variables, and the relationship between the independent variables and the dependent variable is approximately linear. However, when this is not the case, OLS's ability to accurately predict outcome is limited (Liski et al. 2020). If several collinear variables are included in the model, it will be overfitted and not accurately predict outcome (Costa et al. 2012). This will lead to an increase of the model's R^2 value, which represents the proportion of variance explained by the independent variable(s) (Böhm & Kanzian 2023). When several independent variables are incorporated into a model, it is more appropriate to report the R^2-adjusted value, as it accounts for the additional variables. Since more variables will always increase the R^2 value, the adjusted R^2 provides a more accurate reflection of the model's true predictive capability (Lindroos & Cavalli 2016). Despite this, Lindroos and Cavalli (2016) found that some researchers, when modelling productivity, only reported their models' R^2 value, even though the models incorporated multiple independent variables. This may suggest a misuse of R^2 values, which may not be limited to work productivity studies on cable yarding but could extend to studies modelling productivity for harvesters, feller-bunchers, and harwarders. They also observed models with extremely low (e.g., 0.18) coefficients of determination, and stressed the irrelevance of such models.

The type of equation for models may vary considerably, however, power, linear, and quadratic equations are common for modelling productivity (Visser & Spinelli

2012). The type of equation may vary even if the same independent variable is used. To illustrate, Brewer et al. (2018) and Holzleitner & Kanzian (2022) both developed productivity models for rubber wheeled purpose-built harvesters. They both used stem volume as independent variable, yet, Brewer et al. (2018) chose to develop linear models, while Holzleitner and Kanzian (2022) developed power law models. Furthermore, it is known that there is no single "correct" approach to model productivity, and researchers can apply different types of equations to best suit their data (Visser & Spinelli 2012). Indeed, in the literature, it has been stated that there is a large variability in productivity models (Lindroos & Cavalli 2016; Lindroos et al. 2024). While it is known that certain equation types are common, no literature exists that comprehensively analyzes a large number of researchers and how they actually have modelled productivity in practice. Are some equation types truly more common than others? Are there regional differences in modeling practices? Additionally, there is no literature that has examined how, based on large samples of studies, productivity models' mathematical formula may vary based on, for example, dependent variable or harvesting method. Therefore, further investigations into productivity models' mathematical formula are warranted to potentially develop more accurate models and understand the underlying reasons for their structure.

1.5 Productivity-influencing factors

A multitude of factors affect productivity to a varying degree for harvesting machines. The most important factor is the size of the tree being handled (the so called "piece size", normally described by stem volume, mass, or diameter at breast height) (e.g. Visser & Spinelli 2012; Lahrsen et al. 2022; Schmiedel et al. 2022). Productivity will increase as tree size increases, a relationship called the "piece size law". However, the level of increase in productivity is reduced as tree size becomes larger and at a certain point the productivity will decrease. This is due to the extra time it will take to handle larger trees (Visser & Spinelli 2012). Furthermore, there are other factors that have been found to have an impact on productivity such as slope (e.g. Eriksson & Lindroos 2014; Ackerman et al. 2018), harvested trees per hectare (e.g. Bergström & Di Fulvio 2014; Eriksson & Lindroos 2014), tree species (e.g. Kizha & Han 2016; Esteban et al. 2018; Liski et al. 2020), and operator skills and experience (e.g. Lindroos 2010; Purfürst & Erler 2011; Malinen et al. 2018).

A factor that has commonly been disregarded, yet has been found to affect productivity profoundly, is the human factor (e.g. Lindroos 2010; Purfürst & Erler 2011; Häggström & Lindroos 2016). Purfürst & Erler (2011) studied the effect of human influence on productivity in harvester operations and mentioned that the performance of operators varied between operators and can fluctuate over time for the same operator. They studied the impact different operators had on productivity using data collected from a period of more than three years. It was concluded that, irrespective of tree volume and relative to the mean productivity level, the worst and best operator performed at levels of 56% and 125%, respectively. This shows a difference between absolute values of a factor of 2.2. Purfürst & Erler (2011) also concluded that the operator accounted for 37.3% of the variance in productivity, ranking just below tree size in importance. Furthermore, although operators can have a big impact on productivity, there is no literature that specifies how many operators researchers typically study when developing productivity models. It is known that researchers generally select experienced operators (Koŝir et al. 2015), but the number of operators applied in such studies is unknown.

Further studies have been conducted that highlighted the importance of operator age and experience. For example, Malinen et al. (2018) performed a study to examine the correlation between operator skill, age, and productivity for harvesters in Finland. In the study, it was inferred that operators between the ages of 40 to 45 with at least 16 years of experience had the highest productivity, while older operators indicated a small decline in productivity. It was also concluded that operators with 20 years of experience had a relative productivity of 1.07, while operators with 3 years of experience had a relative productivity of 0.87, indicating a 23.6% higher relative productivity for operators with 20 years of experience.

While there are many factors that can affect productivity, and tree size often being the most important one (e.g. Visser & Spinelli 2012; Lahrsen et al. 2022; Schmiedel et al. 2022), there is no literature that have compiled and analyzed, overall, what factors researchers have chosen to incorporate in productivity models and how well these factors actually have predicted productivity across multiple publications. By identifying and compiling the models it is possible to identify what factors resulted in models with high or low predictive capabilities, as well as identify possible research gaps in the literature, i.e. what factors have already been studied and incorporated in models. Additionally, there is no publication that has examined, on a larger scale, whether there is a difference between the preferred factors used to model productivity between, for instance, regions or harvesting methods. This could potentially explain the variability of productivity models and if, for example, some factors are more suitable to explain productivity for FT machines compared to CTL machines.

1.6 Aim and purpose

Few studies have compiled and examined models for work productivity in forest operations. The few publications available are: Lindroos' and Cavalli's (2016) review of cable yarding productivity models, Aubuchon’s (1982) compendium of cable yarding production models, Peters’ (1991) compilation of feller bunchers’ production models, and Böhm’s and Kanzian’s (2023) review of cable yarding performance studies. Kellog et al. (1992) compiled models for machines in the entire timber procurement process, from felling to loading timber onto trucks, however, they did not conduct an in-depth analysis or comparison of models.

There are several reasons why reviews and analyses of work productivity models are useful. A great number of studies analyzing work productivity in forest operations are conducted worldwide with different practices, and models are dispersed across many publications. Consolidating the data enhances accessibility and makes the information easier to identify, which enables comparisons and analyses of the used practices and the models’ characteristics. This, in turn, can elucidate potential regional and harvesting method-based differences in practices for modelling productivity, which could explain the observed variability in models. Thus, in regard to work productivity models, this review aims to create a compilation of models to facilitate easier access to them, but also to answer the questions:

- Where have researchers developed productivity models for harvesters, feller-bunchers, and harwarders, and to what extent have these studies with models been conducted? What observational units have researchers used to study machines’ productivity, and how many observations did they perform do develop models?

- Have researchers increasingly adopted follow-up studies when developing models?

- What equipment have researchers used for measuring time, and how have researchers implemented operators, in terms of quantity and skill, and delays, when developing productivity models?

- What are the developed models’ characteristics in terms of dependent and independent variables, mathematical structure, and predictive capabilities (R^2 and R^2-adjusted)?

- In terms of models’ characteristics, are there regional differences, and are there differences between harvesting methods?

2. Material and methods

2.1 Literature review

A literature review was conducted to identify productivity models. The methodology was based on a simplified version of the SALSA framework for systematic literature reviews (Mengist et al. 2020). The parts in the SALSA technique applied in this review were: identification of search strings, documentation of when the search was conducted, creation of inclusion and exclusion criteria, selection of publications, data extraction, and analysis of the data collected.

The databases chosen were Web of Science Core Collection, Web of Science CABI: CAB Abstracts, and Scopus. Appropriate search strings were identified and used in the search fields (Table 1). The search covered the years 2013 to 2023. In Web of Science, the research area was set to "Forestry" and the language was set to English. A complementary search in each of the Web of Science databases using the string "harvest*" instead of "harvester" was conducted to identify publications which may not explicitly have mentioned machine type in the title, abstract, or keywords. However, this search was not exhaustive, meaning not all publications were examined. The search was concluded when no further relevant publications were found. It was additionally observed that Web of Science did not index publications between 2013 and 2016 from the International Journal of Forest Engineering. Considering the significance of this journal, a manual search was conducted for the years absent in Web of Science.

Table 1. Search strings applied in the literature search. Blocks 1 and 2 were applied in Web of Science, while all three blocks were applied in Scopus

***Tabell 1**. Söktermer som användes i litteratursökningen. Block 1 och 2 användes i Web of Science, medan alla block användes i Scopus*

Block 1	Block 2	Block 3
"mechani* harvest*" OR harvester* OR "harvest* machine*" OR "feller-bunch*" OR "feller bunch*" OR "fellerbunch*" OR fellerbundler* OR "feller bundler*" OR "feller-bundler*" OR excavator OR harwarder OR "single grip" OR "single-grip" OR singlegrip OR "harvester head*" OR "cutting head*" OR "felling head*" OR "bunching head*" OR "processing head*"	model* OR production OR productivit* OR performance OR "time and motion stud*" OR "time motion stud*" OR "time stud*" OR "work stud*" OR "time consumption" OR regression*	forest* OR timber OR tree OR wood OR "clear-cut" OR clearcut OR thinning OR felling* OR "whole-tree" OR "whole tree" OR wholetree OR "full-tree" OR "fulltree" OR "full tree" OR ctl OR "cut to length" OR "cut-to-length"

The search yielded several hundred publications in the exhaustive search in each database (Table 2) and several inclusion and exclusion criteria were created to determine which publications would be eligible for the review (Table 3). Furthermore, the identification of eligible publications was done in two steps. The first step consisted of compiling publications which met all the inclusion criteria, except inclusion criterion 6, into a Zotero library. This was done by reading the title and, if needed, the abstract. Step one yielded 434, 408, and 286 pertinent publications in Scopus, CABI: CAB Abstract, and CORE Collection, respectively. The manual search of the International Journal of Forest Engineering yielded another seven suitable publications. In total, 667 unique publications were identified which could contain productivity models. Step 2 consisted of scanning through publications to identify those which met inclusion criterion six.

Table 2. Summary of search results with the search strings in Table 1, and with applied filters

***Tabell 2**. Summering av sökresultat med söktermerna i Tabell 1, och med applicerade filter*

Database	Search date in year 2023	Total	Published in 2013-2023	Research area Forestry	English
Core	20th Nov	17 202	13 991	488	428
CABI	17th Nov	20 670	5 239	781	768
Scopus	20th Nov	1 800	1 111		1 012

Table 3. Inclusion and exclusion criteria for the literature search
***Tabell 3**. Inklusions- och exklusionskriterier för litteraturstudien*

Criteria	Criteria definition
Inclusion 1	The publication is a scientific article or conference paper
Inclusion 2	The publication is in English
Inclusion 3	The publication is published between 2013 and 2023
Inclusion 4	The publication is accessible for students and employees at the Swedish University of Agricultural Sciences
Inclusion 5	The publication focuses on forest operations and pertains to harvesters, feller-bunchers, or harwarders and could possibly contain productivity models
Inclusion 6	The publication includes models that predict productivity, time of input per unit, time per work cycle or work element
Exclusion 1	The publication does not fulfil all the inclusion criteria

2.2 Data extraction

From the publications that met the inclusion criteria, several types of data were extracted to Excel. The extracted data included the author(s) of the publications, geographic information (continent and country), harvesting method, machine type, and model. The work elements constituting a work cycle will differ substantially depending on harvesting method. Therefore, the machines were categorized based on this. For CTL-machines, they were further categorized as harvester and harwarder. Harvesters were then divided into purpose-built and excavator-based, depending on if the machines were specifically tailored to forestry. Lastly, these machines were categorized as wheeled or tracked. Furthermore, machines that performed FT-harvesting were first categorized as feller-buncher or harwarder. Secondly, feller-bunchers were subcategorized as swing-boom or drive-to-tree variants. These were subsequently categorized as purpose-built or excavator-based depending on if the machines were specifically designed for forestry. Lastly, the machines were categorized as tracked or wheeled (Figure 2).

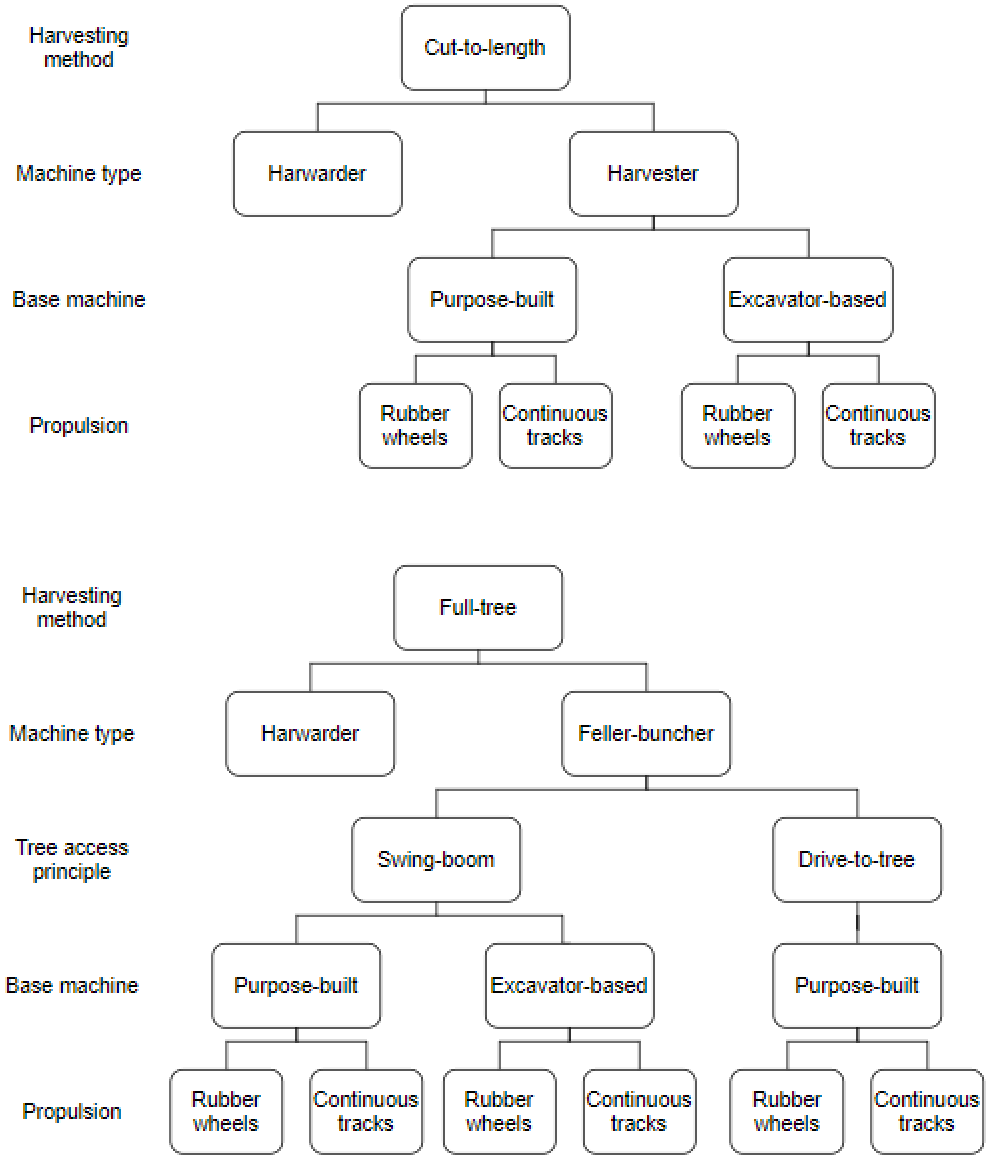

Figure 2. Classification of machine types. Notably, additional information on tree access principle is provided only for feller-bunchers, as it is presumed that all harvesters and harwarders are equipped with a swing-boom

Figur 2. Klassificering av maskintyper. Notera att ytterligare information om trädtillgångsprincip endast tillhandahålls för fällare-läggare, eftersom det antas att alla skördare och drivare är utrustade med en kran

The head type and model were noted, along with if the machine performed debarking and multi-tree cutting. Additionally, the type of study was classified as a time study if a researcher or observer collected time data in the field, or if cameras recorded the machine and subsequent analysis was performed in the office. The study type was classified as a follow-up study if records from OBC's for time consumption were utilized in analysis. If the publication was classified as a time study, the equipment and the total time recorded during the study was noted. Further, the type of forest operation was documented.

Stand descriptions were also documented in terms of noting tree species, stand age, mean values and value ranges of diameter at breast height and stem volume. If stem volume was not explicitly mentioned in the publication, it was disregarded even if it could be inferred. However, tree weight or biomass was noted if available as supplementary data if stem volume was absent. Moreover, ground condition, ground roughness, and slope were reported. If a publication did not use a terrain classification system, the authors' own description of the stand was noted. Additionally, the number of operators and their experience were documented.

Key information regarding the models and assessment of models were extracted. Observational unit, i.e. shift, plot, cycle, or element level of time studies was noted. The number of observations used to develop the models were also noted. Furthermore, the models were extracted, and their goodness of fit statistics were documented in the form of coefficients of determination (R^2 and R^2-adjusted) as well as the statistical significance of the models (F-value and P-value).

2.3 Analysis

Descriptive analyses of the extracted data were conducted, and regional and harvesting method-based differences were analyzed regarding equipment type, observational unit, models' independent and dependent variables, and mathematical structure. Additionally, an arbitrary categorization of the independent variables was applied and is provided in Appendix 9. The categories include: Movement/distances travelled; Weight of handled unit and/or output (trees/stems/logs/biomass); Diameter/DBH of harvested trees/stems/logs; Machine data; Height of harvested trees; Harvesting intensity/density; Miscellaneous; Work cycle-based observations; Miscellaneous features of harvested trees; Operator features; Terrain and work conditions; Treatment/execution of harvest; Volume of handled unit and/or output (tree/stem/log). Furthermore, for the analyses regarding regional variations, Europe was divided into Northern, Southern, Western, and Eastern Europe, according to the United Nations geoscheme (Appendix 3).

3. Results

3.1 Identified publications

In total, 115 publications that fulfilled all the inclusion criteria were identified, which comprised 105 articles and 10 conference papers. The publications originated from six continents and 22 countries (Appendix 2 and Table 4) and covered a wide range of forest types (Appendix 5) and operations (Appendix 4). The publications predominantly originated from Europe. Publications from the United States, Australia, Finland, Sweden, and Latvia collectively constituted more than half of the total number of publications.

Table 4. Quantity of publications over continent and country of origin in alphabetic order
Tabell 4*. Antal publikationer fördelat på kontinent och ursprungsland i alfabetisk ordning*

Continent	Country	Quantity
Africa, n=8	South Africa	8
Asia, n=2	Turkey	2
Australia, n=15	Australia	15
Europe, n=67	Austria	2
	Bulgaria	1
	Finland	15
	France	1
	Germany	5
	Hungary	1
	Italy	4
	Latvia	10
	Poland	7
	Romania	1
	Slovakia	4
	Slovenia	1
	Spain	3
	Sweden	10
	Sweden, Finland, Slovenia	1

	Russia	1
North America, n=17	Canada	1
	United States	16
South America, n=6	Brazil	5
	Uruguay	1

The identified publications studied several types of machines, with numerous publications studying multiple machine types (Appendix 4). Most publications studied purpose-built CTL-harvesters with rubber tires (Table 5). In three publications, the machine type was referred to only as "harvester", with no information of base machine or type of propulsion. In three publications, FT-harwarders were studied, but they did not perform conventional FT-harvesting. Instead, the harwarders were equipped with bundling units, where trees were cut and then fed into the bundling unit. In Table 5, these machines were put into the Full-Tree category as Feller-Buncher with bundling units. In three publications, simulations were conducted for the machines. In one publication, the authors studied a "skidder-harvester" which was categorized separately in Table 5.

Table 5. Summary of machine types in publications. DTT = drive-to-tree; SB = swing-boom; B = bundling unit; Sim = simulation; CT = continuous tracks; RW = rubber wheels

Tabell 5*. Summering av maskintyper i publikationer. DTT = drive-to-tree; SB = swing-boom; B = buntningsenhet; Sim = simulation; CT = kontinuerliga band; RW = gummihjul*

Harvest Method	Machine Type	Base Machine	Propulsion	Quantity
Cut-To-Length	Harvester	Excavator-Based	CT	14
		Purpose-Built	CT	14
			RW	49
		Unknown	Unknown	3
	Harvester (Sim)	Purpose-Built	RW	2
	Harwarder	Purpose-Built	RW	3
	Skidder-Harvester	Purpose-Built	RW	1
Full-Tree	Feller-Buncher (DTT)	Excavator-Based	CT	1
		Purpose-Built	RW	2
	Feller-Buncher (SB)	Excavator-Based	CT	9
		Purpose-Built	CT	17
			RW	6
	Feller-Buncher (B)	Purpose-Built	RW	3
	Feller-Buncher (SB), (Sim)	Purpose-Built	RW	2
	Harwarder	Purpose-Built	RW	1

Regarding the harvesting method employed in regions, considerable variations could be observed (Table 6). For example, North American and Southern European publications usually studied machines conducting FT-harvesting, while the rest more frequently studied CTL-harvesting.

Table 6. Relative distribution (%) of harvesting method employed in publications across regions in alphabetic order. CTL = cut-to-length; FT = full-tree; B (FT) = full-tree harwarder with bundling unit. Multiple harvesting methods were studied in some regions and the sum of the percentages therefore exceed 100%. Note that one publication was conducted in both northern and southern Europe and therefore the total number of publications in the table is 116

Tabell 6*. Relativ fördelning (%) av avverkningsmetod som använts i publikationer fördelat på regioner i alfabetisk ordning. CTL = kortvirkesmetod; FT = helträdsmetod; B (FT) = helträds-drivare med buntningsenhet. I vissa regioner studerades flera avverkningsmetoder och därför överstiger summan av procenten 100%. Notera att en publikation var utförd både i norra och södra Europa och därmed är totala antalet pub1ikationer i tabellen 116*

Harvesting System	Africa, n=8	Asia, n=2	Australia, n=15	N. Europe, n=36	S. Europe, n=9	W. Europe, n=8	E. Europe, n=15	N. America, n=17	S. America, n=6
CTL, n=82	100.0		66.7	75.0	33.3	87.5	93.3	41.2	100.0
FT, n=36		100.0	40.0	25.0	66.7	12.5	6.7	70.6	
B (FT), n=3				5.6	11.1				

The data collection was predominantly manual (Appendix 2). Seven publications used follow-up data, while 101 used manual data collection. One publication used both manual and follow-up data collection for time separately, while in two publications it could not be inferred what type of data collection was used. In another publication, the operator maintained a record of harvesting time and in three publications productivity models were developed via simulations. Further, a wide variety of equipment was used for manual data collection (Appendix 2). The most common equipment was hand-held computers, which were used in 41 publications. Cameras and stopwatches were present in 31 and 22 publications, respectively. In 18 publications, multiple kinds of equipment were used. Other equipment used were apps, tablets, “Field Data Minute-Book”, “MultiDat Field recorder”, a hand-held datalogger, and a studyboard with stopwatches. In 32 publications, the equipment used for manual data collection was not provided. Regional variations in terms of equipment could also be observed (Table 7).

Table 7. Relative distribution (%) of equipment type for time measurement used in publications across regions from most common to least common. Note that one publication was conducted in both northern and southern Europe and therefore the total number of publications in the table is 116

***Tabell** 7. Relativ fördelning (%) av utrustning för tidsmätning som använts i publikationer fördelat på regioner från vanligast till ovanligast. Notera att en publikation var utförd både i norra och södra Europa och därför är totala antalet pub1ikationer i tabellen 116*

Equipment	Africa, n=8	Asia, n=2	Australia, n=15	N. Europe, n=36	S. Europe, n=9	W. Europe, n=8	E. Europe, n=15	N. America, n=17	S. America, n=6
Handheld Pc, n=41	62.5		13.3	58.3	66.7	62.5	6.7	11.8	
Unknown, n=33	12.5		33.3	25.0	22.2		40.0	35.3	66.7
Camera, n=31	12.5		46.7	19.4	11.1	62.5	33.3	29.4	16.7
Stopwatch, n=21		100.0	6.7	5.6	11.1	12.5	40.0	41.2	16.7
App, n=2	25.0								
"Field Data Minute-Book", n=1							6.7		
"MultiDat Field recorder", n=1								5.9	
Datalogger connected to OBC, n=1				2.8					
Hand-Held Data Logger, n=1				2.8					
Studyboard with Stopwatches, n=1					11.1				
Tablet, n=1			6.7						

There was a considerable variation in the experience of operators applied in publications (Appendix 5). The experience of operators ranged from only a couple of months of training to 45 years of experience. In 25 publications, the skill of the operator was referred to only as “skilled”, “experienced” or other similar term. Forty publications did not provide information regarding the experience or skill of operators. Furthermore, the number of operators used in studies varied considerably (Appendix 5). Forty-two publications studied one operator, while the number of operators in the rest of the publications ranged from 2-120. Forty-eight publications did not provide information on the number of operators, or the number of operators could not be deduced with certainty.

Number of observations used for models varied considerably (Appendix 11) and ranged from 6–140 465. However, in 23.7% of models, the number of observations could not be ascertained. Moreover, there were similarities in the type of observational units studied across regions (Table 8). Element level studies were the most common in all regions, except South America, where plot level studies were equally prevalent.

Table 8. Relative distribution (%) of observational unit of publications across regions from most common to least common. Note that one publication was conducted in both northern and southern Europe and therefore the total number of publications in the table is 116

Tabell 8*. Relativ fördelning (%) av observationsenhet i publikationer fördelat på regioner från vanligast till ovanligast. Notera att en publikation var utförd både i norra och södra Europa och därför är totala antalet pub1ikationer 116 i tabellen*

Region	Element, n=82	Plot, n=14	Cycle, n=12	Unknown, n=7	Shift, n=1
Africa, n=8	62.5		37.5		
Asia, n=2	100.0				
Australia, n=15	66.7	6.7	20.0	6.7	
N. Europe, n=36	77.8	11.1	2.8	8.3	
S. Europe, n=9	66.7	11.1	11.1	11.1	
W. Europe, n=8	100.0				
E. Europe, n=15	60.0	26.7		6.7	6.7
N. America, n=17	70.6	11.8	17.6		
S. America, n=6	33.3	33.3	16.7	16.7	

3.2 Productivity models

In the 115 publications identified, 422 predictive models were identified and are provided in detail in Appendix 8. The models predicted many different things, or in other words, varied in which dependent variables they had. Therefore, the dependent variables were categorized into ten categories. For productivity models, there were three dependent variables: volume/time (PV), weight/time (PW), and units/time (PU). For time consumption models, there were three dependent variables: time/volume (TV), time/weight (TW), and time/unit (TU). There were four dependent variables for time consumption irrespective of output: time per work cycle (W), time per work element(s) regarding handling of trees (E), time for moving (M), and time for loading (L). Productivity as volume/time (PV) was the dependent variable most frequently modelled (Table 9) and multiple publications featured several of the mentioned dependent variable types. Moreover, seven models were developed for both purpose-built and excavator-based harvesters, and one model was developed for both a purpose-built swing-boom feller-buncher and an excavator-based drive-to-tree feller-buncher. Therefore, the number of models in Table 7 is 430, instead of 422.

Table 9. Quantity of models with different machine types and dependent variables. SB = swing-boom; DTT = drive-to-tree; B = bundling unit; Sim = simulation; Productivity = PV (volume/time), PW (weight/time), PU (units/time); Time per unit of output: TV = (time/volume), TW (time/weight), TU (time/unit); Time for work cycle = W; Time for work element(s) regarding handling of tree = E; Time for moving = M; Time for loading = L

Tabell 9*. Kvantitet av modeller med olika maskintyper och beroende variabler. SB = swing-boom; DTT = drive-to-tree; B = buntningsenhet; Sim = simulation; Produktivitet = PV (volym/tid), PW (vikt/tid), PU (enheter/tid); Tid per enhet av output: TV = (tid/volym), TW (tid/vikt), TU (tid/enhet); Tid per arbetscykel = W; Tid för arbetsmoment angående hantering av träd = E; Tid för förflyttning = M; Tid för lastning = L*

Machine type	PV	PW	PU	TV	TW	TU	W	E	M	L	Total
CTL/Harvester/Excavator-Based/Tracked	44						4	9	1		58
CTL/Harvester/Purpose-Built/Tracked	28	2					3	4	2		39
CTL/Harvester/Purpose-Built/Wheeled	91	4	2	3	2	10	9	43	8		172
CTL/Harvester/Unknown/Unknown	15			11			11				37
CTL/Harvester (Sim)/Purpose-Built/Wheeled	4										4
CTL/Harwarder/Purpose-Built/Wheeled	3			1							4
CTL/Skidder-Harvester/Purpose-Built/Wheeled	2						2				4
FT/Feller-Buncher (SB)/Excavator-Based/Tracked	16	3	1				6	4	1		31
FT/Feller-Buncher (SB)/Purpose-Built/Tracked	3	4					22				29
FT/Feller-Buncher (SB)/Purpose-Built/Wheeled		17		1	3						21
FT/Feller-Buncher (B)/Purpose-Built/Wheeled		4	1			1		1			7
FT/Feller-Buncher (DTT)/Purpose-Built/Wheeled		2					3				5
FT/Feller-Buncher (DTT)/Excavator-Based/Tracked		1									1
FT/Feller-Buncher (SB), (Sim)/Purpose-Built/Wheeled	15										15
FT/Harwarder/Purpose-Built/Wheeled								1	1	1	3
Total	221	37	4	16	5	11	60	62	13	1	

There were considerable variations in terms of the dependent variables modeled across regions (Table 10). It was, for example, more common to model time for a work cycle in North American publications compared to other regions.

Table 10. Relative distribution (%) of dependent variables across regions from most common to least common. Productivity = PV (volume/time), PW (weight/time), PU (units/time); Time per unit of output: TV = (time/volume), TW (time/weight), TU (time/unit); Time for work cycle = W; Time for work element(s) regarding handling of tree = E; Time for moving = M; Time for loading = L. Note that one publication was conducted in both northern and southern Europe and therefore the total number of publications in the table is 116

Tabell 10*. Relativ fördelning (%) av beroende variabler fördelat på regioner från vanligast till ovanligast. Produktivitet = PV (volym/tid), PW (vikt/tid), PU (enheter/tid); Tid per enhet av output: TV = (tid/volym), TW (tid/vikt), TU (tid/enhet); Tid per arbetscykel = W; Tid för arbetsmoment angående hantering av träd = E; Tid för förflyttning = M; Tid för lastning = L. Notera att en publikation var utförd både i norra och södra Europa och därför är totala antalet pub1ikationer 116 i tabellen*

Region	PV, n=57	PW, n=16	PU, n=4	TV, n=4	TW, n=4	TU, n=4	W, n=25	E, n=25	M, n=10	L, n=1
Africa, n=8	87.5							12.5		
Asia, n=2	100.0									
Australia, n=15	60.0	26.7					33.3	6.7		
N. Europe, n=36	41.7	8.3	8.3	8.3	8.3	8.3		38.9	19.4	2.8
S. Europe, n=9	11.1	66.7	11.1				22.2	22.2		
W. Europe, n=8	87.5				12.5			12.5	12.5	
E. Europe, n=15	60.0	13.3		6.7			26.7	33.3	6.7	
N. America, n=17	5.9	5.9				5.9	82.4			
S. America, n=6	100.0							16.7	16.7	

In total, the models were comprised of 128 unique independent variables excluding random effects and residual errors (Appendix 9). However, several of the variables assessed the same aspect, albeit in different units. When excluding these, 121 variables remained. Stem volume over bark in m^3 and diameter at breast height in cm were most common and were present in 35 and 31 publications, respectively (Table 11). Thirty-four variables were used in at least two publications, while the remaining 94 variables were not shared over individual publication.

Table 11. Summary of the most common independent variables in models

Tabell 11*. Summering av de vanligaste oberoende variablerna i modeller*

Variable	Unit	No. of publications
Stem volume over bark	m^3	35
Diameter at breast height	cm	31
Movement to trees/movement per work cycle	m	12
Harvested trees per hectare	trees/ha	9
Trees per work cycle	no.	8
Stem volume over bark	dm^3	8

Differences across regions were observed in terms of the incorporation of variables in models (Table 12). For instance, it was more common to incorporate “Movement/distances travelled” and “Work cycle-based” variables in North America compared to other regions. Additionally, similarities could be observed across regions. For example, all regions incorporated “Diameter/DBH of harvested trees/stems/logs” variables in their models, a distinction not shared by any other variables.

Table 12. Relative distribution (%) of independent variable categories across regions from most common to least common. Note that one publication was conducted in both northern and southern Europe and therefore the total number of publications in the table is 116

***Tabell 12**. Relativ fördelning (%) av oberoende variabelkategorier fördelat på regioner från vanligast till ovanligast. Notera att en publikation var utförd både i norra och södra Europa och därför är totala antalet pub1ikationer i tabellen 116*

Independent variable category	Africa, n=8	Asia, n=2	Australia, n=15	N. Europe, n=36	S. Europe, n=9	W. Europe, n=8	E. Europe, n=15	N. America, n=17	S. America, n=6
Volume of handled unit and/or output (tree/stem/log), n=54	62.5	100.0	80.0	44.4		62.5	60.0	5.9	66.7
Diameter/DBH of harvested trees/stems/logs, n=43	37.5	100.0	6.7	47.2	33.3	50.0	26.7	52.9	16.7
Work cycle-based, n=24	12.5		6.7	13.9	22.2	12.5	6.7	76.5	
Miscellaneous features of harvested trees, n=21	37.5		6.7	11.1	33.3	12.5	26.7	29.4	
Harvesting intensity/density, n=17				33.3	22.2		13.3	5.9	
Movement/distances travelled, n=16	12.5			2.8			13.3	70.6	
Weight of handled unit and/or output (trees/stems/logs/biomass), n=13			6.7	8.3	66.7		13.3	11.8	
Machine data, n=11	25.0		6.7	8.3		12.5	20.0		16.7
Treatment/execution of harvest, n=11	12.5		6.7	11.1		25.0	13.3		16.7
Miscellaneous, n=8				2.8	11.1	12.5	13.3	17.6	
Height of harvested trees, n=6		100.0		11.1	11.1				
Terrain and work conditions, n=4	37.5			2.8					
Operator features, n=2	12.5				11.1				

There were differences in terms of incorporation of independent variables across harvesting systems (Table 13). For example, it was more common to incorporate "Movement/Distance" and "Cycle-based" variables in the FT harvesting system than in the CTL system. Moreover, similarities could also be observed. For instance, the incorporation of the "Harvesting intensity/density" variable was fairly consistent across the CTL and FT systems.

Table 13. Relative distribution (%) of independent variable categories across harvesting systems. CTL = cut-to-length; FT = full-tree; B = FT full-tree harwarder with bundling unit

Tabell 13*. Relativ fördelning (%) av oberoende variabelkategorier fördelat på avverkningssystem. CTL = kortvirkesmetod; FT = helträdsmetod; B (FT) = helträdsmetod -drivare med buntningsenhet*

Independent variable category	B (FT), n=3	CTL, n=82	FT, n=36
Volume of handled unit and/or output (tree/stem/log), n=54	33.3	51.2	38.9
Diameter/DBH of harvested trees/stems/logs, n=43		41.5	30.6
Work cycle-based, n=24	66.7	11.0	38.9
Miscellaneous features of harvested trees, n=21		20.7	13.9
Harvesting intensity/density, n=17	33.3	13.4	16.7
Movement/distances travelled, n=16		9.8	25.0
Weight of handled unit and/or output (trees/stems/logs/biomass), n=13	33.3	6.1	22.2
Machine data, n=11		11.0	5.6
Treatment/execution of harvest, n=11		12.2	2.8
Miscellaneous, n=8		6.1	8.3
Height of harvested trees, n=6			16.7
Terrain and work conditions, n=4		4.9	
Operator features, n=2		2.4	

The type of mathematical function for models varied greatly (Table 14). The models were classified into seven categories of equation types: exponential, linear, logarithmic linear, non-linear, pure power law, second-degree polynomial, and third-degree polynomial, where linear models were most common (39% of all models). There was also a difference between the type of mathematical function used for the models' dependent variables. The proportion of models that were purely linear for work cycle time and productivity (volume/unit) were 65.0% and 29.9%, respectively. Furthermore, variations in terms of models' mathematical structure were observed, with different types being more common in some regions (Table 15). For example, it was more common to use linear models in Asia, Eastern Europe, and North America compared to the rest of the regions. Moreover, there was a considerable difference in the number of predictors in models. Several models were only comprised of one predictor, while others were comprised of multiple predictors. For example, Eriksson & Lindroos (2014) created a model with 14 different predictors.

Table 14. Relative distribution (%) of models' mathematical structure within dependent variables (columns) from most common to least common. Productivity = PV (volume/time), PW (weight/time), PU (units/time); Time per unit of output: TV = (time/volume), TW (time/weight), TU (time/unit); Time for work cycle = W; Time for element(s) regarding handling of tree = E; Time for moving = M; Time for loading = L

Tabell 14. *Relativ fördelning (%) av modellers matematiska struktur för beroende variabler (kolumner) från vanligast till ovanligast. Produktivitet = PV (volym/tid), PW (vikt/tid), PU (enheter/tid); Tid per enhet av output: TV = (tid/volym), TW (tid/vikt), TU (tid/enhet); Tid per arbetscykel = W; Tid per arbetsmoment angående hantering av träd = E; Tid för förflyttning = M; Tid för lastning = L*

Mathematical function type	PV, n=214	PW, n=36	PU, n=4	TV, n=16	TW, n=5	TU, n=11	W, n=60	E, n=62	M, n=13	L, n=1	total
Purely linear, n=153	29.9	47.2	75.0	12.5	20.0	81.8	65.0	22.6	30.8		153
Purely second-degree polynomial, n=51	18.2					9.1	1.7	14.5	7.7		51
Purely power law, n=50	14.5	27.8	25.0	6.3	60.0		3.3	3.2			50
Log-linear, n=40	8.9	16.7						17.7	30.8		40
Non-linear with power law terms, n=36	6.1	2.8		68.8			18.3				36
Purely third-degree polynomial, n=24	6.5							16.1			24
Purely Exponential, n=15						9.1	11.7	11.3			15
Exponential with logarithmic transformation, n=15	7.0										15
Linear with division operation, n=7				12.5				1.6	23.1	100.0	7
Non-linear with power law and linear terms, n=7	0.5				20.0			8.1			7
Non-linear with quadratic term and logarithmic transformation, n=6	2.8										6
Second-degree polynomial with interaction terms, n=6	0.9							4.8	7.7		6
Non-linear with quadratic term, interaction term and logarithmic transformation, n=3	1.4										3

Linear with interaction term, n=2	0.9										2
Linear with logarithmic transformations and interaction terms, n=2	0.9										2
Non-linear with power law terms and division operation, n=2		5.6									2
Linear with logarithmic transformations, n=1	0.5										1
Nonlinear with exponential terms and division operation, n=1	0.5										1
Nonlinear with exponential terms, division operations, and interaction effects, n=1	0.5										1
Sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	

Table 15. Relative distribution (%) of models' mathematical structure across regions from most common to least common. Note that one publication was conducted in both northern and southern Europe and therefore the total number of publications in the table is 116

***Tabell 15**. Relativ fördelning (%) av modellers matematiska struktur fördelat på regioner från vanligast till ovanligast. Notera att en publikation var utförd både i norra och södra Europa och därför är totala antalet pub1ikationer i tabellen 116*

Mathematical function type	Africa, n=8	Asia, n=2	Australia, n=15	N. Europe, n=36	S. Europe, n=9	W. Europe, n=8	E. Europe, n=15	N. America, n=17	S. America, n=6
Purely linear, n=57	62.5	100.0	20.0	30.6	66.7	12.5	86.7	94.1	16.7
Purely power law, n=21	25.0		26.7	19.4	11.1	50.0	13.3	5.9	
Purely Second-degree polynomial, n=20	25.0	50.0		25.0	11.1	37.5	6.7		50.0
Log-linear, n=17			40.0	22.2	11.1		6.7		16.7
Purely Third-degree polynomial, n=7				16.7		12.5			

Purely Exponential, n=6		20.0	5.6			6.7	
Linear with division operation, n=5			13.9				
Non-linear with power law terms, n=4		6.7		11.1		13.3	
Non-linear with power law and linear terms, n=3			2.8		25.0		
Exponential with logarithmic transformation, n=2		6.7					16.7
Non-linear with quadratic term and logarithmic transformation, n=2			5.6				
Second-degree polynomial with interaction terms, n=2						6.7	16.7
Linear with interaction term, n=1	12.5						
Linear with logarithmic transformations, n=1			2.8				
Linear with logarithmic transformations and interaction terms, n=1			2.8				
Nonlinear with exponential terms and division operation, n=1	12.5						
Nonlinear with exponential terms, division operations, and interaction effects, n=1	12.5						
Non-linear with power law terms and division operation, n=1				11.1			
Non-linear with quadratic term, interaction term and logarithmic transformation, n=1			2.8				

There was a difference in whether the models included or excluded delays. In 379 models, the delays were excluded from the model. Delays were included in 39 models and in these, eight models used a factor of 1.2 to substitute the actual delays in the study. Thirteen models included delays shorter than 15 minutes, and 18 models included the delays in the actual study. Further, whether delays were incorporated in models or not could not be deduced with complete certainty for four models.

Coefficients of determination were often reported for models and their predictive ability varied considerably (Appendix 11). R^2 and R^2-adjusted values were reported for 303 and 115 models, respectively. For 32 models, R^2 and R^2-adjusted values were both reported, while 36 models lacked both R^2 and R^2-adjusted values. The coefficients of determination R^2 and R^2-adjusted values ranged from 0.032-0.998 and 0.007-0.99, respectively. Moreover, the presence of information of statistical significance for models varied considerably. For 141 models, the statistical significance of only predictors was reported, while the statistical significance of the model was reported for 200 models. However, only 20 models were tested using validation data. For 81 models, no kind of statistical significance at all was noted. Lastly, 10 models lacked both coefficients of determination and information on statistical significance.

4. Discussion

4.1 Quantity of publications and models

In summary, 115 publications with 422 models for productivity for harvesters, feller-bunchers, and harwarders were identified. This clearly shows that a substantial number of publications were published each year regarding machines' performances. Additionally, it must be noted that several publications related to harvesting productivity were omitted from the review since these lacked mathematical models. In those, the productivity or time consumption was recorded, but no regression model was developed. This further emphasizes the extensive number of studies on harvesting productivity that were conducted between 2013 and 2023. In comparison, Lindroos' and Cavalli's (2016) and Böhm's and Kanzian's (2023) reviews of cable yarding productivity consisted of 21 publications with 82 models, and 70 publications with 98 models, respectively. Lindroos' & Cavalli's (2016) systematic review was more exhaustive and comprehensive as they covered more databases. This further highlights the abundance of work studies that have been conducted for the type of machinery covered in this review, since there is a possibility that publications that contained models but were only available in other databases have inadvertently been missed.

Lindroos & Cavalli (2016) observed that their compilation of publications was rather patchy in terms of geographic location of studies. This observation holds true to some extent for this review as well. While this review contained publications from more countries, an unproportional number of publications originated from the same few countries. This could be the result of several reasons. The terminology used in the search might have been somewhat biased and the chosen search strings could have favored the terminology used in these countries. However, it is more plausible that more studies simply are being conducted and published in these countries.

Interestingly, only a very limited number of publications were follow-up studies. This is somewhat surprising since the possibility for such studies has been around for a decade, and the several benefits compared to time studies could have been expected to promote a wider use of them. For example, time studies are usually relatively expensive and time-consuming to conduct compared to follow-up studies (e.g. Olivera et al. 2016; Brewer et al. 2018; Liski et al. 2020). However, there are also certain negative aspects to follow-up studies which could outweigh the positives and explain why researchers might be hesitant to conduct them. The dataset can, for instance, be of lower detail (Eriksson & Lindroos 2014). Another important limitation might be that follow-up data from regular operations require that the data owner (e.g. a forest company) allows the use and publication of the data. Further, the absence of direct observations in the field or by camera also limits the ability to capture different work elements' time. Since a substantial number of publications were conducted as work element level studies, these might not have been possible to perform with follow-up data and is likely the reason for the low number of follow-up studies. Moreover, follow-up studies are almost exclusive to CTL-machinery with sensors and processing heads. A substantial number of publications studied FT-machinery, possibly explaining the small number of follow-up studies. However, the ratio of time studies to follow-up studies, and CTL-machinery to FT-machinery, differ considerably.

Regarding equipment type used for modelling purposes, some differences to the results of Koŝir et al. (2015) were observed. Handheld-computers were the most frequently used in this review's identified publications compared to their results, where studyboards with stopwatches were the most prominent. Another difference is the use of video cameras, where they appeared more frequently in this review's results. However, it is also important to note the absence of information regarding equipment types in this review. Thirty-three publications did not provide information on equipment type, and this lack of information could significantly affect the results. Furthermore, similarly to Koŝir et al. (2015), a bias towards European publications was induced in this study, yet some differences were still observed. For example, in African, Northern, Southern, and Western European regions, it was more common to use Handheld-computers compared to other regions, which could indicate a difference in practice regarding equipment type.

4.2 Model characteristics

The most common independent variable in models was piece size, which is no surprise given the well-known relationship of piece size and productivity (e.g. Visser & Spinelli 2012; Eriksson & Lindroos 2014; Olivera et al. 2016; Ackerman et al. 2018). Yet, there was a large variation in which other variables were incorporated in models. However, it should be emphasized that several of the publications examined were not strictly productivity studies. For example, Santos et al. (2020) incorporated engine speed in revolutions/min and hydraulic pump flow in liters/min to model time consumption for moving, felling, processing, and productivity. The main aim of Santos et al. (2020) was to study the relationships between these variables, and the models did yield good coefficients of determination. However, they may not be typical or the most effective when trying to predict productivity in harvesting operations under various environmental conditions. Nevertheless, it exemplifies the various aims for productivity models, and that it is reasonable that several publications' models were comprised of "unconventional" variables.

While several trends could be observed in terms of incorporation of independent variables in models using the arbitrary categories, some were more prominent than others. For example, in North American publications, 76.5% and 70.6% incorporated "Work cycle-based" and "Movement/distances travelled" variables in models, respectively. This, combined with the fact that 82.4% of all publications in North American publications predicted work cycle time, suggests that in North America, particularly in The United States, it is more common to model productivity as work cycle times, incorporating these variables, rather than, for example, output/time, which was more common in other regions. Additionally, the "Work cycle-based" and "Movement/distances travelled" variables were more common in FT-machines' models, which were also more commonly studied in North American publications. However, the proportion of FT-machine studies incorporating these variables (25.0% and 38.9%, respectively) is not proportional to the higher percentage of North American publications featuring these variables, further suggesting that these variables are more commonly used in North America. Additionally, in North American publications, element level studies were the most frequent, which was similar to other regions, except South America. Even though element level studies were conducted, researchers in these publications still decided to model productivity as work cycle time.

It is crucial to consider the purposes of the identified publications, as these could influence the choice of independent variables. For example, Böhm & Kanzian (2023) identified several purposes within publications with models. While this review did not consider the purposes of the identified publications, many differed in their primary purpose which could have influenced the incorporated variables and the observed trends. For example, it was more common to incorporate variables regarding weight in southern Europe compared to other regions. This could be the consequence of the fact that the majority (78%) of publications in southern Europe focused on short-rotation forestry, coppice harvesting, or biomass harvesting, where weight might be easier and more appropriate to measure, considering the purposes of the publications. Additionally, in 66.7% of southern European publications, productivity was modelled in weight/time, which further explains the high proportion of southern European publications including weight related variables.

When it comes to the models' predictive capabilities, the identified models spanned from explaining almost nothing (0.7%) to almost all (99.0%) of the observed variation. In fact, numerous publications' models exhibited exceptionally low coefficients of determination (R^2 and R^2-adjusted). Lindroos & Cavalli (2016) stressed the irrelevance of such models due to low predictive capabilities. However, as mentioned previously, the main aim of several publications in this review was not necessarily to develop models with high predictive powers, but rather explore the effects of various factors. Consequently, it is reasonable that several models exhibited low predictive capabilities. Reporting models with low statistical significance and low coefficients of determination could still offer insightful contributions. For example, if no statistical significance exists between two variables, it might simply indicate the absence of relationship between them, and the purpose of the publication might be to display that lack of relationship. Another reason is that it might show that further studies are needed in that specific research area. Lahrsen et al. (2022) highlighted that two studies contradicted each other regarding the impact of snow, and hence the importance of further research in that area.

For the identified productivity models, it was more common to report R^2 values instead of R^2-adjusted values. This is similar to the results of Lindroos & Cavalli (2016) and Böhm & Kanzian (2023). Adding more predictors will inevitably increase R^2 and can result in an overfitted model. However, R^2-adjusted penalizes this, and provides a more robust evaluation of the models' actual ability to represent the proportion of variance (Böhm & Kanzian 2023). Thus, an overfitted model will not accurately predict outcome and it is, therefore, preferable to report R^2-adjusted for regression models with multiple predictors.

There was a wide variation of what was reported in terms of statistical significance. In several publications, no statistical significance at all was reported. Some publications only reported statistical significance of the predictors and not the actual model, while a few publications validated their models with datasets reserved for this purpose. Validating a model with a reserved dataset is more robust, as it is not the data the model has been trained on (Raschka 2018). Thus, it is preferable to test the predictive capabilities of a model this way. However, manual data collection is relatively expensive and time-consuming (e.g. Olivera et al. 2016; Brewer et al. 2018; Liski et al. 2020). Consequently, researchers might be reluctant to collect larger datasets, or, at least, be reluctant to set aside a part of an already small number of data points for data validation. This would be a possible explanation for the absence of validation data in studies. Further, as previously mentioned, the nature of several publications was not to create good productivity models, but to explore various factors' effect on productivity, which to some extent might explain the lack of validation data.

Concerning the type of equation of models, considerable variation was observed. This was anticipated as there is no literature that describes the optimal structure of models. Nevertheless, it is well known and common to model the relationship between piece size and productivity as a power, linear, or quadratic function (Visser & Spinelli 2012). This statement holds true to the results of this study. Most productivity models were linear, polynomial, or power law functions. However, contrary to the statement by Visser and Spinelli (2012) that most productivity models are power functions, it was observed in this review that the majority of researchers used linear functions for productivity. Regional differences could also be observed regarding models' mathematical structure. For instance, high proportions of publications from Asia (100.0%, only 2 publications), Eastern Europe (86.7%), and North America (94.1%) developed at least one purely linear model, which was not the case for other regions. Despite the strong similarities in mathematical structure, what they modelled, and, to a certain extent, the independent variables, differed considerably.

4.3 The usefulness of the models

In theory, managers and researchers could use these models in planning, follow-up, and control of harvest operations, but several of the identified models are unsuitable for this. Several models exhibited poor predictive capabilities and lacked information on statistical significance, rendering the models unsuitable for predictions in practice. Moreover, it is essential to use productivity models in appropriate work conditions. If a model is applied in conditions for which it was not developed from, it would not predict outcome accurately (Liski et al. 2020). Therefore, when models are to be used in real-world settings, it is necessary to ensure that the work conditions are similar to those from which the models were developed from. Moreover, some productivity models were derived from relatively few observations under relatively short time periods. Consequently, events that only seldom occur could therefore have been inadvertently missed (Eriksson & Lindroos 2014). Applying a productivity model derived from limited data to predict the outcome of another forest operation could therefore yield inaccurate results. Thus, it would be beneficial if productivity models were based on a large number of observations collected over an extended period of time.

4.4 Operators

The number of operators used in publications and their experience varied widely. The human factor in forest operation has been studied widely and is known to affect productivity (e.g. Purfürst & Erler 2011; Häggström & Lindroos 2016; Malinen et al. 2018). To negate this factor, a large sample of operators would be required (Bergstrand 1987). To study a large quantity of operators in a single time study would be unfeasible. It would be too time-consuming and, therefore, too expensive. The majority of time studies in this review studied one or a few operators. This could be somewhat limiting due to the individual and inter-individual differences in productivity. In the study by Purfürst & Erler (2011), a difference in productivity of a factor of 1.8 for experienced operators was observed and the human factor was, after stem volume, the second most important factor to influence productivity. Consequently, when conducting a time study with only one or a few operators, and even though the stand characteristics are very similar, the resulting productivity and productivity models could presumably be different. To negate the possible variation in operator performance, which could affect values of productivity models, long term data collected automatically could be used (Strandgard et al. 2013). Spinelli & De Arruda Moura (2019) used follow-up datasets from 120 operators, which was the largest number of operators clearly stated to be used for developing productivity models observed in this review. However, even though no actual number was provided in Eriksson & Lindroos (2014), their study used data from more than 400 harvesters, most of which can be expected to have been operated by at least two operators. Hence, these types of follow-up studies utilizing large number of operators are likely to reduce the possible bias induced by differences in operator performances.

4.5 Delays

In total, 379 models predicted productivity or time consumption excluding delays and 39 models included delays. Delays may occur erratically, and the occurrence of delays differ depending on work conditions and machine types. In a shorter time study, it can, therefore, be difficult to precisely determine the extent of delays with certainty and the applicability of these delay times to other studies. Consequently, instead of including the actual delays observed in a study, factors may instead be implemented that have been developed from several longer time studies (Spinelli & Visser 2008). Eight models in this review had such factors instead of the actual delays observed in the studies due to the relatively short period the machines were studied. Moreover, in four models, whether the dependent variable included or excluded delay time could not be deduced with complete certainty. It could simply be that the author of this review could not deduce it. However, if this is not the case and the publication did not actually explicitly provide information on whether they included delays or not is problematic if the model were to be applied in harvesting. Even if a publication has provided clear information that the model included delays, there is still a possibility that the model might not accurately predict the actual outcome due to the erratic nature of delays. Spinelli & Visser (2008) conducted 34 studies and delays constituted, on average, 28.9% of the total scheduled machine time. This suggests that delays can constitute a relatively big portion of the total scheduled time. Delays should thus be incorporated into models with caution, and the data of delays should be based on long-term studies (Spinelli & Visser 2008). Fortunately, it appears that researchers prefer to omit delays from models and only include productive time since the majority of models (89.5%) were structured in this manner. This is similar to the results of Lindroos & Cavalli (2016) and Böhm & Kanzian (2023).

4.6 Strengths, weaknesses, and improvements for future reviews

Some weaknesses can be found in this review that could have been improved and, ultimately, have given better and more comprehensive results. Even though this study covered a relatively voluminous dataset, more publications could probably have been identified. A wider range of databases could have been searched to identify publications. Snowballing techniques could also have been used, in terms of using the reference lists from identified publications to track down additional ones. Furthermore, the time interval for publications considered eligible for this review could have been extended to include more publications. More data could possibly have altered the outcome to some extent. However, given the large number of publications already included in this review, it is uncertain how significantly these additional publications would have affected the results.

Another limitation is the choice of search strings applied in databases. More search strings could have been added throughout the study such as “on-board-computer”, “OBC”, and other similar strings to favor follow-up studies. Likewise, it is somewhat unclear whether the search strings had a propensity for time studies. It was uncertain if more publications that used follow-up data could have been identified with more comprehensive search strings, since only a limited number of publications of that sort were identified.

The decision to refine the search results in Web of Science with the filter “forestry” is somewhat questionable. Logically, all studies eligible for this review should have been in this research area, however, this might not be the case. Thus, the exhaustiveness of this review is uncertain. However, given the relatively large dataset, the number of publications and models in this review should likely suffice to draw conclusions regarding productivity models and trends in the literature.

If the review were to be conducted again, or if a similar review were to be conducted for other types of machinery, some aspects should be changed to improve reproducibility, transparency, and to ascertain exhaustiveness. The aforementioned points should obviously be considered, which would make the review more exhaustive and comprehensive. Further, it would be preferable if the review was a systematic literature review (SLR). This review cannot be classified as a SLR as several parts of the methodology for SLRs were omitted. In this review, some parts of the SALSA framework were not as detailed as they are in SLRs (Mengist et al. 2020). One aspect of the SALSA framework that could have been more detailed was the inclusion criteria, particularly inclusion criterion 5: The publication focuses on forest operations and pertains to harvesters, feller-bunchers, or harwarders and could possibly contain productivity models. This criterion could be interpreted as somewhat broad and subjective, relying on the author's own interpretation of the likelihood that the publications included productivity models, based on the title and abstract of the publication. Consequently, a bias was possibly induced which could have affected the outcome. It would, therefore, be beneficial for future similar reviews to more precisely define this type of inclusion criterion to make the selection process entirely objective. This would, in turn, enhance the reproducibility and transparency of the review.

One aspect of the SALSA framework that was entirely omitted was a visualization of the exclusion of publications, such as those in Fernández del Amo et al. (2018). A flow diagram could have been created to visualize inclusion and exclusion of publications. Instead of piling all the eligible publications together, separate tables or flowcharts should have been created to show how many eligible publications were identified in each database, and how many were excluded for each exclusion criterion. Implementing this approach would have increased the transparency and reproducibility of the review.

Meta-analysis could be performed if a similar review were to be conducted. In a meta-analysis, the results of several publications are combined, and statistical analysis is performed to identify patterns, draw conclusions, and resolve uncertainties in research. Results that are not discernible from a single study could be discerned from several through meta-analysis (Russo 2007). There are meta-analyses available regarding factors' effect on harvesting productivity, such as those on ground-based harvesting by Louis et al. (2022) and on cable-yarder logging by Böhm & Kanzian (2023). While Louis et al. (2022) covered several crucial factors for fully mechanized harvesting, some variables were omitted due to, for instance, lack of observations, such as operator experience. Further factors such as presence of downed trees due to wind damage or insect outbreaks were not analyzed either. Incorporating these kinds of variables in future meta-analyses could yield new and potentially valuable insights into these factors' effect on productivity.

Despite some flaws, this review is the most extensive compilation and analysis of productivity models to date for the studied harvesting machinery. The identified publications covered a wide range of forest types, work conditions, machine types, and harvest operations. The quantity of data collected and scrutinized should offer insights into, for example, the variables, type of functions, and predictive capabilities of productivity models for harvesters, feller-bunchers, and harwarders.

4.7 Future research

There are few publications that have compiled and scrutinized models that predict work productivity or time consumption for machinery in forestry. The publications available are Aubuchon (1982), Peters (1991), Lindroos & Cavalli (2016), and Böhm & Kanzian (2023). Hence, there is a lack and further need of studies regarding compilation and scrutinization of models. No publications regarding compilation and review of models exists for, for instance, forwarders, skidders, processors, stroke boom delimbers, mulchers, chippers, or helicopters. Furthermore, while all the models in this review could be considered productivity models, several of them were not created to be the most optimal models. Several publications did not aim to create productivity models, but rather explore the effects of various factors on productivity. Therefore, in future studies, it could be beneficial to scrutinize these productivity models produced with conventional predictive purposes, while omitting publications with models that had other objectives. Thus, comparisons could be made for productivity models specifically developed for practical use in prediction of productivity.

Not only do reviews like this one, along with those by Lindroos & Cavalli (2016) and Böhm & Kanzian (2023), provide insight into the productivity models themselves, but they can assist researchers in future studies. Some misconceptions and lack of useful information were present both in this review and Lindroos & Cavalli (2016) and Böhm & Kanzian (2023), such as lack of statistical significance for the actual model and lack of R^2-adjusted values, where R^2-adjusted would have been more preferable than R^2 values. As mentioned previously, several publications' aim was not to develop optimal models, however, if researchers still decide to publish these models, it would be beneficial to provide the information mentioned.

From the findings of this review, it appears that only a limited number of productivity models for fully mechanized harvesting have been developed and published using follow-up data in the period 2013-2023. This would indicate that researchers seem to have favored manual data collection when studying harvesting machines. Nevertheless, several of the identified models developed from follow-up data showed promising results in terms of predictive capabilities. Due to the beneficial aspects of follow-up studies, such as lower cost (e.g. Olivera et al. 2016; Brewer et al. 2018; Liski et al. 2020), along with the evidently relatively good predictive power of identified models, these results may facilitate further development of models with follow-up data. In addition, due to the relatively low cost and good predictive capabilities, companies that keep records of production data would likely be interested in this method of developing and enhancing future models (Eriksson & Lindroos 2014).

Regression analysis is a common statistical method to analyze factors' effect on productivity (Acuna et al. 2012). It is, however, important to note that traditional statistical methods, such as linear regression analysis, may not perform adequately for very large amounts of data (Rossit et al. 2019). This, in combination with the vast amounts of data collected with sensors and OBCs from harvesters, could potentially limit the possibility to analyze follow-up data with only traditional methods. The traditional statistical methods may not take full advantage of the data. Researchers, such as Rossit et al. (2019), have therefore utilized ”Big Data” and data mining techniques to address these limitations. The results on modelling productivity and analysis of different variables' effect on productivity with decision trees and k-means algorithms were promising, probably facilitating further use of these approaches in combination with automatic data collection with OBCs. Additionally, due to the already large amounts of data collected from OBCs, and the anticipated developments in technology which would likely further increase the available data amount (Gao et al. 2022), would make machine learning techniques a prominent method for analyzing large volumes of data (Liski et al. 2020). Liski et al. (2020) predicted harvester productivity with Ordinary Least Squares regression (OLS), Gradient boosted machine (GBM), and Support vector machine (SVM). OLS proved to be a sufficient method, however, GBM and SVM showed great potential for future research.

There are certain variables that OBCs do not capture, such as slope (Olivera et al. 2016). Since slope could potentially affect productivity and be incorporated in models, which was done by Eriksson & Lindroos (2014), Williams & Ackerman (2016), Ackerman et al. (2018), and Norihiro et al. (2018), it would be beneficial to collect information regarding slope when harvesting is performed in areas with steep slopes. Olivera et al. (2016) conducted a follow-up study on a harvester equipped with a combined GSM-GNSS antenna. The attachment of the antenna enabled the collection of geospatial information, and with this information and subsequent data processing, it was possible to assign a slope value for each stem. It was concluded that slope did not have a significant effect on productivity, as slope values only ranged from 0-12%. This type of combination of different data sources is evidently a potential useful method for bypassing some of the constraints which automatic data collection induces. Consequently, more types of variables and data can be combined to analyze productivity and develop improved productivity models.

Discrepancies between automatic and manual measurements of diameter at breast height and volume have been observed (Brewer et al. 2018). Brewer et al. (2018) observed that diameter at breast height and volume values measured by harvester heads were significantly lower than those obtained by manual measurements with diameter at breast height tape. In their study, they conducted a conventional time study to develop productivity models and compared these to models developed using consecutive timestamps from follow-up data. Notably, they only used values from the manual measurements of diameter at breast height and volume for both methodologies. Given the significant difference in measurements, the productivity models likely would vary as well if harvester head measurements were used in conjunction with the follow-up timestamps. However, the extent of this variation remains uncertain as Brewer et al. (2018) did not examine this. Therefore, in future studies, it would be beneficial to scrutinize the extent to which this discrepancy in measurement types influences productivity models. Such studies could elucidate the differences between models derived from conventional time studies and those derived from follow-up data, providing insights into how these measurement discrepancies affect model accuracy.

The aforementioend points regarding future research and development for automatic collection of data and follow-up studies have mainly been aimed at CTL harvesters. Feller-bunchers do normally not capture continuous and automatic production data due to lack of sensors and processing heads (Lahrsen et al. 2022). It is, therefore, more difficult to perform follow-up studies for these types of machines compared to CTL harvesters. Nevertheless, research efforts have been made to develop methods enabling the automatic recording of time for feller-buncher work elements, such as those in Pan et al. (2022), which could potentially enhance the effectiveness and lower the cost of work studies. Pan et al. (2022) used machine learning methods utilizing sound and video data to classify a feller-buncher's operational state. The study showed promising results for automatic recording of the feller-bunchers work. However, some inaccuracies for the work element ”pile” were observed, indicating the need for further studies to refine these methods. They also noted the possibility of combining auditory and visual data with data from the feller-buncher's CAN-bus, which could potentially increase the accuracy of the method's classification of work elements. Notably, even if these methods could provide highly accurate data for the time spent for each work element or work cycle, the methods would not provide data on diameter at breast height or volume. Consequently, some fieldwork would still be required to derive productivity, which limits the potential automatic procedure of analyzing feller-bunchers' productivity. A certain technique to bypass this constraint was proposed by Pan & McDonald (2019), who conducted a study to estimate tree size from the cutting sound of a feller-buncher. The prediction accuracy was relatively high, however, compared to Scandinavian standards for diameter at breast height measurement accuracy for CTL harvesters, it was not adequate. Consequently, without further refinements, this technique is infeasible for practical applications. This highlights the need for further research to develop automatic methods for inferring feller-bunchers' productivity.

4.8 Conclusions

After analysis of productivity models for harvesters, feller-bunchers, and harwarders published in 2013-2023, several conclusions can be drawn:

From the databases this review covered with the applied search strings, 115 publications pertaining to harvesters, feller-bunchers, and harwarders including productivity models were identified. This clearly shows that a considerable number of publications regarding these machines' productivity are published annually, especially since several productivity related publications were omitted due to lack of productivity models. Furthermore, the identified publications in this review covered a wide variety of forest types, work conditions, operations, machine types and models. The publications originated from 22 countries and the majority originated from Europe. However, publications from the United States, Australia, Finland, Sweden, and Latvia collectively constituted more than half of the total number of publications.

Several types of equipment were used in the publications, with notable differences compared to earlier studies. In this review, the most common type of equipment reported was hand-held computers. However, caution is needed, as more than a quarter of the publications did not specify the equipment type used. Despite this limitation, regional differences were observed. For instance, in African, Northern, Southern, and Western European regions, hand-held computers were the most prevalent equipment, which was not the case for other regions.

Interestingly, only a handful of publications presented productivity models based on follow-up data. This was contrary to expectations, as modern OBCs in harvesters automatically collect data on production activities and were expected to be more commonly used to rapidly collect large amounts of data. However, this does not appear to be the case. A possible reason for this could be that several of the identified publications studied machines on work element level. Since follow-up data from OBCs cannot easily distinguish between work elements, these studies would not have been possible to conduct with follow-up data.

The number of operators studied in publications varied considerably. While most studies focused on a single operator, the number of operators included ranged from 1 to 120. However, more than a third of publications did not provide information on the number of operators studied, or it could not be ascertained. Additionally, the experience level of operators varied widely, with some researchers studying operators with only a few months of experience, while others focused on those with several decades of experience.

A wide range of unique variables were incorporated in models, yet a clear trend could be observed, i.e. the vast majority of researchers incorporated tree size in models. Trends across regions and harvesting methods were also observed, with some being more prominent than others. For example, in North American publications, as well as those utilizing FT-harvesting, it was more common to incorporate "Cycle based" and "Movement/distance" independent variables in models. Additionally, it was more common to model productivity as work cycle time in North America, despite most North American publications conducting element level studies.

The type of mathematical function used to describe productivity varied considerably, and most researchers used a linear function to model productivity. However, notable regional trends were evident in this regard as well. For example, a higher proportion of publications from Asia, Eastern Europe, and North America developed purely linear models.

Regarding delays in productivity models, most models excluded delays. However, when delays were included, various approaches were observed. Some models included all recorded delays, while others used a delay factor of 1,2, and some included delays shorter than 15 minutes. In a few cases, it was unclear whether the authors included or excluded delays in their model.

A considerable difference in predictive capabilities for models was observed, with some models having exceptionally low predictive capabilities, whereas others predicted productivity accurately. Moreover, what was reported in terms of statistical significance varied. It was common to report statistical significance of the whole model, however, it was also common to report statistical significance of only the predictors and not the actual model. In a surprisingly large number of cases, no statistical significance at all was reported.

References

Ackerman, P., Martin, C., Brewer, J. & Ackerman, S. (2018). Effect of slope on productivity and cost of Eucalyptus pulpwood harvesting using single-grip purpose-built and excavator-based harvesters. *International Journal of Forest Engineering*, 29 (2), 74–82. https://doi.org/10.1080/14942119.2018.1431491

Acuna, M., Bigot, M., Guerra, S., Hartsough, B., Kanzian, C., Kärhä, K., Lindroos, O., Magagnotti, N., Roux, S., Spinelli, R., Talbot, B., Tolosana, E. & Zormaier, F. (2012). *Good Practice Guidelines for Biomass Production Studies*. https://res.slu.se/id/publ/41090 [2023-09-12]

Anon (2023a). *553C | Peterson Cat*. https://www.petersoncat.com/products/new/wheel-feller-bunchers/553c [2024-04-23]

Anon (2023b). *Forest Operations Equipment Catalog: Feller Buncher*. *US Forest Service*. https://www.fs.usda.gov/forestmanagement/equipment-catalog/fellerbuncher.shtml [2023-09-22]

Anon (2023c). *Forest Operations Equipment Catalog: Felling Heads*. *US Forest Service*. https://www.fs.usda.gov/forestmanagement/equipment-catalog/fellingheads.shtml [2023-09-22]

Anon (2023d). *Forest Operations Equipment Catalog: Harvester*. *US Forest Service*. https://www.fs.usda.gov/forestmanagement/equipment-catalog/harvester.shtml [2023-09-22]

Aubuchon, R.R. (1982). Compendium of cable yarding production equations. https://doi.org/10.13031/2013.31766

Bergroth, J., Palander, T. & Kärhä, K. (2006). Excavator-based harvesters in wood cutting operations in Finland. *Forestry Studies*, 45, 74–88

Bergstrand, K.G. (1987). Planning and analysis of time studies on forest technology [comparative studies, correlation studies]. *Meddelande - Forskningsstiftelsen Skogsarbeten (Sweden)*, (17). https://agris.fao.org/search/en/providers/122495/records/64775121bc45d9ecdbc084d4 [2024-05-20]

Bergström, D. & Di Fulvio, F. (2014). Evaluation of a novel prototype harvester head in early fuel-wood thinnings. *International Journal of Forest Engineering*, 25 (2), 156–170. https://doi.org/10.1080/14942119.2014.945697

Bergström, D., Di Fulvio, F. & Nuutinen, Y. (2016). Effect of forest structure on operational efficiency of a bundle-harvester system in early thinnings. *Croatian Journal of Forest Engineering*, 37 (1), 37–49

Bergström, D., Fernandez-Lacruz, R., de la Fuente, T., Höök, C., Krajnc, N., Malinen, J., Nuutinen, Y., Triplat, M. & Nordfjell, T. (2022). Effects of boom-corridor thinning on harvester productivity and residual stand structure. *International Journal of Forest Engineering*, 33 (3), 226–242. https://doi.org/10.1080/14942119.2022.2058258

Billingsley, J., Visala, A. & Dunn, M. (2008). Robotics in Agriculture and Forestry. I: *Springer Handbook of Robotics*. 1065–1077. https://doi.org/10.1007/978-3-540-30301-5_47

Björheden, R., Apel, K., Shiba, M., & Michael A. Thompson (1995). International Union of Forestry Research Organisations WP 3.04.02: Forest work study nomenclature: test edition valid 1995-2000.-All Databases. https://www.webofscience.com/wos/alldb/full-record/CABI:19970605015 [2024-03-07]

Brewer, J., Talbot, B., Belbo, H., Ackerman, P. & Ackerman, S. (2018). A comparison of two methods of data collection for modelling productivity of harvesters: manual time study and follow-up study using on-board-computer stem records. *Annals of Forest Research*, 109–124. https://doi.org/10.15287/afr.2018.962

Böhm, S. & Kanzian, C. (2023). A review on cable yarding operation performance and its assessment. *International Journal of Forest Engineering*, 34 (2), 229–253. https://doi.org/10.1080/14942119.2022.2153505

Costa, C., Menesatti, P. & Spinelli, R. (2012). Performance modelling in forest operations through partial least square regression. *Silva Fennica*, 46 (2), 241–252. https://doi.org/10.14214/sf.57

Eriksson, M. & Lindroos, O. (2014). Productivity of harvesters and forwarders in CTL operations in northern Sweden based on large follow-up datasets. *International Journal of Forest Engineering*, 25 (3), 179–200. https://doi.org/10.1080/14942119.2014.974309

Esteban, E., Spinelli, R., Aminti, G., Laina, R. & López Vicens, I. (2018). Productivity, Efficiency and Environmental Effects of Whole-Tree Harvesting in Spanish Coppice Stands Using a Drive-to-Tree Disc Saw Feller-Buncher. *Croatian Journal of Forest Engineering*, 39, 163–172

Fernández del Amo, I., Erkoyuncu, J.A., Roy, R., Palmarini, R. & Onoufriou, D. (2018). A systematic review of Augmented Reality content-related techniques for knowledge transfer in maintenance applications. *Computers in Industry*, 103, 47–71. https://doi.org/10.1016/j.compind.2018.08.007

Gao, W., Qiu, Q., Yuan, C., Shen, X., Cao, F., Wang, G. & Wang, G. (2022). Forestry Big Data: A Review and Bibliometric Analysis. *Forests*, 13 (10), 1549. https://doi.org/10.3390/f13101549

Holzleitner, F. & Kanzian, C. (2022). Integrated in-stand debarking with a harvester in cut-to-length operations – processing and extraction performance assessment. *International Journal of Forest Engineering*, 33 (1), 66–79. https://doi.org/10.1080/14942119.2021.2013049

Häggström, C. & Lindroos, O. (2016). Human, technology, organization and environment – a human factors perspective on performance in forest harvesting. *International Journal of Forest Engineering*, 27 (2), 67–78. https://doi.org/10.1080/14942119.2016.1170495

Johansson, J. & Gullberg, T. (2002). Multiple Tree Handling in the Selective Felling and Bunching of Small Trees in Dense Stands. *International Journal of Forest Engineering*, 13 (2), 25–34. https://doi.org/10.1080/14942119.2002.10702460

Jonsson, R. (2021). Harwarders in Final Felling. https://www.skogforsk.se/cd_20210601113145/contentassets/c2f5646a94fc434d9297b2ba9b3d0e71/arbetsrapport-1083-eng.pdf [2023-09-21]

Jonsson, R., Rönnqvist, M., Flisberg, P., Jönsson, P. & Lindroos, O. (2023). Country-wide analysis of the potential use of harwarders for final fellings in Sweden. *Scandinavian Journal of Forest Research*, 38 (1–2), 105–120. https://doi.org/10.1080/02827581.2023.2168045

Kanzian, C. (2023). Are productivity studies in forest operations old fashioned and no more publishable? *Silva Fennica*, 57 (3). https://www.silvafennica.fi/article/23074 [2024-08-26]

Kemmerer, J. & Labelle, E.R. (2021). Using harvester data from on-board computers: a review of key findings, opportunities and challenges.

European Journal of Forest Research, 140 (1), 1–17. https://doi.org/10.1007/s10342-020-01313-4

Kizha, A.R. & Han, H.-S. (2016). Processing and sorting forest residues: Cost, productivity and managerial impacts. *Biomass and Bioenergy*, 93, 97–106. https://doi.org/10.1016/j.biombioe.2016.06.021

Koŝir, B., Magagnotti, N. & Spinelli, R. (2015). The role of work studies in forest engineering: status and perspectives. *International Journal of Forest Engineering*, 26 (3), 160–170. https://doi.org/10.1080/14942119.2015.1111043

Lahrsen, S., Mologni, O., Magalhães, J., Grigolato, S. & Röser, D. (2022). Key factors influencing productivity of whole-tree ground-based felling equipment commonly used in the Pacific Northwest. *Canadian Journal of Forest Research*, 52 (4), 450–462. https://doi.org/10.1139/cjfr-2021-0266

Laitila, J. & Väätäinen, K. (2020). Productivity of harvesting and clearing of brushwood alongside forest roads. *Silva Fennica*, 54, 21. https://doi.org/10.14214/sf.10379

Lindroos, O. (2010). Scrutinizing the Theory of Comparative Time Studies with Operator as a Block Effect. *International Journal of Forest Engineering*, 21 (1), 20–30. https://doi.org/10.1080/14942119.2010.10702587

Lindroos, O. & Cavalli, R. (2016). Cable yarding productivity models: a systematic review over the period 2000–2011. *International Journal of Forest Engineering*, 27 (2), 79–94. https://doi.org/10.1080/14942119.2016.1198633

Lindroos, O., Pettersson, J. & Nordfjell, T. (2024). How stem size variations in forest stands influence harvester productivity and the use of productivity models. *International Journal of Forest Engineering*,. https://www.tandfonline.com/doi/abs/10.1080/14942119.2024.2387523 [2024-08-25]

Liski, E., Jounela, P., Korpunen, H., Sosa, A., Lindroos, O. & Jylhä, P. (2020). Modeling the productivity of mechanized CTL harvesting with statistical machine learning methods. *International Journal of Forest Engineering*, 31 (3), 253–262. https://doi.org/10.1080/14942119.2020.1820750

Loren Kellogg, Pete Bettinger, Steve Robe, & Alan Steffert (1992). Mechanized harvesting: a compendium of research.

Louis, L.T., Kizha, A.R., Daigneault, A., Han, H.-S. & Weiskittel, A. (2022). Factors Affecting Operational Cost and Productivity of Ground-Based Timber Harvesting Machines: a Meta-analysis. *Current Forestry Reports*, 8 (1), 38–54. https://doi.org/10.1007/s40725-021-00156-5

Lundbäck, M., Häggström, C. & Nordfjell, T. (2021). Worldwide trends in methods for harvesting and extracting industrial roundwood. *International Journal of Forest Engineering*, 32 (3), 202–215. https://doi.org/10.1080/14942119.2021.1906617

Malinen, J., Taskinen, J. & Tolppa, T. (2018). Productivity of Cut-to-Length Harvesting by Operators' Age and Experience. *Croatian Journal of Forest Engineering*, 39

Mcewan, A., Magagnotti, N. & Spinelli, R. (2016). The effects of number of stems per stool on cutting productivity in coppiced Eucalyptus plantations. *Silva Fennica*, 50. https://doi.org/10.14214/sf.1448

Mengist, W., Soromessa, T. & Legese, G. (2020). Method for conducting systematic literature review and meta-analysis for environmental science research. *MethodsX*, 7, 100777. https://doi.org/10.1016/j.mex.2019.100777

Norihiro, J., Ackerman, P., Spong, B. & Längin, D. (2018). Productivity Model for Cut-to-Length Harvester Operation in South African Eucalyptus Pulpwood Plantations. *Croatian Journal of Forest Engineering*, 39, 1–13

Nuutinen, Y., Väätäinen, K., Heinonen, J., Antti, A. & Röser, D. (2008). The accuracy of manually recorded time study data for harvester operation shown via simulator screen. *Silva Fennica*, 42. https://doi.org/10.14214/sf.264

Olivera, A., Visser, R., Acuna, M. & Morgenroth, J. (2016). Automatic GNSS-enabled harvester data collection as a tool to evaluate factors affecting harvester productivity in a Eucalyptus spp. harvesting operation in Uruguay. *International Journal of Forest Engineering*, 27 (1), 15–28. https://doi.org/10.1080/14942119.2015.1099775

Pan, P. & McDonald, T. (2019). Tree size estimation from a feller-buncher's cutting sound. *Computers and Electronics in Agriculture*, 159, 50–58. https://doi.org/10.1016/j.compag.2019.02.021

Pan, P., McDonald, T., Smidt, M. & Dias, R. (2022). Use of vision and sound to classify feller-buncher operational state. *International Journal of Forest Engineering*, 33 (2), 129–138. https://doi.org/10.1080/14942119.2022.2037927

Peters, P.A. (1991). Correlating production of accumulating Feller-bunchers. https://doi.org/10.13031/2013.31766 [2023-09-12]

Purfürst, F.T. & Erler, J. (2011). The Human Influence on Productivity in Harvester Operations. *International Journal of Forest Engineering*, 22 (2), 15–22. https://doi.org/10.1080/14942119.2011.10702606

Raschka, S. (2018). Model Evaluation, Model Selection, and Algorithm Selection in Machine Learning.

Rocha, Q., Lima, R.C., Munis, R., Pereira, G. & Simões, D. (2022). Economic viability of the whole tree harvest under conditions of uncertainty: a study in southeastern Brazil. *International Journal of Forest Engineering*, 33. https://doi.org/10.1080/14942119.2022.2029316

Rossit, D.A., Olivera, A., Viana Céspedes, V. & Broz, D. (2019). A Big Data approach to forestry harvesting productivity. *Computers and Electronics in Agriculture*, 161, 29–52. https://doi.org/10.1016/j.compag.2019.02.029

Russo, M.W. (2007). How to Review a Meta-analysis. *Gastroenterology & Hepatology*, 3 (8), 637–642

Santos, D.W.F.D.N., Valente, D.S.M., Fernandes, H.C., De Souza, A.P. & Cecon, P.R. (2020). Technical, Economic, and Environmental Parameters of Excavator-Based Harvester in Function of Engine Speed and Hydraulic Pump Flow. *Croatian journal of forest engineering*, 41 (2), 205–218. https://doi.org/10.5552/crojfe.2020.761

Schmiedel, S., Beaudoin, D. & Rönnqvist, M. (2022). Stand-specific working methods for harvester operators: a simulation study. *International Journal of Forest Engineering*, 33 (3), 250–261. https://doi.org/10.1080/14942119.2022.2068291

Spinelli, R. & De Arruda Moura, A.C. (2019). Decreasing the Fuel Consumption and CO2 Emissions of Excavator-Based Harvesters with a Machine Control System. *Forests*, 10 (1), 43. https://doi.org/10.3390/f10010043

Spinelli, R. & Visser, R. (2008). Analyzing and Estimating Delays in Harvester Operations. *International Journal of Forest Engineering*, 19 (1), 36–41. https://doi.org/10.1080/14942119.2008.10702558

Strandgard, M., Walsh, D. & Acuna, M. (2013). Estimating harvester productivity in Pinus radiata plantations using StanForD stem files. *Scandinavian Journal of Forest Research*, 28 (1), 73–80. https://doi.org/10.1080/02827581.2012.706633

Szewczyk, G. & Sowa, J.M. (2017). The accuracy of measurements in a time study of harvester operations. *New Zealand Journal of Forestry Science*, 47 (1), 24. https://doi.org/10.1186/s40490-017-0105-3

Visser, R. & Spinelli, R. (2012). Determining the shape of the productivity function for mechanized felling and felling-processing. *Journal of Forest Research*, 17 (5), 397–402. https://doi.org/10.1007/s10310-011-0313-2

Williams, C. & Ackerman, P. (2016). Cost-productivity analysis of South African pine sawtimber mechanised cut-to-length harvesting. *Southern Forests: a Journal of Forest Science*, 78 (4), 267–274. https://doi.org/10.2989/20702620.2016.1183096

Appendix 1. Publications included in the review

Ackerman, P., Martin, C., Brewer, J. & Ackerman, S. (2018). Effect of slope on productivity and cost of Eucalyptus pulpwood harvesting using single-grip purpose-built and excavator-based harvesters. *International Journal of Forest Engineering*, 29 (2), 74–82. https://doi.org/10.1080/14942119.2018.1431491

Ackerman, S., Astrup, R. & Talbot, B. (2021). The effect of tree and harvester size on productivity and harvester investment decisions. *International Journal of Forest Engineering*, 33, 1–11. https://doi.org/10.1080/14942119.2021.1981046

Ackerman, S.A., McDermid, H., Ackerman, P. & Terblanche, M. (2022). The effectiveness of a small-scale combination harvester/forwarder in industrial plantation first thinning operations. *International Journal of Forest Engineering*, 33 (1), 56–65. https://doi.org/10.1080/14942119.2021.1978798

Acosta, F.C., Silva, I.M., Garcia, M.L. & de Melo, R.R. (2021). Productivity and costs of harvester cutting of teak trees for thinning. *Floresta e Ambiente*, 28 (2), 1–8. https://doi.org/10.1590/2179-8087-FLORAM-2020-0002

Acuna, M., Strandgard, M., Wiedemann, J. & Mitchell, R. (2017). Impacts of Early Thinning of a Eucalyptus globulus Labill. Pulplog Plantation in Western Australia on Economic Profitability and Harvester Productivity. *Forests*, 8 (11), 415. https://doi.org/10.3390/f8110415

Alam, M., Walsh, D., Strandgard, M. & Brown, M. (2014). A log-by-log productivity analysis of two Valmet 475EX harvesters. *International Journal of Forest Engineering*, 25 (1), 14–22. https://doi.org/10.1080/14942119.2014.891668

Apafaian, A., Proto, A.R. & Borz, S. (2017). Performance of a mid-sized harvester-forwarder system in integrated harvesting of sawmill, pulpwood and firewood. *Annals of Forest Research*, 60. https://doi.org/10.15287/afr.2017.909

Berendt, F., Esteban, E., Hoffmann, S., Alonso, P. & Schweier, J. (2020). Harvester Productivity in Inclined Terrain with Extended Machine Operating Trail Intervals: A German Case Study Comparison of Standing and Bunched Trees. *Sustainability*, 12, 10. https://doi.org/10.3390/su12219168

Berg, S., Bergström, D. & Nordfjell, T. (2014). Simulating conventional and integrated stump- and round-wood harvesting systems: a comparison of productivity and costs. *International Journal of Forest Engineering*, 25 (2), 138–155. https://doi.org/10.1080/14942119.2014.941640

Bergström, D. & Di Fulvio, F. (2014). Evaluation of a novel prototype harvester head in early fuel-wood thinnings. *International Journal of Forest Engineering*, 25 (2), 156–170. https://doi.org/10.1080/14942119.2014.945697

Bergström, D., Di Fulvio, F. & Nuutinen, Y. (2016). Effect of Forest Structure on Operational Efficiency of a Bundle-Harvester System in Early Thinnings. *Croatian Journal of Forest Engineering*, 37, 37–49

Bergström, D., Fernandez-Lacruz, R., de la Fuente, T., Höök, C., Krajnc, N., Malinen, J., Nuutinen, Y., Triplat, M. & Nordfjell, T. (2022). Effects of boom-corridor thinning on harvester productivity and residual stand structure. *International Journal of Forest Engineering*, 33 (3), 226–242. https://doi.org/10.1080/14942119.2022.2058258

Bilici, E., Akay, A.E. & Abbas, D. (2019). Assessing the effects of site factors on the productivity of a feller buncher: a time and motion analysis. *Journal of Forestry Research*, 30 (4), 1471–1478. https://doi.org/10.1007/s11676-018-0696-4

Brewer, J., Talbot, B., Belbo, H., Ackerman, P. & Ackerman, S. (2018). A comparison of two methods of data collection for modelling productivity of harvesters: Manual time study and follow-up study using on-board-computer stem records. *Annals of Forest Research*, 61. https://doi.org/10.15287/afr.2018.962

Brown, M., Alam, M. & Acuna, M. (2013). Self-Levelling Feller-Buncher Productivity Based On Lidar-Derived Slope. *Croatian Journal of Forest Engineering*, 34

Carter, Z., Pan, F., Lin, Y., Miller, R.O. & Srivastava, A. (2017). A traditional ground-based system for woody biomass harvesting in Short Rotation Woody Crop (SRWC) plantations – a case study in Michigan. *International Journal of Forest Engineering*, 28 (1), 47–56. https://doi.org/10.1080/14942119.2017.1253982

Chakroun, M., Bouvet, A., Ruch, P. & Montagny, X. (2016). Performance of two shear heads for harvesting biomass in hardwood stands in France. *Biomass and Bioenergy*, 91, 227–233. https://doi.org/10.1016/j.biombioe.2016.05.029

Chung, W., Morrissette, B., Green, P., Garrelts, B., Leshchinsky, B., Belart, F., Sessions, J., Wimer, J. & Garland, J. (2022). Effects of Pre-Bunching Trees With a Tethered Feller-Buncher on Cable Logging Productivity and Costs: A Case Study in Southern Oregon. *Forest Science*, 68 (3), 325–333. https://doi.org/10.1093/forsci/fxac008

Di Fulvio, F. & Bergström, D. (2013). Analyses of a single-machine system for harvesting pulpwood and/or energy-wood in early thinnings. *International Journal of Forest Engineering*, 24 (1), 2–15. https://doi.org/10.1080/14942119.2013.798935

Erber, G., Holzleitner, F., Kastner, M. & Stampfer, K. (2016). Effect of multi-tree handling and tree-size on harvester performance in small-diameter hardwood thinnings. *Silva Fennica*, 50. https://doi.org/10.14214/sf.1428

Eriksson, M. & Lindroos, O. (2014). Productivity of harvesters and forwarders in CTL operations in northern Sweden based on large follow-up datasets. *International Journal of Forest Engineering*, 25 (3), 179–200. https://doi.org/10.1080/14942119.2014.974309

Fernandez-Lacruz, R., Di Fulvio, F. & Bergström, D. (2013). Productivity and profitability of harvesting power line corridors for bioenergy. *Silva Fennica*, 47. https://doi.org/10.14214/sf.904

Fernandez-Lacruz, R., Edlund, M., Bergström, D. & Lindroos, O. (2021). Productivity and profitability of harvesting overgrown roadside verges – a Swedish case study. *International Journal of Forest Engineering*, 32 (1), 19–28. https://doi.org/10.1080/14942119.2020.1822664

George, A.K., Kizha, A.R. & Kenefic, L. (2022). Timber harvesting on fragile ground and impacts of uncertainties in the operational costs. *International Journal of Forest Engineering*, 33 (1), 12–21. https://doi.org/10.1080/14942119.2022.1988432

Ghaffariyan, M. (2013). Comparing productivity-cost of roadside processing system and roadside chipping system in Western Australia. *Journal of Forest Science*, 59, 204–210. https://doi.org/10.17221/81/2012-JFS

Ghaffariyan, M., Acuna, M. & Brown, M. (2019). MACHINE PRODUCTIVITY EVALUATION FOR HARVESTERS AND FORWARDERS IN THINNING OPERATIONS IN AUSTRALIA. *Silva Balcanica*, 20, 13–25. https://doi.org/10.6084/m9.figshare.9929051

Ghaffariyan, M., Brown, M. & Spinelli, R. (2013). Evaluating Efficiency, Chip Quality and Harvesting Residues of a Chipping Operation with Flail and Chipper in Western Australia. *Croatian Journal of Forest Engineering*, 34, 189–199

Ghaffariyan, M.R., Spinelli, R., Magagnotti, N. & Brown, M. (2015). Integrated harvesting for conventional log and energy wood assortments: a case study in a pine plantation in Western Australia. *Southern Forests: a Journal of Forest Science*, 77 (4), 249–254. https://doi.org/10.2989/20702620.2015.1052946

Green, P.Q., Chung, W., Leshchinsky, B., Belart, F., Sessions, J., Fitzgerald, S.A., Wimer, J.A., Cushing, T. & Garland, J.J. (2020). Insight into the Productivity, Cost and Soil Impacts of Cable-assisted Harvester-forwarder Thinning in Western Oregon. *Forest Science*, 66 (1), 82–96. https://doi.org/10.1093/forsci/fxz049

Grönlund, Ö. & Eliasson, L. (2019). Birch shelterwood removal – harvester and forwarder time consumption, damage to understory spruce and net revenues. *International Journal of Forest Engineering*, 30 (1), 26–34. https://doi.org/10.1080/14942119.2019.1595943

Gülci, N., Yüksel, K., Gülci, S., Serin, H., Bilici, E. & Akay, A.E. (2021). Analysis of a feller-buncher productivity: a case study of whole-tree harvesting from Marmara region, Turkey. *Annals of Forest Research*, 64 (1), 99–110. https://doi.org/10.15287/afr.2020.2033

Han, H., Chung, W., She, J., Anderson, N. & Wells, L. (2018). Productivity and Costs of Two Beetle-Kill Salvage Harvesting Methods in Northern Colorado. *Forests*, 9 (9), 572. https://doi.org/10.3390/f9090572

Hiesl, P. & Benjamin, J. (2013). A multi-stem feller-buncher cycle-time model for partial harvest of small-diameter wood stands. *International Journal of Forest Engineering*, 24, 101–108. https://doi.org/10.1080/14942119.2013.841626

Hiesl, P. & Benjamin, J. (2015). Estimating Processing Times of Harvesters in Thinning Operations in Maine. *Forest Products Journal*, 65, 180–186. https://doi.org/10.13073/FPJ-D-14-00065

Hiesl, P., Benjamin, J.G. & Roth, B.E. (2015). Evaluating harvest costs and profit of commercial thinnings in softwood stands in west-central Maine: A case study. *The Forestry Chronicle*, 91 (02), 150–160. https://doi.org/10.5558/tfc2015-026

Holzleitner, F. & Kanzian, C. (2022). Integrated in-stand debarking with a harvester in cut-to-length operations – processing and extraction performance assessment. *International Journal of Forest Engineering*, 33 (1), 66–79. https://doi.org/10.1080/14942119.2021.2013049

Horvath, A.L., Matyas, K.S. & Czupy, I. (2016). The effect of independent variables of time equations at the logging with harvesters. Gendek, A. & Moskalik, T. (eds) *Proceedings of 49th International Symposium on Forestry Mechanization (FORMEC)*, Warsaw, 2016. 53–59. Warsaw Univ Life Sciences-Sggw. https://www.webofscience.com/wos/woscc/full-record/WOS:000432784600009 [2024-04-12]

Jernigan, M., Gallagher, T., Mitchell, D., Smidt, M. & Teeter, L. (2015). High Tonnage Harvesting and Skidding for Loblolly Pine Energy Plantations. *Forest Products Journal*, 66, 150902080548008. https://doi.org/10.13073/FPJ-D-14-00055

Jylhä, P. & Bergström, D. (2016). Productivity of harvesting dense birch stands for bioenergy. *Biomass and Bioenergy*, 88, 142–151. https://doi.org/10.1016/j.biombioe.2016.03.016

Kärhä, K., Anttonen, T., Poikela, A., Palander, T., Laurén, A., Peltola, H. & Nuutinen, Y. (2018a). Evaluation of Salvage Logging Productivity and Costs in Windthrown Norway Spruce-Dominated Forests. *Forests*, 9. https://doi.org/10.3390/f9050280

Kärhä, K., Poikela, A. & Palander, T. (2018b). Productivity and Costs of Harwarder Systems in Industrial Roundwood Thinning. *Croatian Journal of Forest Engineering*, 39, 23–33

Kärhä, K., Räsänen, M. & Palander, T. (2019). The Profitability of Cross-Cutting Practices in Butt-Rotten Picea abies Final-Felling Stands. *Forests*, 10 (10), 874. https://doi.org/10.3390/f10100874

Karpachev, S.P. & Bykovskiy, M.A. (2019). Simulation modelling of the felling-bunching machine logging operation with the multiple-tree accumulating head. *IOP Conference Series: Earth and Environmental Science*, 226 (1), 012021. https://doi.org/10.1088/1755-1315/226/1/012021

Kim, Y., Chung, W., Han, H. & Anderson, N.M. (2017). Effect of Downed Trees on Harvesting Productivity and Costs in Beetle-Killed Stands. *Forest Science*, 63 (6), 596–605. https://doi.org/10.5849/FS-2016-100R3

Kizha, A.R. & Han, H.-S. (2016). Processing and sorting forest residues: Cost, productivity and managerial impacts. *Biomass and Bioenergy*, 93, 97–106. https://doi.org/10.1016/j.biombioe.2016.06.021

Kormanek, M. & Baj, D. (2018). Analysis of Operation Performance in the Process of Machine Wood Harvesting with Fao Far 6840 Mini-Harvester. *Agricultural Engineering*, 22 (1), 73–82. https://doi.org/10.1515/agriceng-2018-0007

Kormanek, M. & Kępa, M. (2016). Analysis of Performance of Timber Harvesting With the Use of Highlander Harvester. *Agricultural Engineering*, 20. https://doi.org/10.1515/agriceng-2016-0045

Krč, J., Vranesis, U. & Košir, B. (2015). Comparison of mechanized and motor-manual cutting operation in mixed stands of southern Slovenia. *Sumarski List*, 139, 351–360

Labelle, E.R., Bergen, M. & Windisch, J. (2017). The effect of quality bucking and automatic bucking on harvesting productivity and product recovery in a pine-dominated stand. *European Journal of Forest Research*, 136 (4), 639–652. https://doi.org/10.1007/s10342-017-1061-4

Labelle, E.R., Breinig, L. & Sycheva, E. (2018). Exploring the Use of Harvesters in Large-Diameter Hardwood-Dominated Stands. *Forests*, 9. https://doi.org/10.3390/f9070424

Labelle, E.R. & Huss, L. (2018). Creation of value through a harvester on-board bucking optimization system operated in a spruce stand. *Silva Fennica*, 52. https://doi.org/10.14214/sf.9947

Labelle, E.R., Soucy, M., Cyr, A. & Pelletier, G. (2016). Effect of tree form on the productivity of a cut-to-length harvester in a hardwood dominated stand. *Croatian Journal of Forest Engineering*, 37 (1), 175–183

Labelle, E.R., Windisch, J. & Gloning, P. (2019). Productivity of a single-grip harvester in a beech dominated stand: a case-study under Bavarian conditions. *Journal of Forest Research*, 24 (2), 100–106. https://doi.org/10.1080/13416979.2019.1566995

Laina, R., Tolosana, E. & Ambrosio, Y. (2013). Productivity and cost of biomass harvesting for energy production in coppice natural stands of *Quercus pyrenaica* Willd. in central Spain. *Biomass and Bioenergy*, 56, 221–229. https://doi.org/10.1016/j.biombioe.2013.04.016

Laitila, J., N Iemistö, P. & Väätäinen, K. (2016). Productivity of Multi-Tree Cutting in Thinnings and Clear Cuttings of Young Downy Birch (Betula pubescens) Dominated Stands in the Integrated Harvesting of Pulpwood and Energy Wood. *Baltic Forestry*, 22, 116–131

Laitila, J. & Väätäinen, K. (2014). The Cutting Productivity of the Excavator-based Harvester in Integrated Harvesting of Pulpwood and Energy Wood. *Baltic Forestry*, 19, 289–300

Laitila, J. & Väätäinen, K. (2020). Productivity of harvesting and clearing of brushwood alongside forest roads. *Silva Fennica*, 54, 21. https://doi.org/10.14214/sf.10379

Laitila, J. & Väätäinen, K. (2021). Productivity and cost of harvesting overgrowth brushwood from roadsides and field edges. *International Journal of Forest Engineering*, 32 (2), 140–154. https://doi.org/10.1080/14942119.2021.1903790

Laitila, J. & Väätäinen, K. (2023). The productivity and cost of harvesting whole trees from early thinnings with a felling head designed for continuous cutting and accumulation. *International Journal of Forest Engineering*, 34 (1), 76–89. https://doi.org/10.1080/14942119.2022.2094192

Laitila, J., Väätäinen, K. & Antti, A. (2013). Comparison of two harvesting methods for complete tree removal on tree stands on drained peatlands. *Suo*, 64, 77–95

Laitila, J., Väätäinen, K. & Kilpeläinen, H. (2020). Integrated harvesting of industrial roundwood and energy wood from clearcutting of a Scots pine-dominated peatland forest. *International Journal of Forest Engineering*, 31 (1), 19–28. https://doi.org/10.1080/14942119.2020.1672462

Lazdiņš, A., Iecelnieks, E., Zimelis, A. & Spalva, G. (2019). Evaluation of Work Methods for Production of Solid Biofuel from Harvesting Residues in Commercial Thinning of Coniferous Forests. Malinovska, L. & Osadcuks, V. (eds) *Proceedings of 18th International Scientific Conference on Engineering for Rural Development (ERD)*, Jelgava, 2019. 1546–1551. Latvia Univ Agriculture, Faculty Engineering, Inst Mechanics. https://doi.org/10.22616/ERDev2019.18.N457

Lazdiņš, A., Kaleja, S. & Zimelis, A. (2014). Factors Affecting Productivity and Cost of Solid Biofuel in Mechanized Forest Ditch Cleaning. Treija, S. & Skujeniece, S. (eds) *Proceedings of 20th Annual International Scientific Conference on Research for Rural Development*, Jelgava, 2014. 90–96. Latvia Univ Life Sciences & Technologies. https://www.webofscience.com/wos/alldb/full-record/WOS:000378846800013 [2024-05-20]

Lazdiņš, A., Kaleja, S., Zimelis, A., Spalva, G. & Bardulis, A. (2021). PRODUCTIVITY AND CARBON DIOXIDE (CO_2) EMISSIONS OF COMPACT CLASS VIMEK 404 T5 HARVESTER IN THINNING OF YOUNG BIRCH STANDS IN AFFORESTED CROPLAND. Malinovska, L. & Osadcuks, V. (eds) *Proceedings of 20th International Scientific Conference on Engineering for Rural Development*, Jelgava, 2021. 780–785. Latvia Univ Agriculture, Faculty Engineering, Inst Mechanics. https://doi.org/10.22616/ERDev.2021.20.TF173

Lazdiņš, A., Prindulis, U., Kaleja, S., Daugaviete, M. & Zimelis, A. (2016). Productivity of Vimek 404 T5 harvester and Vimek 610 forwarder in early thinning. *Agronomy Research*, 14 (2), 475–484

Leszczyński, K., Stańczykiewicz, A., Kulak, D., Szewczyk, G. & Tylek, P. (2021). Estimation of Productivity and Costs of Using a Track Mini-Harvester with a Stroke Head for the First Commercial Thinning of a Scots Pine Stand. *Forests*, 12 (7), 870. https://doi.org/10.3390/f12070870

Liski, E., Jounela, P., Korpunen, H., Sosa, A., Lindroos, O. & Jylhä, P. (2020). Modeling the productivity of mechanized CTL harvesting with statistical machine learning methods. *International Journal of Forest Engineering*, 31 (3), 253–262. https://doi.org/10.1080/14942119.2020.1820750

Louis, L.T. & Kizha, A.R. (2021). Wood biomass recovery cost under different harvesting methods and market conditions. *International Journal of Forest Engineering*, 32 (2), 164–173. https://doi.org/10.1080/14942119.2021.1874206

Magagnotti, N., Spinelli, R., Kärhä, K. & Mederski, P.S. (2021). Multi-tree cut-to-length harvesting of short-rotation poplar plantations. *European Journal of Forest Research*, 140 (2), 345–354. https://doi.org/10.1007/s10342-020-01335-y

Manner, J., Karlsen, T. & Ersson, B.T. (2023). A pilot study of Continuous Cover Forestry in boreal forests: Decreasing the harvest intensity during selection cutting increases piece size, which in turn increases harvester productivity. *Journal of Forest Science*, 69 (4), 172–177. https://doi.org/10.17221/22/2023-JFS

Mcewan, A., Magagnotti, N. & Spinelli, R. (2016). The effects of number of stems per stool on cutting productivity in coppiced Eucalyptus plantations. *Silva Fennica*, 50. https://doi.org/10.14214/sf.1448

Mederski, P., Bembenek, M., Karaszewski, Z., Łacka, A., Szczepańska-Álvarez, A. & Rosińska, M. (2016). Estimating and Modelling Harvester Productivity in Pine Stands of Different Ages, Densities and Thinning Intensities. *Croatian Journal of Forest Engineering*, 37, 27–36

Norihiro, J., Ackerman, P., Spong, B. & Längin, D. (2018). Productivity Model for Cut-to-Length Harvester Operation in South African Eucalyptus Pulpwood Plantations. *Croatian Journal of Forest Engineering*, 39, 1–13

Nuutinen, Y. & Björheden, R. (2016). Productivity and work processes of small-tree bundler Fixteri FX15a in energy wood harvesting from early pine dominated thinnings. *International Journal of Forest Engineering*, 27 (1), 29–42. https://doi.org/10.1080/14942119.2015.1109175

Olivera, A., Visser, R., Acuna, M. & Morgenroth, J. (2016). Automatic GNSS-enabled harvester data collection as a tool to evaluate factors affecting harvester productivity in a Eucalyptus spp. harvesting operation in Uruguay. *International Journal of Forest Engineering*, 27 (1), 15–28. https://doi.org/10.1080/14942119.2015.1099775

Petitmermet, J., Sessions, J., Bailey, J. & Zamora-Cristales, R. (2019). Cost and Productivity of Tethered Cut-to-Length Systems in a Dry-Forest Fuel-Reduction Treatment: A Case Study. *Forest Science*, 65 (5), 581–592. https://doi.org/10.1093/forsci/fxz010

Petty, A. & Kärhä, K. (2014). Productivity and cost evaluations of energy-wood and pulpwood harvesting systems in first thinnings. *International Journal of Forest Engineering*, 25 (1), 37–50. https://doi.org/10.1080/14942119.2014.893129

Polowy, K. & Molińska-Glura, M. (2023). Data Mining in the Analysis of Tree Harvester Performance Based on Automatically Collected Data. *Forests*, 14 (1), 165. https://doi.org/10.3390/f14010165

Prinz, R., Väätäinen, K. & Routa, J. (2021). Cutting duration and performance parameters of a harvester's sawing unit under real working conditions. *European Journal of Forest Research*, 140 (1), 147–157. https://doi.org/10.1007/s10342-020-01320-5

Ramantswana, M., McEwan, A. & Steenkamp, J. (2013). A comparison between excavator-based harvester productivity in coppiced and planted Eucalyptus grandis compartments in KwaZulu-Natal, South Africa. *Southern Forests: a Journal of Forest Science*, 75 (4), 239–246. https://doi.org/10.2989/20702620.2013.858213

Rosińska, M., Bembenek, M., Picchio, R., Karaszewski, Z., Duka, A. & Mederski, P. (2022). Determining Harvester Productivity Curves of Thinning Operations in Birch Stands of Central Europe. *Croatian journal of forest engineering*, 43. https://doi.org/10.5552/crojfe.2022.1691

Santos, D., Valente, D., Carlos, F., Furtado Júnior, M. & Santos, L. (2022). MODELING TECHNICAL, ECONOMIC AND ENVIRONMENTAL PARAMETERS OF FOREST MACHINES ACCORDING TO THE VOLUME OF THE TREES. *FLORESTA*, 52, 261. https://doi.org/10.5380/rf.v52i2.76192

Santos, D.W.F. do N., Junior, M.R.F., Dadalto, J.P., Santos, L.N. do & Leite, D.M. (2021). Modeling of technical, economic, environmental and ergonomic parameters of forestry machines in function of the quantity of days of the working scale. *Revista Engenharia na Agricultura - REVENG*, 29 (Contínua), 41–48. https://doi.org/10.13083/reveng.v29i1.11172

Santos, D.W.F.D.N., Valente, D.S.M., Fernandes, H.C., De Souza, A.P. & Cecon, P.R. (2020). Technical, Economic, and Environmental Parameters of Excavator-Based Harvester in Function of Engine Speed and Hydraulic Pump Flow. *Croatian journal of forest engineering*, 41 (2), 205–218. https://doi.org/10.5552/crojfe.2020.761

Schweier, J., Spinelli, R., Magagnotti, N. & Becker, G. (2015). Mechanized coppice harvesting with new small-scale feller-bunchers: Results from harvesting trials with newly manufactured felling heads in Italy. *Biomass and Bioenergy*, 72, 85–94. https://doi.org/10.1016/j.biombioe.2014.11.013

Slugeň, J., Peniaško, P., Messingerová, V. & Jankovský, M. (2014). Productivity of a John Deere Harvester Unit in Deciduous Stands. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 62 (1), 231–238. https://doi.org/10.11118/actaun201462010231

Soman, H., Kizha, A.R., Muñoz Delgado, B., Kenefic, L.S. & Kanoti, K. (2020). Production economics: comparing hybrid tree-length with whole-tree harvesting methods. *Forestry: An International Journal of Forest Research*, 93 (3), 389–400. https://doi.org/10.1093/forestry/cpz065

Soman, H., Kizha, A.R. & Roth, B.E. (2019). Impacts of silvicultural prescriptions and implementation of best management practices on timber harvesting costs. *International Journal of Forest Engineering*, 30 (1), 14–25. https://doi.org/10.1080/14942119.2019.1562691

Sperandio, G., Acampora, A., Del Giudice, A. & Civitarese, V. (2021). Models for the Evaluation of Productivity and Costs of Mechanized Felling on Poplar Short Rotation Coppice in Italy. *Forests*, 12 (7), 954. https://doi.org/10.3390/f12070954

Spinelli, R., Brown, M., Giles, R., Huxtable, D., Relaño, R.L. & Magagnotti, N. (2014). Harvesting alternatives for mallee agroforestry plantations in Western Australia. *Agroforestry Systems*, 88 (3), 479–487. https://doi.org/10.1007/s10457-014-9707-4

Spinelli, R. & De Arruda Moura, A.C. (2019). Decreasing the Fuel Consumption and CO2 Emissions of Excavator-Based Harvesters with a Machine Control System. *Forests*, 10 (1), 43. https://doi.org/10.3390/f10010043

Spinelli, R., Magagnotti, N., De Francesco, F., Kováč, B., Heger, P., Heilig, D., Heil, B., Kovács, G. & Zemánek, T. (2022). Cut-to-Length Harvesting Options for the Integrated Harvesting of the European Industrial Poplar Plantations. *Forests*, 13 (9), 1478. https://doi.org/10.3390/f13091478

Spinelli, R., Magagnotti, N., Kovacs, B., Heger, P. & Mihelic, M. (2023). Productivity and cost assessment of two harvesting methods for medium-rotation poplar plantations. *Scandinavian Journal of Forest Research*, 38 (1–2), 79–86. https://doi.org/10.1080/02827581.2023.2177336

Spinelli, R., Magagnotti, N. & Labelle, E.R. (2020a). The Effect of New Silvicultural Trends on Mental Workload of Harvester Operators. *Croatian journal of forest engineering*, 41. https://doi.org/10.5552/crojfe.2020.747

Spinelli, R., Magagnotti, N. & Lombardini, C. (2020b). Low-Investment Fully Mechanized Harvesting of Short-Rotation Poplar (populus spp.) Plantations. *Forests*, 11 (5), 502. https://doi.org/10.3390/f11050502

Stoilov, S., Angelov, G., Aladzhov, S. & Nichev, P. (2021). PRODUCTIVITY MODELS AND COSTS OF COMBINED SKIDDER -HARVESTER IN CONIFEROUS FORESTS. *FORESTRY IDEAS*, 27, 169–181

Strandgard, M. & Mitchell, R. (2018). Impact of number of stems per stool on mechanical harvesting of a Eucalyptus globulus coppiced plantation in south-west Western Australia. *Southern Forests: a Journal of Forest Science*, 80 (2), 137–142. https://doi.org/10.2989/20702620.2017.1292448

Strandgard, M. & Mitchell, R. (2019). Comparison of cost, productivity and residue yield of cut-to-length and fuel-adapted harvesting in a Pinus radiata D.Don final harvest in Western Australia. *New Zealand Journal of Forestry Science*, 49. https://doi.org/10.33494/nzjfs492019x37x

Strandgard, M. & Mitchell, R. (2020). Comparison of the productivity, cost and stem breakage of two- and three-machine harvest systems clearfelling a mature Pinus radiata stand. *Australian Forestry*, 83 (2), 91–98. https://doi.org/10.1080/00049158.2020.1775379

Strandgard, M., Mitchell, R. & Acuna, M. (2016). General productivity model for single grip harvesters in Australian eucalypt plantations. *Australian Forestry*, 79 (2), 108–113. https://doi.org/10.1080/00049158.2015.1127198

Strandgard, M., Walsh, D. & Mitchell, R. (2015). Productivity and Cost of Whole-tree Harvesting without Debarking in a Eucalyptus nitens plantation in Tasmania, Australia. *Southern Forests: a Journal of Forest Science*, 77, 173–178. https://doi.org/10.2989/20702620.2014.1001669

Tajbos, J. & Messingerova, V. (2014). Production rate and economic efficiency of mid-class harvesters in thinnings of mountainous terrains of Central Slovakia. *Electronic Journal of Polish Agricultural Universities. Series: Forestry*, 17 (2). http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.agro-81d69467-ca2b-41d5-8f04-7bb0969394a8 [2024-04-12]

Tolosana, E., Laina, R. & González-Prieto, Ó. (2023). Biomass Harvesting from Salvage Clearcuts on Young Eucalypt Stands and Post-Wildfire Pine Thinnings with Fixteri FX15a Feller-Bundler in Spain. *Forests*, 14 (9), 1821. https://doi.org/10.3390/f14091821

Tolosana, E., Spinelli, R., Aminti, G., Laina, R. & López-Vicens, I. (2018). Productivity, efficiency and environmental effects of whole-tree harvesting in Spanish coppice stands using a drive-to-tree disc saw Feller-Buncher. *Croatian Journal of Forest Engineering*, 39 (2), 163–172

Townsend, L., Dodson, E., Anderson, N., Worley-Hood, G. & Goodburn, J. (2019). Harvesting forest biomass in the US southern Rocky Mountains: cost and production rates of five ground-based forest operations. *International Journal of Forest Engineering*, 30 (2), 163–172. https://doi.org/10.1080/14942119.2018.1563851

Walsh, D. & Strandgard, M. (2014). Productivity and cost of harvesting a stemwood biomass product from integrated cut-to-length harvest operations in Australian *Pinus radiata* plantations. *Biomass and Bioenergy*, 66, 93–102. https://doi.org/10.1016/j.biombioe.2014.01.017

Walsh, D., Strandgard, M. & Carter, P. (2014). Evaluation of the Hitman PH330 acoustic assessment system for harvesters. *Scandinavian Journal of Forest Research*, 29 (6), 593–602. https://doi.org/10.1080/02827581.2014.953198

Williams, C. & Ackerman, P. (2016). Cost-productivity analysis of South African pine sawtimber mechanised cut-to-length harvesting. *Southern Forests: a Journal of Forest Science*, 78 (4), 267–274. https://doi.org/10.2989/20702620.2016.1183096

Zimelis, A., Kaleja, S. & Ariko, S. (2020). EVALUATION OF PRODUCTIVITY AND COSTS OF MALWA FOREST MACHINE IN SANITARY FELLINGS IN

LATVIA. *Proceedings of Research for Rural Development*, 2020. 61–65. https://doi.org/10.22616/rrd.26.2020.009

Zimelis, A., Kaleja, S. & Luguza, S. (2018). Factors affecting productivity of machined logging in thinning using small size forest machines. *Proceedings of Research for Rural Development*, 2018. 47–52. https://doi.org/10.22616/rrd.24.2018.007

Zimelis, A., Kaleja, S. & Okmanis, M. (2019). Complex forest management system based on small size forest machines. *Proceedings of Engineering for Rural Development*, 2019. 475–480. https://doi.org/10.22616/ERDev2019.18.N021

Zimelis, A., Kaleja, S., Spalva, G. & Lazdins, A. (2017a). Impact of feed rollers on productivity and fuel consumption. *Proceedings of Engineering for Rural Development*, 2017. 756–760. https://doi.org/10.22616/ERDev2017.16.N152

Zimelis, A., Lazdin¸š, A. & Spalva, G. (2017b). Comparison of productivity of vimek harvester in birch plantation and young coniferous stands. *Proceedings of Research for Rural Development*, 2017. 107–112. https://doi.org/10.22616/rrd.23.2017.016

Zimelis, A. & Spalva, G. (2022). PRODUCTIVITY AND GHG BALANCE OF HARVESTING AND FORWARDING IN THINNING OF ASPEN HYBRID PLANTATIONS. *Proceedings of Engineering for Rural Development*, 2022. 537–542. https://doi.org/10.22616/ERDev.2022.21.TF181

Zimelis, A., Spalva, G., Saule, G., Daugaviete, M. & Lazdiņš, A. (2016). Productivity and cost of biofuel in ditch cleaning operations using tracked excavator based harvester. *Agronomy Research*, 14 (2), 579–589

Appendix 2. Information regarding the included publications

Information regarding the publications included in the review. TOWS = type of work study.

Author(s)	Note	Publ. Type	Continent	Country	TOWS	Equipment for manual data collection
Ackerman et al. (2018)		Article	Africa	South Africa	Time study	Trimble Geo-Xm Handheld Pc
Ackerman et al. (2021)		Article	Africa	South Africa	Follow-up study	-
Ackerman et al. (2022)		Article	Africa	South Africa	Time study	Purpose-Built Time Study App (Forest Operations Time Study)
Acosta et al. (2021)		Article	South America	Brazil	Time study	2 Stopwatches
Acuna et al. (2017)		Article	Australia	Australia	Time study	Hanhart 2656 1/100 Minute Digital Stopwatch, Digital Video Recorder, Camera
Alam et al. (2014)		Article	Australia	Australia	Time study	Digital Video Camera
Apăfăian et al. (2017)		Article	Europe	Romania	Time study	Traveler Dc-12 Digital Video Camera
Berendt et al. (2020)		Article	Europe	Germany	Time study	Digital Stopwatch
Berg et al. (2014)		Article	Europe	Sweden	Simulation	-
Bergström & Di Fulvio (2014)		Article	Europe	Sweden	Time study	Allegro Field Pc
Bergström et al. (2016)		Article	Europe	Sweden	Time study	Allegro Field Pc
Bergström et al. (2022)		Article	Europe	Sweden, Finland, Slovenia	Time study	Sony X1000Vr Camera, Sony Fdr-X3000R Camera Allegro Field Pc, Trimble Nomad 900 Handheld Pc
Bilici et al. (2019)		Article	Asia	Turkey	Time study	Chronometer
Brewer et al. (2018)		Article	Africa	South Africa	Time study, Follow-up study	Android Application (Time Study App)
Brown et al. (2013)		Article	Australia	Australia	Time study	Digital Video Camera
Carter et al. (2017)		Article	North America	United States	Time study	Centi-Minute Flyback Stopwatch
Chakroun et al. (2016)		Article	Europe	France	Time study	Panasonic Toughbook Cf-U1 Rugged Ultra-Mobile Handheld Pc
Chung et al. (2022)		Article	North America	United States	Time study	Stopwatches, Video Recorder

Di Fulvio & Bergström (2013)		Article	Europe	Sweden	Time study	Allegro Field Pc
Erber et al. (2016)		Article	Europe	Austria	Time study	Algiz 7 Handheld Pc, Video Documentation Device
Eriksson & Lindroos (2014)		Article	Europe	Sweden	Follow-up study	-
Fernandez-Lacruz et al. (2013)		Article	Europe	Sweden	Time study	Allegro Handheld Pc, Chronometer
Fernandez-Lacruz et al. (2021)		Article	Europe	Sweden	Time study	Husky Hunter Fs3 Handheld Pc
George et al. (2022)		Article	North America	United States	Time study	-
Ghaffariyan (2013)		Article	Australia	Australia	Time study	-
Ghaffariyan et al. (2019)	*Used several time studies to create the model	Article	Australia	Australia	*Time study	-
Ghaffariyan et al. (2013)		Article	Australia	Australia	Time study	-
Ghaffariyan et al. (2015)		Article	Australia	Australia	Time study	Handheld Pcs
Green et al. (2020)		Article	North America	United States	Time study	Video Cameras, Manual Stopwatch
Grönlund & Eliasson (2019)		Article	Europe	Sweden	Time study	Allegro Handheld Pc
Gülci et al. (2021)		Article	Asia	Turkey	Time study	Selex 7064 Chronometers
Han et al. (2018)		Article	North America	United States	Time study	Stopwatches
Hiesl & Benjamin (2013)		Article	North America	United States	Time study	Palm Tungsten E2 Handheld Pc
Hiesl & Benjamin (2015)		Article	North America	United States	Time study	Palm Tungsten E2 Handheld Pc
Hiesl et al. (2015)	*The operator maintained a record of harvesting time	Article	North America	United States	*	-
Holzleitner & Kanzian (2022)		Article	Europe	Austria	Time study	Video Cameras
Horváth et al. (2016)		Proceedings Paper	Europe	Hungary	Time study	Stopwatch, Field Data Minute-Book And Measuring Tape
Jernigan et al. (2015)		Article	Europe	United States	Time study	Stopwatch, Video Recorder, Multidat Field Recorder
Jylhä & Bergström (2016)		Article	Europe	Finland	Time study	Digital Video Camera
Kärhä et al. (2018a)		Article	Europe	Finland	Time study	Sony Hdr-Cx220E Camera
Kärhä et al. (2018b)		Article	Europe	Finland	Follow-up study	-
Kärhä et al. (2019)		Article	Europe	Finland	Time study	Gopro Hero Chdha-30 Camera
Karpachev & Bykovskiy (2019)		Proceedings Paper	Europe/Asia	Russia	Simulation	-
Kim et al. (2017)		Article	North America	United States	Time study	-
Kizha & Han (2016)		Article	North America	United States	Time study	Stopwatch
Kormanek & Baj (2018)		Article	Europe	Poland	Time study	Stopwatch, Sony Ccd Tr600 Camera
Kormanek & Kępa (2016)		Article	Europe	Poland	Time study	Stopwatch, Jvc Gz-Mg Camera
Krč et al. (2015)		Article	Europe	Slovenia	Time study	Handheld Pc

Labelle et al. (2017)	Article	Europe	Germany	Time study	Handheld Pc, Video Camera
Labelle et al. (2018)	Article	Europe	Germany	Time study	Juniper Allegro Handheld Pc, Video Camera
Labelle & Huß (2018)	Article	Europe	Germany	Time study	Digital Video Camera
Labelle et al. (2016)	Article	North America	Canada	Time study	Digital Video Camera
Labelle et al. (2019)	Article	Europe	Germany	Time study	Handheld Pc
Laina et al. (2013)	Article	Europe	Spain	Time study	Psion Workabout Handheld Pc
Laitila et al. (2016)	Article	Europe	Finland	Time study	Rufco-900 Handheld Pc
Laitila & Väätäinen (2014)	Article	Europe	Finland	Time study	Rufco-900 Handheld Pc
Laitila & Väätäinen (2020)	Article	Europe	Finland	Time study	Rufco-900 Handheld Pc
Laitila & Väätäinen (2021)	Article	Europe	Finland	Time study	Rufco-900 Handheld Pc
Laitila & Väätäinen (2023)	Article	Europe	Finland	Time study	Gopro 7 Camera, Rufco-900 Handheld Pc
Laitila et al. (2013)	Article	Europe	Finland	Time study	Rufco-900 Handheld Pc
Laitila et al. (2020)	Article	Europe	Finland	Time study	Gopro 6 Camera, Handheld Pc
Lazdiņš et al. (2019)	Proceedings Paper	Europe	Latvia	Time study	-
Lazdiņš (2014)	Conference paper	Europe	Latvia	Time study	-
Lazdiņš et al. (2021)	Proceedings Paper	Europe	Latvia	Time study	Hand-Held Data Logger
Lazdiņš et al. (2016)	Article	Europe	Sweden	Time study	Allegro Cx Handheld Pc
Leszczyński et al. (2021)	Article	Europe	Poland	Time study	Psion Workabout Data Recorder
Liski et al. (2020)	Article	Europe	Finland	Follow-up study	-
Louis & Kizha (2021)	Article	North America	United States	Time study	Analog Stopwatch
Magagnotti et al. (2021)	Article	Europe	Poland	Time study	-
Manner et al. (2023)	Article	Europe	Sweden	Time study	Stopwatch
McEwan et al. (2016)	Article	Africa	South Africa	Time study	Husky Hunter Handheld Pcs
Mederski et al. (2016)	Article	Europe	Poland	Time study	-
Norihiro et al. (2018)	Article	Africa	South Africa	Time study	Trimble Geoxt Handheld Pc
Nuutinen & Björheden (2016)	Article	Europe	Finland	Time study	Rufco Dl 2 Handheld Pc
Olivera et al. (2016)	Article	South America	Uruguay	Follow-up study	-
Petitmermet et al. (2019)	Article	North America	United States	Time study	Gopro Hero Silver 4 Cameras
Petty & Kärhä (2014)	Article	Europe	Finland	Time study	-
Polowy & Molińska-Glura (2023)	Article	Europe	Poland	Follow-up study	-
Prinz et al. (2021)	Article	Europe	Finland	Time study	Datalogger, Digital Video Camera
Ramantswana et al. (2013)	Article	Africa	South Africa	Time study	Trimble Nomad 900 Handheld Pc

Rosińska et al. (2022)	Article	Europe	Poland	Time study	-
Santos et al. (2022)	Article	South America	Brazil	-	-
Santos et al. (2021)	Article	South America	Brazil	Time study	-
Santos et al. (2020)	Article	South America	Brazil	Time study	Video Cameras, Mobile Digital Video Recorder
Schweier et al. (2015)	Article	Europe	Italy	Time study	Husky Hunter Handheld PC
Slugeň et al. (2014)	Article	Europe	Slovakia	Time study	Digital Video Camera
Soman et al. (2020)	Article	North America	United States	Time study	-
Soman et al. (2019)	Article	North America	United States	Time study	-
Sperandio et al. (2021)	Article	Europe	Italy	Time study	Minerva Chronometric Table
Spinelli et al. (2014)	Article	Australia	Australia	Time study	-
Spinelli & De Arruda Moura (2019)	Article	South America	Brazil	Follow-up study	-
Spinelli et al. (2022)	Article	Europe	Slovakia	Time study	Stopwatch, Camera
Spinelli et al. (2023)	Article	Europe	Slovakia	Time study	Stopwatches
Spinelli et al. (2020a)	Article	Europe	Italy	Simulation	-
Spinelli et al. (2020b)	Article	Europe	Italy	Time study	Stopwatches, Handheld Pcs
Stoilov et al. (2021)	Article	Europe	Bulgaria	Time study	Stopwatch
Strandgard & Mitchell (2018)	Article	Australia	Australia	Time study	Camera
Strandgard & Mitchell (2019)	Article	Australia	Australia	Time study	Tablet
Strandgard & Mitchell (2020)	Article	Australia	Australia	Time study	Juniper Archer Pda Handheld Pc
Strandgard et al. (2016)	Article	Australia	Australia	Time study	-
Strandgard et al. (2015)	Article	Australia	Australia	Time study	Digital Video Camera
Tajbos & Messingerova (2014)	Article	Europe	Slovakia	Time study	-
Tolosana et al. (2023)	Article	Europe	Spain	Time study	-
Tolosana et al. (2018)	Article	Europe	Spain	Time study	Husky Hunter Handheld Pc
Townsend et al. (2019)	Article	North America	United States	Time study	-
Walsh & Strandgard (2014)	Article	Australia	Australia	Time study	Camera
Walsh et al. (2014)	Article	Australia	Australia	Time study	Camera
Williams & Ackerman (2016)	Article	Africa	South Africa	Time study	Trimble Geoxm Handheld Pc, Camera
Zimelis et al. (2020)	Conference Paper	Europe	Latvia	Time study	-
Zimelis et al. (2018)	Proceedings paper	Europe	Latvia	Time study	Allegro II Handheld Pc
Zimelis et al. (2019)	Proceedings paper	Europe	Latvia	Time study	Allegro Cx Handheld Pc

Zimelis et al. (2017a)	Proceedings paper	Europe	Latvia	Time study	Allegro Field Computer Handheld Pc
Zimelis et al. (2017b)	Proceedings Paper	Europe	Latvia	Time study	Field Computer Allegro II Handheld Pc
Zimelis & Spalva (2022)	Conference paper	Europe	Latvia	-	-
Zimelis et al. (2016)	Article	Europe	Latvia	Time study	Allegro Cx Handheld Pc

Appendix 3. Countries in each European region

Northern Europe	**Southern Europe**	**Western Europe**	**Eastern Europe**
Finland	Italy	Austria	Bulgaria
Latvia	Slovenia	France	Hungary
Sweden	Spain	Germany	Poland
			Romania
			Russia
			Slovakia

Appendix 4. Machines and forest operations

Machines and their characteristics, time the machines were recorded, and type of harvest operation. N = number of machines; HM = harvesting method, CTL = cut-to-length, FT = full-tree, B (FT) = feller-buncher producing bundles; M = machine type, H = harvester, H Sim = harvester simulation, FB = feller-buncher (swing-boom), FB DT = drive-to-tree feller-buncher, FB Sim = feller-buncher simulation, HW = harwarder, SH = skidder-harvester; BM = base machine, EB = excavator-based, PB = purpose-built; Pr = Propulsion type, CT = continuous tracks, RW = rubber wheels; Deb = debarking; MTC = multi tree cutting. In the time recorded colum: P = time without delays, T = total time.

Authors	Note	N	HM	M	BM	Pr	Machine Model	Head Model	Deb	MTC	Time recorded	Operation
Ackerman et al. (2018)		-	CTL	H	EB	CT	Volvo EC-210-BF	Maskiner SP-591LX	Yes	No	P-323.08 min	Thinning
		-	CTL	H	PB	CT	TimberPro TL-725B	Maskiner SP-591LX	Yes	No	P-240.35 min	Thinning
Ackerman et al. (2021)		2	CTL	H	PB	RW	Ponsse Bear	Ponsse H8	No	-	12 months	Clearcutting
		2	CTL	H	PB	RW	Ponsse Beaver	Ponsse H6	No	-	12 months	Clearcutting
Ackerman et al. (2022)		-	CTL	HW	PB	RW	Malwa 560C	Log Max 928A	No	No	-	First Thinning From Below
Acosta et al. (2021)		-	CTL	H	EB	CT	CAT 315D	Log Max 5000	No	No	P-6.408 hours	Third Thinning
Acuna et al. (2017)		-	CTL	H	EB	CT	CAT 322L	Waratah HTH620	Yes	No	-	Final Felling
Alam et al. (2014)		-	CTL	H	PB	CT	Valmet 475EX	Rosin 997 (2006 model, no. 5)	No	No	-	Clearcutting
		-	CTL	H	PB	CT	Valmet 475EX	Rosin 997 (2006 model, no. 2)	No	No	-	Clearcutting
Apăfăian et al. (2017)		-	CTL	H	PB	RW	Valmet 911.4	Valmet 360.2	No	No	P-14.134 hours	Clearcutting
Berendt et al. (2020)		-	CTL	H	PB	RW	405FH4 8WD	Waratah H415	No	No	P-912.4 min	Thinning
Berg et al. (2014)	*Whole tree is uprooted	-	CTL	H Sim	PB	RW	-	John Deere H480C	No	No	-	Clearcutting
		-	*FT	FB Sim	PB	RW	Timberpro TB830-B	-	No	No	-	Clearcutting
Bergström & Di Fulvio (2014)		-	CTL	H	PB	RW	Ecolog 560 D	MAMA	No	Yes	P-12.3 hours	Thinning From Below
		-	FT	FB	PB	RW	Ecolog 560 D	C16	No	Yes	P-6.3 hours	Thinning From Below
Bergström et al. (2016)		-	B (FT)	FB	PB	RW	Logman 811 FC	Nisula 280E+	No	Yes	P-26.76 hours	Selective Thinning From Below

Bergström et al. (2022)	*Trees could be cut in multiple parts	-	*FT	FB	PB	RW	Valmet 901.4	Bracke C16.c	No	Yes	P-56.07 hours	Selective Thinning From Below, Boom-Corridor Thinning
Bilici et al. (2019)	*Taller trees cut in two parts	-	*FT/FT	FB	EB	CT	-	Westtech Woodcracker C450	No	No	-	Clearcutting
Brewer et al. (2018)		2	CTL	H	PB	RW	Ponsse Bear	H8	No	No	-	Clearcutting
		2	CTL	H	PB	RW	Ponsse Beaver	H6	No	No	-	Clearcutting
Brown et al. (2013)		-	FT	FB	PB	CT	Valmet 475EXL	Quadco hotsaw	No	No	-	Clearcutting
Carter et al. (2017)		-	FT	FB	PB	CT	John Deere 653G	-	No	Yes	P-14.4 hours	Clearcutting
Chakroun et al. (2016)	*Trees could be cut in two parts	-	*FT	FB	EB	CT	Doosan 140 lcr	Jacquier C360, Sève S350	No	Yes	-	Includes Coppice, Clearcutting And Thinning
Chung et al. (2022)		-	FT	FB	PB	CT	Tigercat LS855E	-	No	No	P-3.8 hours	Clearcutting
Di Fulvio & Bergström (2013)	The same machine but with two different processing heads	-	CTL	HW	PB	RW	Ponsse Dual	Ponsse H53e	No	Yes	T-23.9 hours	Thinning From Below
		-	CTL	HW	PB	RW	Ponsse Dual	Ponsse EH25	No	Yes	-	Thinning From Below
Erber et al. (2016)		-	CTL	H	PB	RW	Komatsu 911	Naarva EF 28	No	Yes	T-7.1 hours	Undergrowth Removal
Eriksson & Lindroos (2014)	*Examples of machine models used	>700	CTL	H	PB	RW	Valmet 901	-	No	-	T-3 years	Thinning (Cutting Strips Or Ghost Trails)
		-	CTL	H	PB	RW	Komatsu 901	-	No	-	T-3 years	Thinning (Cutting Strips Or Ghost Trails)
		-	CTL	H	PB	RW	John Deere 1070	-	No	-	T-3 years	Thinning (Cutting Strips Or Ghost Trails)
		-	CTL	H	PB	RW	Valmet 911	-	No	-	T-3 years	Clearcutting (With And Without Seed Trees)
		-	CTL	H	PB	RW	John Deere 1270	-	No	-	T-3 years	Clearcutting (With And Without Seed Trees)
Fernandez-Lacruz et al. (2013)		-	FT	FB	PB	RW	Skogsjan 495	Bracke C16.b	No	Yes	P-14.34 hours	Powerline Corridor Clearing
Fernandez-Lacruz et al. (2021)	*Taller trees were bucked	-	*FT	FB	PB	RW	Rottne H8	AFH Naarva-Grip 1500-25EH	No	Yes	P-2.51 hours	Roadside Verge Clearing/Harvesting
George et al. (2022)		-	CTL	H	PB	RW	Ponsse Scorpion King	-	No	No	-	Shelterwood Harvest
		-	CTL	H	PB	RW	John Deere 1270 G	-	No	No	-	Shelterwood Harvest
Ghaffariyan (2013)		-	FT	FB	PB	CT	Tigercat 511C	-	No	No	-	Clearcutting
		-	FT	FB	PB	CT	Tigercat 822C	-	No	No	-	Clearcutting
Ghaffariyan et al. (2019)		-	CTL	H	-	-	-	-	-	-	-	Thinning
Ghaffariyan et al. (2013)		-	FT	FB	PB	CT	Tigercat 845C	Tigercat 2001	No	No	-	Clearcutting
Ghaffariyan et al. (2015)		-	CTL	H	PB	CT	CAT 541	Rosin RD977	No	No	-	Clearcutting
Green et al. (2020)		-	CTL	H	PB	RW	Ponsse Bear	-	No	No	-	Thinning
Grönlund & Eliasson (2019)		-	CTL	H	PB	RW	Valmet 901.4	SP 250	No	Yes	-	Shelterwood Harvest

	-	CTL	H	PB	RW	John Deere 1070	H754	No	Yes	-	Shelterwood Harvest
	-	CTL	H	PB	RW	Gremo 1050h	SP 561	No	Yes	-	Shelterwood Harvest
Gülci et al. (2021)	-	FT	FB	EB	CT	-	Wood Cracker C450	No	No	-	Clearcutting
Han et al. (2018)	-	FT	FB	PB	CT	TimberPro TL735 B	-	No	-	-	Clearcutting/Salvage Harvesting
Hiesl & Benjamin (2013)	6	FT	FB	PB	CT	-	-	No	Yes	-	Partial Harvest
Hiesl & Benjamin (2015)	-	CTL	H	PB	RW	Ponsse Ergo	-	No	No	-	Thinning
	-	CTL	H	PB	RW	Timberjack 1270 D	-	No	No	-	Thinning
	-	CTL	H	PB	RW	Valmet 911.4	-	No	No	-	Thinning
	-	CTL	H	PB	RW	Ponsse Fox	-	No	No	-	Thinning
Hiesl et al. (2015)	-	CTL	H	PB	RW	Ponsse Ergo	-	No	-	T-3792 min	Thinning From Below
	-	FT	FB	PB	CT	CAT 501	-	No	-	T-3876 min	Thinning From Below
Holzleitner & Kanzian (2022)	-	CTL	H	PB	RW	John Deere 1270 G	John Deere H415	Yes	No	-	Thinning
Horváth et al. (2016)	-	CTL	H	-	-	-	-	No	No	-	Unspecified Harvesting
Jernigan et al. (2015)	-	FT	FB	PB	CT	Tigercat 845D	-	No	Yes	-	Clearcutting
Jylhä & Bergström (2016)	-	FT	FB	PB	RW	Valmet 911.3	Bracke C16.b	No	Yes	-	Clearcutting
Kärhä et al. (2018a)	-	CTL	H	PB	RW	Ponsse Ergo	Ponsse H73	No	No	-	Clearcutting, Salvage Harvesting
	-	CTL	H	PB	RW	John Deere 1270D ECOIII	John Deere H414	No	No	-	Clearcutting, Salvage Harvesting
	-	CTL	H	PB	RW	Logset 8H GT	Logset TH 75X	No	No	-	Clearcutting, Salvage Harvesting
Kärhä et al. (2018b)	3	CTL	HW	PB	RW	Ponsse Wisent Dual	-	No	-	-	Clearcutting, Thinning, Other/Combined Cuttings
	2	CTL	HW	PB	RW	Valmet 801 Combi	-	No	-	-	Clearcutting, Thinning, Other/Combined Cuttings
Kärhä et al. (2019)	-	CTL	H	PB	RW	John Deere 1270G	John Deere H414	No	No	-	Final Felling
	-	CTL	H	PB	RW	Komatsu 911.5	Komatsu 365	No	No	-	Final Felling
	-	CTL	H	PB	RW	Komatsu 931.1	Komatsu 365	No	No	-	Final Felling
	-	CTL	H	PB	RW	Ponsse Ergo	Ponsse H7	No	No	-	Final Felling
Karpachev & Bykovskiy (2019)	-	FT	FB Sim	PB	RW	-	-	No	Yes	-	Unspecified Harvesting
Kim et al. (2017)	-	FT	FB	PB	CT	Tigercat LX830C	Tigercat 5702	No	Yes	-	Clearcutting/Salvage Harvesting
Kizha & Han (2016)	2	FT	FB	PB	CT	John Deere 959K	-	No	No	-	Clearcutting
Kormanek & Baj (2018)	-	CTL	H	PB	RW	Fao Far 6840	Arbo Stroke 400 S	No	No	T-6 hours	Negative Thinning
Kormanek & Kępa (2016)	-	CTL	H	PB	RW	Highlander harvester	Woody 60	No	No	T-6 hours	Unspecified Harvesting
Krč et al. (2015)	-	CTL	H	PB	RW	Timberjack 1270 D	H 754	No	No	T-13.3 hours	Thinning
Labelle et al. (2017)	-	CTL	H	EB	CT	Atlas Königstiger T23	Ponsse H6	No	No	-	Thinning
Labelle et al. (2018)	-	CTL	H	PB	RW	TimberPro TF840-B	SP Maskiner SP861LF	No	No	-	Regeneration Cut

		-	CTL	H	PB	RW	Rottne H20	Rottne EGS700	No	No	-	Regeneration Cut
		-	CTL	H	PB	CT	Impex Hannibal T50	Lako 1118	No	No	-	Regeneration Cut
		-	CTL	H	PB	CT	Impex Hannibal T40	Ponsse H8	No	No	-	Regeneration Cut
Labelle & Huß (2018)		-	CTL	H	PB	RW	Ponsse Bear	Ponsse H8	No	No	-	Regeneration Harvest
Labelle et al. (2016)		-	CTL	H	PB	CT	Landrich	Ponsse H8	No	No	P-14.1 hours	Overstory Removal
Labelle et al. (2019)		-	CTL	H	PB	RW	TimberPro 620-E	LogMax 7000C	No	No	-	Clearcutting, Selective Cutting
Laina et al. (2013)		-	FT	FB	PB	RW	Timberjack 1070	"harvesting head 745"	No	Yes	-	Includes Coppice, Thinning From Below
		-	CTL	H	PB	RW	Timberjack 1270 C	"harvesting head H270""	No	No	-	Includes Coppice, Thinning From Below
Laitila et al. (2016)		-	CTL	H	PB	RW	Komatsu 901.4	Komatsu 350.1	No	Yes	-	Clearcutting, Thinning
Laitila & Väätäinen (2014)		-	CTL	H	EB	CT	New Holland Kobelco E 135 B SR LCD	Naarva EF 28	No	Yes	-	Thinning
Laitila & Väätäinen (2020)	*Trees >8m cut in two parts	-	*FT	HW	PB	RW	Ponsse Buffalo Dual	Moipu 300 F1	No	Yes	-	Harvesting/Clearing Of Brushwood Along Roads
Laitila & Väätäinen (2021)		-	FT	FB	EB	CT	New Holland Kobelco E 200 SR	Risupeto	No	Yes	-	Harvesting Overgrowth Brushwood
Laitila & Väätäinen (2023)		-	FT	FB	EB	CT	Kobelco SK140SRL-7	Risupeto II	No	Yes	-	Selective Thinning
Laitila et al. (2013)	*In one harvesting system, the whole tree is lifted up then bucked	-	*CTL	H	PB	RW	Ponsse Cobra HS 10	Ponsse H53	No	No	-	Clearcutting
Laitila et al. (2020)		-	CTL	H	PB	RW	Komatsu 911.5	Komatsu C93	No	No	-	Clearcutting
Lazdiņš et al. (2019)		-	CTL	H	-	-	-	-	No	-	T-22.5 hours	Thinning
Lazdiņš (2014)		-	CTL	H	PB	RW	Ponsse Fox	H6	No	Yes	-	Ditch Cleaning/Harvesting
Lazdiņš et al. (2021)		-	CTL	H	PB	RW	Vimek 404 T5	Keto Forst Silver	No	-	-	Thinning
Lazdiņš et al. (2016)		-	CTL	H	PB	RW	Vimek 404T6	-	No	No	-	Precommercial Thinning
Leszczyński et al. (2021)		-	CTL	H	EB	CT	Kubota KX057-4	Arbro 400 S	No	-	-	Thinning
Liski et al. (2020)		-	CTL	H	PB	RW	Komatsu 901.4	340	No	-	-	Selective Thinning From Below, Clearcutting, Seed-Tree Cutting, Strip Harvesting
		4	CTL	H	PB	RW	John Deere 1170E	H413	No	-	-	Selective Thinning From Below, Clearcutting, Seed-Tree Cutting, Strip Harvesting
		3	CTL	H	PB	RW	John Deere 1170E	H460	No	-	-	Selective Thinning From Below, Clearcutting, Seed-Tree Cutting, Strip Harvesting
		2	CTL	H	PB	RW	John Deere 1170E	H414	No	-	-	Selective Thinning From Below, Clearcutting, Seed-Tree Cutting, Strip Harvesting

	2	CTL	H	PB	RW	Komatsu 901TX.1	350	No	-	-	Selective Thinning From Below, Clearcutting, Seed-Tree Cutting, Strip Harvesting
	3	CTL	H	PB	RW	John Deere 1270E	H414	No	-	-	Selective Thinning From Below, Clearcutting, Seed-Tree Cutting, Strip Harvesting
	-	CTL	H	PB	RW	John Deere 1270E	H415	No	-	-	Selective Thinning From Below, Clearcutting, Seed-Tree Cutting, Strip Harvesting
	3	CTL	H	PB	RW	John Deere 1270E	H480	No	-	-	Selective Thinning From Below, Clearcutting, Seed-Tree Cutting, Strip Harvesting
Louis & Kizha (2021)	-	FT	FB	PB	CT	John Deere 853	-	No	Yes	-	Clearcutting, Partial Harvesting
Magagnotti et al. (2021)	-	CTL	H	PB	RW	Ponsse Beaver	Ponsse H6	No	Yes	P-7.2 hours	Clearcutting
Manner et al. (2023)	-	CTL	H	PB	RW	Ponsse Scorpion	Ponsse H6	No	No	-	Selection Cutting
McEwan et al. (2016)	-	CTL	H	EB	CT	Sumitomo SH210	Waratah HTH616C	Yes	No	T-19.8 hours	Includes Coppice, Unspecified Harvesting
Mederski et al. (2016)	-	CTL	H	PB	RW	Komatsu 931.1	Komatsu 365	No	-	-	Thinning
Norihiro et al. (2018)	-	CTL	H	EB	CT	Hitachi Zaxis 200	Waratah H616	Yes	No	-	Clearcutting
	-	CTL	H	PB	CT	Timberpro TL-725B	Maskiner SP 591-LX	No	No	-	Includes Coppice, Clearcutting
	-	CTL	H	EB	CT	Volvo EC-210bf	Maskiner SP 591-LX	No	No	-	Includes Coppice, Clearcutting
	-	CTL	H	EB	CT	Hitachi Zaxis 200	Waratah H616	Yes	No	-	Clearcutting
	-	CTL	H	EB	CT	Hitachi Zaxis 200	Maskiner SP 591-LX	No	No	-	Clearcutting
	-	CTL	H	EB	CT	Komatsu PC 200	Maskiner SP 591-LX	Yes	No	-	Includes Coppice, Clearcutting
Nuutinen & Björheden (2016)	-	B (FT)	FB	PB	RW	Logman 811 FC	Nisula 280E+	No	Yes	-	Thinning
Olivera et al. (2016)	-	CTL	H	PB	RW	Ponsse Ergo 8W	Ponsse H7euca	Yes	No	T-1414 hours	Unspecified Harvesting
Petitmermet et al. (2019)	-	CTL	H	PB	RW	Ponsse Bear	-	No	-	T-107 hours	Thinning, Dry-Forest-Fuel-Reduction Treatment
Petty & Kärhä (2014)	-	CTL	H	PB	RW	Ponsse Ergo	Ponsse H7	No	Yes	-	Thinning
Polowy & Molińska-Glura (2023)	-	CTL	H	PB	RW	John Deere 1070E	John Deere H412	No	-	-	Thinning, Clearing After Wind Damage
	-	CTL	H	PB	RW	John Deere 1070G	John Deere H412	No	-	-	Thinning, Clearing After Wind Damage
Prinz et al. (2021)	-	CTL	H	PB	RW	Ponsse Scorpion	H6	No	No	P-137 min	Final Felling
	-	CTL	H	PB	RW	Ponsse Ergo	H7	No	No	P-141 min	Final Felling
Ramantswana et al. (2013)	-	CTL	H	EB	CT	Hitachi Zaxis 200-3	Waratah HTH616	Yes	No	-	Includes Coppice, Unspecified Harvesting
Rosińska et al. (2022)	-	CTL	H	PB	RW	John Deere 1270 D	758HD	No	No	-	Thinning
	-	CTL	H	PB	RW	John Deere 1270E	H480C	No	No	-	Thinning
	-	CTL	H	PB	RW	Ponsse Ergo	H73	No	No	-	Thinning

		-	CTL	H	PB	RW	Ponsse Ergo 6	H7	No	No	-	Thinning
		-	CTL	H	PB	RW	Ponsse Ergo 6	H73	No	No	-	Thinning
		-	CTL	H	PB	RW	Sampo Rosenlew 1066	HTH460	No	No	-	Thinning
		-	CTL	H	PB	RW	TBM Preus 84	Kesla 24RHII	No	No	-	Thinning
		-	CTL	H	PB	RW	Timberjack 1070D	HTH460	No	No	-	Thinning
		-	CTL	H	PB	RW	Valmet 901.3	351.1	No	No	-	Thinning
Santos et al. (2022)		-	CTL	H	PB	CT	Komatsu PC200F-8M0	Komatsu 370E	Yes	-	-	Clearcutting
Santos et al. (2021)		-	CTL	H	PB	CT	Komatsu PC200F-8M0	Komatsu model 370E	Yes	-	-	Unspecified Harvesting
Santos et al. (2020)		-	CTL	H	PB	CT	Komatsu PC200F-8M0	Komatsu 370E	Yes	No	-	Unspecified Harvesting
Schweier et al. (2015)		-	FT	FB	EB	CT	Hitachi Zaxis 210	COMAF GD350	No	-	T-3.8 hours	Includes Coppice, Unspecified Harvesting
		-	FT	FB	EB	CT	CAT 317 LN	Cut-Tree 450	No	-	T-3.8 hours	Includes Coppice, Unspecified Harvesting
		-	FT	FB	EB	CT	Hitachi EX 135	Cut-Tree 450	No	-	T-2.5 hours	Includes Coppice, Unspecified Harvesting
		-	FT	FB	EB	CT	Hitachi EX 165	Biasi	No	-	T-2.4 hours	Includes Coppice, Unspecified Harvesting
		-	FT	FB	EB	CT	Hitachi EX 165	Biasi	No	-	T-2.1 hours	Unspecified Harvesting
Slugeň et al. (2014)		-	CTL	H	PB	RW	John Deere 1070D	JD H754	No	No	T-7.03 hours	Includes Coppice, Thinning
Soman et al. (2020)		-	FT	FB	PB	CT	John Deere 753G	-	No	No	-	Clearcutting
Soman et al. (2019)		-	FT	FB	PB	CT	John Deere 753G	-	No	Yes	-	Clearcutting, Overstorey Removal, Partial Harvesting
Sperandio et al. (2021)	*FT: Trees could be cut in two parts	-	*FT	FB	EB	CT	Volvo EC 140 CL	Westtech C350	No	Yes	T-16.5 hours	Coppice, Unspecified Harvesting
Spinelli et al. (2014)		-	FT	FB	PB	CT	Tigercat 845C	-	No	-	-	Unspecified Harvesting
		-	FT	FB DT	EB	CT	Posi-track RC-100	Tree Terminator	No	-	-	Unspecified Harvesting
Spinelli & De Arruda Moura (2019)		53	CTL	H	EB	CT	Komatsu PC200-8	Komatsu Forest 370	Yes	-	P-40 000 hours	Unspecified Harvesting
Spinelli et al. (2022)		-	CTL	H	PB	RW	Agama AH6	Nisula 325H	No	No	-	Unspecified Harvesting
		-	CTL	H	PB	RW	Rottne H8	EGS 406	No	No	-	Unspecified Harvesting
		-	CTL	H	PB	RW	Sampo HR46	Kesla 18RH	No	No	-	Unspecified Harvesting
		-	CTL	H	PB	RW	Vimek 404	Keto Forst V4	No	No	-	Unspecified Harvesting
Spinelli et al. (2023)		-	CTL	H	PB	RW	Rottne H8D	EGS 406	No	-	-	Unspecified Harvesting
Spinelli et al. (2020a)		-	CTL	H Sim	PB	RW	John Deere 1270E	-	-	-	-	Selection Cutting
Spinelli et al. (2020b)		-	FT	FB	EB	CT	Liebherr 317	Westtech Woodcracker 350	No	Yes	-	Unspecified Harvesting
Stoilov et al. (2021)		-	CTL	SH	PB	RW	HSM 805 ZL	Woody 50	No	-	-	Combined Regular And Shelterwood Cutting

Strandgard & Mitchell (2018)	*Some trees had several stems, but each stem was processed individually	-	*CTL	H	EB	CT	Hyundai 210LC-9	SP 591LX	Yes	*Yes	-	Includes Coppice, Clearcutting
Strandgard & Mitchell (2019)		-	CTL	H	PB	CT	John Deere 903KH	Waratah 624C	No	No	-	Final Harvest
Strandgard & Mitchell (2020)		-	CTL	H	PB	RW	John Deere 1470e	JD H290	No	No	-	Clearcutting
		-	FT	FB	EB	CT	Komatsu PC 300 HW	Rosin 800	No	No	-	Clearcutting
Strandgard et al. (2016)		5	CTL	H	EB	CT	CAT 320D	Southstar 450	Yes	No	-	Clearcutting
		2	CTL	H	EB	CT	CAT 322C	Waratah 616	Yes	No	-	Clearcutting
		-	CTL	H	EB	CT	CAT 322C	Waratah 616b	Yes	No	-	Clearcutting
		5	CTL	H	EB	CT	CAT 322CL	Waratah 620	Yes	No	-	Clearcutting
		-	CTL	H	EB	CT	CAT 322CL	Waratah 616C	Yes	No	-	Clearcutting
		3	CTL	H	EB	CT	CAT 324D	Waratah 618c	Yes	No	-	Clearcutting
		5	CTL	H	PB	CT	CAT 324D FM	Waratah 616C	Yes	No	-	Clearcutting
		6	CTL	H	PB	CT	CAT 324D FM	Waratah 616D	Yes	No	-	Clearcutting
		-	CTL	H	EB	CT	CAT 324DL	Waratah 616c	Yes	No	-	Clearcutting
		-	CTL	H	PB	CT	CAT 521	Waratah 620	Yes	No	-	Clearcutting
		5	CTL	H	PB	CT	CAT 511	Waratah 616C	Yes	No	-	Clearcutting
		-	CTL	H	PB	CT	Valmet 425EX	Valmet 378	Yes	No	-	Clearcutting
		-	CTL	H	EB	CT	Volvo 210	Waratah 616	Yes	No	-	Clearcutting
		3	CTL	H	EB	CT	Volvo 210B	Waratah 616	Yes	No	-	Clearcutting
		3	CTL	H	EB	CT	Volvo 210B	Waratah 616C	Yes	No	-	Clearcutting
		-	CTL	H	EB	CT	Volvo EC210BLC	Waratah 616B	Yes	No	-	Clearcutting
		-	CTL	H	EB	CT	Volvo EC210BLC	Maskiner 591	Yes	No	-	Clearcutting
		-	CTL	H	EB	CT	Volvo EC240C	Waratah 616C	Yes	No	-	Clearcutting
		-	CTL	H	EB	CT	Volvo EC250DL	Waratah 616c	Yes	No	-	Clearcutting
Strandgard et al. (2015)		-	FT	FB	PB	CT	Timbco 445B	Quadco hotsaw	No	Yes	-	Clearcutting
Tajbos & Messingerova (2014)		-	CTL	H	PB	RW	John Deere 770D	-	No	No	-	Thinning
		-	CTL	H	PB	RW	Valmet 911.1	-	No	No	-	Thinning
Tolosana et al. (2023)		-	B (FT)	FB	PB	RW	Logman 811 FC	Nisula 280E+	No	-	T-30.4 hours	Clearcutting, Salvage Harvesting, Thinning
Tolosana et al. (2018)		-	FT	FB DT	PB	RW	John Deere 643J	JD FD45	No	Yes	-	Includes Coppice, Thinning
Townsend et al. (2019)		-	FT	FB DT	PB	RW	Tigercat 726G	-	No	Yes	-	Restoration Harvest
		-	FT	FB DT	PB	RW	John Deere 843 L (2)	-	No	Yes	-	Restoration Harvest

	-	FT	FB DT	PB	RW	CAT 573 C	-	No	Yes	-	Restoration Harvest
	-	FT	FB	PB	CT	TimberPro TL735 B	-	No	Yes	-	Restoration Harvest
	-	CTL	H	EB	CT	John Deere 240D	Logmax 7000 XT	No	Yes	-	Restoration Harvest
Walsh & Strandgard (2014)	-	CTL	H	PB	CT	Timbco 475	Rosin 997	No	No	-	Clearcutting
Walsh et al. (2014)	-	CTL	H	PB	CT	Tigercat H860C	Waratah HTH624C-Super	No	No	-	Unspecified Harvesting
Williams & Ackerman (2016)	-	CTL	H	PB	CT	John Deere 753	Waratah HTH623C	No	No	T-628.3 min	Clearcutting
Zimelis et al. (2020)	-	CTL	H	PB	RW	Malwa	-	No	No	-	Selective Felling
Zimelis et al. (2018)	-	CTL	H	PB	RW	Vimek 404 SE	Keto Forest Eco	No	No	-	Thinning
	-	CTL	H	PB	RW	Vimek 404 SE	Keto Forest Extreme	No	No	-	Thinning
Zimelis et al. (2019)	-	CTL	H	PB	RW	Vimek 404SE	Bracke C.12	No	No	-	Thinning, Final Felling, Overgrowth Clearing, Ditch Clearing
	-	CTL	H	PB	RW	Vimek 404SE	Keto-Forest Eco	No	No	-	Thinning, Final Felling, Overgrowth Clearing, Ditch Clearing
Zimelis et al. (2017a)	-	CTL	H	PB	RW	Ponsse Ergo	H7	No	No	-	Final Felling
Zimelis et al. (2017b)	-	CTL	H	PB	RW	Vimek 404 T5	-	No	No	-	Thinning
Zimelis & Spalva (2022)	-	CTL	H	PB	RW	Malwa 560H	-	No	-	-	Thinning
Zimelis et al. (2016)	-	CTL	H	EB	CT	New Holland 215B	Ponsse H7	No	Yes	T-174 hours	Ditch Cleaning/Harvesting

Appendix 5. Stand and operator descriptions

Stand descriptions, number of operators and their experience. TSC = tree species composition. In the TSC column, an asterisk (*) indicates that only this tree species' data was used for modelling, and if the asterisk is absent, it was presumed that data for all species were included for modelling. In the stem volume, diameter at breast height (DBH), and slope columns, parentheses ( ) represents the range of minimum and maximum values, while an asterisk followed by parentheses *( ) denotes the range of mean values between areas, units, or treatments.

Author(s)	**TSC**	**Stand Age**	**Stem Volume**	**DBH**	**Ground Condition**	**Ground Roughness**	**Slope**	**Nr. of Operators**	**Operator Experience**
Ackerman et al. (2018)	*Eucalyptus grandis x camaldulensis*	8	0.154 (0.034-0.477) m^{3}ub	15.89 (9.00-27.20) cm	2/3 - Erasmus (1994)	3 - Erasmus (1994)	23 (5-55)%	1	10 Years Experience On Both Machines
Ackerman et al. (2021)	**Pinus patula, Pinus elliotti, Pinus taeda*	-	0.92 (0.01-2.50) m^3, before trimming of data	31.38 (7.30-59.70) cm, before trimming of data	Good Ground Conditions - Erasmus (1994)	-	Predominately Flat - Erasmus (1994)	-	-
Ackerman et al. (2022)	*Pinus patula*	10	0.12 (0.03-0.13) m^3	15.9 (8.2-26.0) cm	Firm - Erasmus (1994)	Even - Erasmus (1994)	Level - Erasmus (1994)	1	-
Acosta et al. (2021)	*Teak*	18	0.3408 m^3	-	Clayey With Good Drainage	-	<15%	1	>5 Years Experience
Acuna et al. (2017)	*Eucalyptus globulus*	9,5	*(0.233-0.464) m^{3}ub	*(167-253) mm	Firm And Even	Firm And Even	(0-6)°	1	Experienced
Alam et al. (2014)	*Radiata pine*	*(34-35)	*(1.8-2.4) m^3	*(39.0-51.2) cm	-	Good	<5°	2	2-8 Years Experience
Apăfăian et al. (2017)	*Picea Abies*	45	0.364 (0.044-0.676) m^3	23 cm	Luvosoil	-	10%	1	-
Berendt et al. (2020)	**Picea abies, *Pseudotsuga menziesii, Pinus sylvestris, Acer pseudoplatanus, Fagus sylvatica*	*(35-56)	*(0.14-0.54) m^3	*(18.5-33.4) cm	-	-	(60-70)%	1	-
Berg et al. (2014)	*Picea abies, Pinus sylvestris, Deciduous*	*(90-200)	*(0.104-2.068) m^3	*(144-419) mm	1 - Berg (1992)	1 - Berg (1992)	1 - Berg (1992)	-	-
Bergström & Di Fulvio (2014)	*Pinus sylvestris, Picea abies, Betula spp*	-	51 *(49-55) dm^3	9.3 *(9.1-9.6) cm	2 - Berg (1992)	3 - Berg (1992)	1 - Berg (1992)	1	Approx. 1 Year Experience With fuel-wood thinning

Bergström et al. (2016)	*Pinus sylvestris, Picea abies, Betula spp., Alnus incana, Pinus Contorta*	30-35	26.5 *(15.0-43.0) dm^3	7.1 *(5.5-8.5) cm	2 - Berg (1992)	1 - Berg (1992)	1 - Berg (1992)	1	1 Year Experience
Bergström et al. (2022)	*Acer pseudoplatanus, Betula spp., Corylus avellana, Fagus sylvatica, Ostrya carpinifolia, Alnus incana, Sorbus aucuparia, Salix spp., Fraxinus excelsior, Ulmus glabra, Pinus sylvestris, Picea abies, Tilia cordata*	*(20-40)	*(10-64) dm^3, whole tree volume	*(3.3-9.4) cm	*(1-2) - Berg (1992)	*(1-2) - Berg (1992)	*(1-2) - Berg (1992)	1	>5 Years Experience
Bilici et al. (2019)	*Pinus brutia*	-	-	*(24.63-34.28), (10-46) cm	-	*(Low-High)	*(15-25), (12-29)%	1	>3 Months Training
Brewer et al. (2018)	*Pinus patula*	22	1.05 *(1.12-1.33) m^{3}ub	*(33.90-36.01) cm	Good - Erasmus (1994)	Low - Erasmus (1994)	(0-14)% - Erasmus (1994)	4	1 Year Experience
Brown et al. (2013)	*Pinus radiata*	24	0.61 (0.06-1.84) m^3	0.29 (0.10-0.46) m	Moist, Soft And Clay Loamy Soils	Some Dolerite Rocks	21 (7-27)°	1	>12 Years Experience (2 With Current Machine)
Carter et al. (2017)	*Hybrid poplar*	7	0.045 m^3	(6.35-11.94) cm	-	Free Of Any Impassable Objects	No Discernible Slope	>1	5-25 Years Experience
Chakroun et al. (2016)	*Oak, Birch, Hornbeam, Other hardwoods, Beech, Ash, Field maple*	30	*(0.029-0.065) m^3	*(8.7-10.1) cm	Firm	-	Even	2	Skilled
Chung et al. (2022)	*Douglas-fir*	60	1.27 m^3	41 cm	Silty Clay Loam Soils	-	45%	-	>3 Years Experience
Di Fulvio & Bergström (2013)	*Pinus sylvestris, Picea abies, Betula spp*	32	*(41-45) dm^3	*(8.4-9.0) cm	2 - Berg (1992)	2 - Berg (1992)	2 - Berg (1992)	1	Several Years Experience
Erber et al. (2016)	*Carpinus betulus*	-	8.2 dm^3	4.0 (1.0-23.0) cm, basal area weighted	Stagnogley Soil	Without Major Obstacles	Flat	1	> 1 Months Experience With The Ef28 Head
Eriksson & Lindroos (2014)	*Pinus sylvestris, Picea abies, Pinus contorta*	-	*(0.11-0.25), (0.03-1.82) m^{3}ub	-	-	*(1.7-1.8), (1.0-5.0) - Berg (1992)	*(1.6-1.7), (1.0-5.0) - Berg (1992)	-	-

Fernandez-Lacruz et al. (2013)	*Betula spp., Salix spp., Picea abies, Pinus sylvestris*	-	1.71 OD kg	*(2.3-4.7) cm, basal area weighted	1 - Berg (1992)	2 - Berg (1992)	1 - Berg (1992)	1	>4 Years Experience
Fernandez-Lacruz et al. (2021)	*Betula spp., Alnus incana, Salix spp., Picea abies, Pinus sylvestris*	24 (14-34)	-	*(1.9-5.7) cm	-	-	-	1	4 Years Experience
George et al. (2022)	*Cedar, Acer rubrum, Larix laricina, Picea rubens, Tsuga canadensis, Pinus strobus, Fraxinus nigra, Betula alleghaniensis, Populus tremuloides, Betula papyrifera, Abies balsamea*	-	-	*(22.1-26.2) cm, quadratic mean diameter (QMD)	Frozen	-	(0-15)%	-	>6 Years Experience
Ghaffariyan (2013)	*Eucalyptus globulus*	*(11-13)	*(0.178-0.205) m³	-	-	-	Flat	-	-
Ghaffariyan et al. (2019)	-	-	-	-	-	-	-	-	-
Ghaffariyan et al. (2013)	*Eucalyptus globulus*	-	0.21 m³	17.8 cm	-	-	Flat	1	4 Years Experience
Ghaffariyan et al. (2015)	*Pinus radiata*	32	1.53 m³	*(42.0-42.1) cm	Firm	Even	Flat	1	20 Years Experience
Green et al. (2020)	*Pseudotsuga menziesii, Abies grandis, Acer macrophyllum*	60	-	*(48.3-49.5) cm	Price Soils	-	*(27-30), (7-50)%	2	25 And 27 Years Experience
Grönlund & Eliasson (2019)	*Birch, Spruce*	*(14-25)	-	*(4.1-12.0) cm	-	-	-	-	-
Gülci et al. (2021)	*Pinus pinaster*	-	0.38 m³	23.13 cm	-	-	16%	1	3 Months Experience
Han et al. (2018)	*Pinus contorta var. latifolia*	-	-	22.4 cm	-	-	Relatively Flat	-	-
Hiesl & Benjamin (2013)	*Fagus grandifolia, Acer rubrum, Betula alleghaniensis, Betula papyrifera, Populus tremuloides, Abies balsamea, Picea rubens, Tsuga Canadensis, Thuja occidentalis*	-	-	(10-63) cm	-	-	(2-14)%	6	1-15 Years Experience

Hiesl & Benjamin (2015)	*Abies balsamea, Picea rubens, Tsuga Canadensis, Thuja occidentalis, Fagus grandifolia, Acer rubrum, Betula alleghaniensis, Betula papyrifera, Populus tremuloides*	-	-	*(13-20), (10-58) cm	-	-	(1-5)%	4	<1 To 15 Years Experience
Hiesl et al. (2015)	*Abies balsamea, Picea rubens, Populus tremuloides, Betula papyrifera, Betula alleghaniensis, Pinus strobus, Thuja occidentalis*	-	*(0.03-0.17) m³	*(9.6-18.7) cm	-	-	-	2	7-30 Years Experience
Holzleitner & Kanzian (2022)	**Picea abies, Larix decidua, Quercus robur, Fagus sylvatica, Betula pendula*	56	0.8 m³	28.7 cm	-	Without Major Obstacles	10%	-	Experienced
Horváth et al. (2016)	*Black locust, Beech, Turkey oak, Hornbeam, Noble poplar, Spruce, Scots pine, Black pine*	-	-	-	-	-	-	-	-
Jernigan et al. (2015)	*Pine*	11	0.14 green tons	-	-	-	Minimum Slope	-	-
Jylhä & Bergström (2016)	*Pinus sylvestris, Picea abies, Betula pubescens, Betula Pendula, Other*	22.7 *(13.6-29.3)	20.1 *(0.6-70.8) dm³, whole tree volume	44.5 *(10.0-98.0) mm	-	-	-	1	Several Years Experience
Kärhä et al. (2018a)	*Norway spruce, Scots pine, Betula spp*	-	0.76 *(0.70-0.85) m³	-	-	-	-	3	>10 Years Experience
Kärhä et al. (2018b)	*Picea abies, Pinus sylvestris, Betula verrucosa, Betula pubescens, Populus tremula*	-	226 *(128-247) dm³	-	Normal To Difficult	Normal To Difficult	Normal To Difficult	11	Some Months To 23 Years Experience
Kärhä et al. (2019)	**Norway spruce, Scots pine, Betula spp, Populus tremula*	-	0.687 m³	27.2 cm	-	-	-	5	>9 Years Experience

Karpachev & Bykovskiy (2019)	-	-	(0.0042-2.26) m³	-	-	-	-	-	-
Kim et al. (2017)	*Lodgepole pine, Douglas-fir, Subalpine fir*	-	-	7.5 in, Quadratic mean diameter	-	-	9%	1	Experienced
Kizha & Han (2016)	*Sequoia sempervirens, Pseudotsuga menziessii, Tsuga heterophylla, Tanoak*	60	-	*(18-23) cm	-	-	≤111%	2	-
Kormanek & Baj (2018)	*Pine*	65	0.62 m³	-	-	-	Flat Forestland	-	Short Experience
Kormanek & Kępa (2016)	*Spruce, Beech, Sycamore*	47	-	-	Podsoil, Soil Strongly Turfed	-	Little Inclination	1	-
Krč et al. (2015)	_*Spruce, Fir, *Beech, Oak, *Maple, Elm, Cherry_	-	0.36 m³	19.55 cm	Not Problematic	Rockiness Is Due To Dolomite Bedrock Very Small	≤45%	-	-
Labelle et al. (2017)	*Pinus sylvestris, Picea abies*	120 *(89-143)	*(0.29-0.89) m³	*(19.5-30.3) cm	-	-	-	1	>10 Years Experience
Labelle et al. (2018)	*Fagus Sylvatica, Quercus robur, Quercus petraea*	-	*(1.7-1.9) m³	*(35.6-39.3) cm	-	-	-	-	-
Labelle & Huß (2018)	_*Picea abies, Fagus sylvatica, Quercus robur, Betula pendula_	80	*(2.8-2.9) m³	*(46.6-47.0) cm	-	-	-	1	Very Experienced
Labelle et al. (2016)	_*Sugar maple, Yellow birch, Other_	-	-	33 cm, quadratic mean diameter	-	-	<10%	1	15 Years Experience
Labelle et al. (2019)	_*Common beech, *Picea abies, Pinus sylvestris_	90 (75-110)	1.74 *(1.13-2.11) m³	37.5 *(29.7-43.6) cm	-	-	<5%	1	Experienced
Laina et al. (2013)	*Quercus pyrenaica*	-	-	*(5.8-10.6) cm	-	-	*(1-24)%	-	-
Laitila et al. (2016)	*Betula pubescens, Pine*	-	*(50-58) dm³	*(5-20) cm	1 - Anon. (1990)	1 - Anon. (1990)	1 - Anon. (1990)	1	20 Years Experience
Laitila & Väätäinen (2014)	*Pinus sylvestris*	(30-40)	57 *(26-83) dm³	-	1 - Anon. (1990)	1 - Anon. (1990)	1 - Anon. (1990)	1	21 Years Experience
Laitila & Väätäinen (2020)	*Pinus sylvestris, Picea abies, Betula pubescens, Other broadleaved tree species*	-	(8–111) dm³	72 (12–163) mm	-	-	-	2	45 Years Experience

	such as Aspen, Alder, Rowan and Willow								
Laitila & Väätäinen (2021)	*Pinus sylvestris, Picea abies, Betula pubescens, Other broadleaved tree species such as Aspen, Alder, Rowan, and Willow*	-	(6-54) dm^3	41 *(21-97) mm, stump diameter	-	-	-	1	20 Years Experience
Laitila & Väätäinen (2023)	*Pinus sylvestris, Picea abies, Betula pendula, Other broadleaves*	(15-25)	*(14.2-52.0) dm^3	*(51-97) mm	1 - Anon. (1990)	1 - Anon. (1990)	1 - Anon. (1990)	1	1 Year Experience
Laitila et al. (2013)	*Pinus sylvestris*	-	-	*(14.5-15.1) cm	Drained Peatland	-	-	1	13 Years Experience
Laitila et al. (2020)	**Scots pine, Norway spruce, Downy birch*	-	-	-	Ditched Peatland	-	-	1	>20 Years Experience
Lazdiņš et al. (2019)	*Pine, Spruce*	-	-	*(17.2-19.2) cm	Dry Sandy Mineral Soils	-	-	-	Trained
Lazdiņš (2014)	*Spruce, Grey alder, Black alder, Birch*	-	-	9 cm	-	-	-	-	Had Previous Experience
Lazdiņš et al. (2021)	*Betula pendula*	-	0.06 m^3	12 cm	-	-	-	-	Experienced
Lazdiņš et al. (2016)	*Spruce*	-	-	*(9.7-10.9) cm	-	-	-	-	Experienced
Leszczyński et al. (2021)	*Scots pine*	25	*(0.074-0.103) m^3	*(11.7-13.5) cm	-	-	-	-	-
Liski et al. (2020)	*Pine, Spruce, Birch, Other broadleaves*	-	0.2741 (0.033-1.267) m^3	-	-	-	-	27	-
Louis & Kizha (2021)	*Picea rubens, Acer saccharum, Acer pensylvanicum, Picea mariana, Betula alleghaniensis, Fagus grandifolia*	-	*(0.05-0.12) m^3	-	Ragmuff-Monson Complex (38%), Telos-Chesuncook-Ragmuff Association (27%), And Chesuncook-Elliottsville Association (23%)	-	(3-35)%	-	-
Magagnotti et al. (2021)	*Populus x euroamericana*	8	0.087 (0.074-0.103) m^3, whole above ground biomass	12 cm	-	-	-	-	Experienced

Manner et al. (2023)	*Pinus sylvestris, Picea abies, Betula spp*	90	0.642 *(0.500-0.867) m^{3}ub	-	2 - Berg (1992)	2 - Berg (1992)	1 - Berg (1992)	1	>10 Years Experience
McEwan et al. (2016)	*Eucalyptus grandis*	11	0.466 m^{3}ub	21 (8-40) cm	-	Smooth - Erasmus (1994)	<20% - Erasmus (1994)	2	1 and 10 Years Experience
Mederski et al. (2016)	*Pinus sylvestris*	*(40-100)	0.14 m^3	*(19.5-25.2) cm	-	-	-	2	7 Years Experience
Norihiro et al. (2018)	*Eucalyptus grandis x camaldulensis, Eucalyptus grandis x urophylla, Eucalyptus smitthii, Eucalyptus dunnii*	*(7-12)	*(0.12-0.38) m^3	*(15.3-21.6), (5.2-35.7) cm	-	-	*(0-61)%	-	Trained
Nuutinen & Björheden (2016)	_*Pine, Spruce, Birch_	*(25-40)	*(27-84) dm^3, above ground volume	-	-	-	-	1	Skilled
Olivera et al. (2016)	*Eucalyptus bicostata, Eucalyptus dunnii, Eucalyptus grandis, Eucalyptus maidenii*	*(15-19)	*(0.29-0.55) m^{3}ub	*(183-223) mm	Loam, Predominantly Deep	-	Gentle, Mostly Below 6%, Occasionally Over 12%	3	10 To More Than 12 Months Experience
Petitmermet et al. (2019)	*Abies concolor, Pinus ponderosa*	-	-	<53.3 cm	Primarily Loamy-Skeletal	-	38 (12-70)%	1	Highly Experienced
Petty & Kärhä (2014)	*Picea abies, Pinus sylvestris, broadleaves, primarily Betula pubescens*	-	63 *(51-77) dm^3	10.9 *(10.0-12.3) cm	High Bearing Capacity	No Foreign Obstacles	Level Terrain	1	>10 Years Experience, <2 Months Multi-Tree Cutting Experience
Polowy & Molińska-Glura (2023)	-	-	0.266 (0.057-0.737) m^3	-	-	-	-	-	Experienced
Prinz et al. (2021)	*Pinus sylvestris, Picea abies, Betula pendula, Other broadleaves*	-	-	*(252-364) mm, mean felling cutting diameter	-	-	-	2	>20 Years Experience
Ramantswana et al. (2013)	*Eucalyptus grandis*	*(7-11)	*(0.165-0.275) m^3	-	-	Smooth - Erasmus (1994)	Level - Erasmus (1994)	-	-
Rosińska et al. (2022)	*Silver birch*	59 *(28-79)	-	23.7 *(12.7-33.5) cm	-	-	-	9	2-10 Years Experience

Santos et al. (2022)	*Eucalyptus grandis x Eucalyptus urophylla*	-	*(0.08-0.20) m^3ub	-	-	-	-	-	-
Santos et al. (2021)	*Eucalyptus grandis x Eucalyptus urophylla*	6,3	0.10 m^3	-	-	-	-	12	5 years of experience
Santos et al. (2020)	*Eucalyptus grandis x Eucalyptus urophylla*	-	*(0.08-0.16) m^3	-	-	-	Flat Relief	1	-
Schweier et al. (2015)	*Quercus pubescens, Quercus ilex, Castanea sativa, Quercus cerris, Populus alba, Robinia pseudoacacia, Populus x euroamericana*	*(5-26)	*(5-109) dry kg	*(7-20), (5-31) cm	-	-	*(2-35)%	-	-
Slugeň et al. (2014)	*Quercus petraea, Fagus sylvatica*	*(70-75)	*(0.38-0.50) m^3	*(22-27) cm	-	-	*(15-17)%	-	-
Soman et al. (2020)	*Abies balsamea, Acer rubrum, Picea rubens, Picea mariana, Pinus strobus, Populus tremuloides, Populus grandidentata, Thuja occidentalis, Tsuga canadensis, Quercus rubra, Picea glauca, raxinus americana, Betula populifolia, Betula papyrifera*	-	-	-	Glacial-Till And Marine Sediment Parent Material	-	<15%	-	5-25 Years Experience
Soman et al. (2019)	*Tsuga canadensis, Betula alleghaniensis, Abies balsamea, Populus spp, Fagus grandifolia, Picea rubens, Betula papyrifera, Pinus strobus*	-	-	-	Howland Silt Loam And Monarda-Burnham Complex	-	<9%	-	-

Sperandio et al. (2021)	*Populus × canadensis*	*(8-11)	*(50.57-101.41), (17-491) kg	*(9.84-13.20) cm	Clayey-Loamy Soil	-	Flat	1	No Previous Experience In Harvesting This Type Of Plantation
Spinelli et al. (2014)	*Eucalyptus polybractea*	20	*(93-96), (67-154) kg	-	Pasture Field	-	-	-	-
Spinelli & De Arruda Moura (2019)	*Eucalyptus urograndis*	*(4-11)	0.145 *(0.1-0.4) m³ub	-	Firm Sandy Soils	-	<10%	120	Professional
Spinelli et al. (2022)	*Populus x euramericana*	5	30 dry kg, stem and branches	12 *(11.9-12.4) cm	-	-	-	4	Significant Experience
Spinelli et al. (2023)	*Populus x euramericana*	6	-	12 *(12.1-12.3) cm	-	-	-	1	Experienced Professional
Spinelli et al. (2020a)	*Spruce, Fir, Broadleaves*	(60-80)	*(0.675-1.374), (0.25-3.1) m³	-	Cambisol	-	-	13	<1-20 Years Experience
Spinelli et al. (2020b)	*Poplar (clone AF8)*	7	103 kg fresh weight, tree mass	15.1 cm	-	-	-	-	Significant Experience
Stoilov et al. (2021)	*Pinus sylvestris, Pinus nigra*	55	-	*(24-30) cm	-	-	19°	2	>2 years of experience
Strandgard & Mitchell (2018)	*Eucalyptus globulus*	10,5	*(0.06-0.21) m³	*(105-167) mm	Good Load-Bearing Capacity	No Obstacles To The Movements Of The Harvesting Machines	<5°	1	>15 Years Experience
Strandgard & Mitchell (2019)	*Pinus radiata*	29	1.2 m³	*(389-396) mm	Duplex Sandy Gravel	-	≤5°	-	Experienced
Strandgard & Mitchell (2020)	*Pinus radiata*	29	*(0.90-0.95) m³	*(326-343) mm	-	-	<15°	-	Experienced
Strandgard et al. (2016)	*Eucalyptus globulus*	11.5 *(8.5-14.0)	0.26 *(0.13-0.46) m³	188 *(152-245) mm	-	Few Obstructions	<5°	24	1-20 Years Experience
Strandgard et al. (2015)	*Eucalyptus nitens*	17	0.18 (0-1.58) m³	18.0 (4.7-47.0) cm	Stable Ground And Basalt Soils	-	<5°	1	1 Year Experience
Tajbos & Messingerova (2014)	*Spruce , Fir, Larch, Birch*	*(25-40)	*(0.01-0.36) m³	*(6-21) cm	-	-	*(15-40)%	-	-
Tolosana et al. (2023)	*Eucalyptus globulus, Quercus suber, Pinus pinaster*	-	*(10.2-17.5) oven dry ton kg	*(9.0-12.4) cm	-	-	-	-	-

Tolosana et al. (2018)	*Quercus ilex, Quercus pyrenaica*	>35	(7.4-22.5) kg, dry weight	*(5.7-7.1) cm	Dry Sandy Soils	-	Flat	-	-
Townsend et al. (2019)	*Pinus ponderosa, Pseudotsuga menziesii, Abies concolor, Quercus gambelii, Populus tremuloides*	-	-	*(22.9-30.7) cm, quadratic mean diameter	-	-	*(7-15)%	-	-
Walsh & Strandgard (2014)	*Pinus Radiata*	34	*(2.24-2.80) m^3	*(49.9-53.6) cm	-	No Obstacles Or Rocks	Flat Terrain	-	-
Walsh et al. (2014)	*Radiata pine*	34	2.1 m^3	*(49.7-50.0) cm	-	No Obstacles Or Rocks	Flat	-	-
Williams & Ackerman (2016)	*Pinus elliottii*	*(21-26)	*(0.99-1.10) m^3	*(35.99-37.50), (22.0-57.5) cm	*(2-3, 2-4, 3-5) - Erasmus (1994)	1 - Erasmus (1994)	*(0-10)%	1	-
Zimelis et al. (2020)	*Pine, Spruce, Birch, Aspen, Black alder, Grey alder, Hard deciduous, Soft deciduous*	-	-	10 (3-30) cm	-	-	-	-	-
Zimelis et al. (2018)	*Norway spruce, Scots pine, Deciduous trees*	-	*(0.02-0.10) m^3	*(4-13) cm	-	-	-	1	-
Zimelis et al. (2019)	-	-	-	(1-20) cm	-	-	-	-	-
Zimelis et al. (2017a)	*Spruce, Birch, Pine*	-	-	-	-	-	-	-	-
Zimelis et al. (2017b)	*Pine, Spruce, Birch*	*(18-67)	*(0.045-0.085) m^3	11 *(8.8-16.2) cm, tree diameter	-	-	-	-	-
Zimelis & Spalva (2022)	*Scarred aspen*	-	0.11 m^3	12.2 cm	-	-	-	-	Long Experience
Zimelis et al. (2016)	*Pine, Spruce, Deciduous*	-	0.28 m^3	-	-	-	-	-	Experienced

Appendix 6. Instructions for appendixes 7-11

Appendix 7 explains the abbreviations for dependent variables used in the models, which are shown in Appendix 8. In Appendix 8, the “Model” column contains the models. In this column, an uppercase letter indicates a variable, whereas a lowercase letter indicates a parameter. The variables are shown in Appendix 9, and the parameters in Appendix 10. Information regarding coefficients of determination, statistical significance, observational unit, and number of observations are shown in Appendix 11.

To use a model, one should first check the models and their dependent variables in Appendix 8. If the abbreviations for dependent variables are unclear, see Appendix 7 for clarification. Next, consult Appendix 8 to see which variables are included in a model. Then, go to Appendix 10 to apply parameters for the model.

Appendix 7. Abbreviations

Abbreviations for units describing mass

GMton = Green metric ton
ODton = Oven-dry ton
ub = under bark (if this abbreviation is not mentioned, it indicates that it is over bark)

Abbreviations for miscellaneous terms

ln = natural logarithm
log = logarithm with base 10
√ = square root

The time units are divided into three categories, delay-free time, time where delays are included, and time where it could not be ascertained if delays were included or excluded. If none of the abbreviations for time including delays or those indicating uncertainty of delays are presented, the time is considered delay-free. For example, if a dependent variable is described as “Cycle (s)”, it indicates that it is time for a work cycle where delays are excluded.

To clarify the usage of several delay-free time terms: even if several terms are used, they fundamentally indicate the same thing, delay-free time.

General terms

Centi-min = 1/100 of a minute
ms = Millisecond

Abbreviations for delay-free time

E_0 = Effective work hour
E_0h = Productive work hour
EWh = Effective work hour
PMh = Productive machine hour
PMH_0 = Productive machine hour
PMmin = Productive machine minute
$PMmin_0$ = Productive machine minute
PSH_0 = Productive system hour
PWmin = Productive work minute

Abbreviations for time where delays are included

* = Delays added as a factor of 1.2
-D = All delays were included
E_{15} = Productive hour including delays less than 15 minutes
h_{15} = Productive hour including delays less than 15 minutes
PMh_{15} = Productive machine hour including delays less than 15 minutes
$PMmin_{15}$ = Productive machine minute including delays less than 15 minutes
SMH = Scheduled machine hour

Abbreviations for dependent variables where it is unclear if delays were included or excluded

-U = Could not ascertain if delays were included or excluded

Appendix 8. Models

Information regarding models. nr = model number; HM = harvesting method, CTL = cut-to-length, FT = full-tree, B (FT) = feller-buncher producing bundles, * = see appendix 3 for information regarding harvesting method; M = machine type, H = harvester, H Sim = harvester simulation, FB = feller-buncher (swing-boom), FB DT = drive-to-tree feller-buncher, FB Sim = feller-buncher simulation, HW = harwarder, SH = skidder-harvester; BM = base machine, EB = excavator-based, PB = purpose-built; Pr = Propulsion type, CT = continuous tracks, RW = rubber wheels; DV Type = dependent variable type, Productivity = PV (volume/time), PW (weight/time), PU (units/time), Time per unit of output = TV (time/volume), TW (time/weight), TU (time/unit), W = time for work cycle, E = time for element(s) regarding handling of tree, M = time for moving, L = time for loading; DV = dependent variable.

Author(s)	**nr**	**HM**	**M**	**GM**	**PR**	**DV Type**	**DV**	**Models**
Ackerman et al. (2018)	1	CTL	H	EB	CT	PV	(m^{3}ub PMh^{-1})	$aV_3{}^b$
	2	CTL	H	PB	CT	PV	(m^{3}ub PMh^{-1})	$a+bV_3$
	3	CTL	H	EB	CT	PV	(m^{3}ub PMh^{-1})	$a+bV_3-cS_1$
	4	CTL	H	PB	CT	PV	(m^{3}ub PMh^{-1})	$a+bV_3+cS_1$
	5	CTL	H	EB	CT	PV	(m^{3}ub PMh^{-1})	$a+bV_3-cS_1-dV_3S_1$
	6	CTL	H	PB	CT	PV	(m^{3}ub PMh^{-1})	$a+bV_3+cS_1-dV_3S_1$
Ackerman et al. (2021)	1	CTL	H	PB	RW	PV	(m^3 PMh^{-1})	$a/((b+exp^{D_1-c})d)-exp^{eD_1}$
	2	CTL	H	PB	RW	PV	(m^3 PMh^{-1})	$a+bE_9+\alpha/((c+exp^{D_1-d}(-e))-exp^{D_1(f+gE_9)}$
Ackerman et al. (2022)	1	CTL	HW	PB	RW	PV	(m^3 PMh^{-1})	$aV_1{}^b$
	2	CTL	HW	PB	RW	PV	(m^3 PMh^{-1})	$aV_1{}^b$
Acosta et al. (2021)	1	CTL	H	EB	CT	PV	(m^3 h^{-1})	$-a+bV_1$
Acuna et al. (2017)	1	CTL	H	EB	CT	PV	(m^{3}ub PMh^{-1})	$exp^{a-bO_{12}+c\,ln(V_3)}$
Alam et al. (2014)	1	CTL	H	PB	CT	PV	(m^3 PMh^{-1})	$a+b\,ln(V_1)$

	2	CTL	H	PB	CT	PV	(m^3 PMh^{-1})	$a+b\mathit{ln}(V_1)$
	3	CTL	H	PB	CT	PV	(m^3 PMh^{-1})	$a+b\mathit{ln}(V_1)$
	4	CTL	H	PB	CT	PV	(m^3 PMh^{-1})	$a+b\mathit{ln}(V_1)$
Apăfăian et al. (2017)	1	CTL	H	PB	RW	E	delimb (s)	$a\mathit{exp}^{bM_4}$
	2	CTL	H	PB	RW	E	delimb, buck (s)	$a\mathit{exp}^{bV_1}$
	3	CTL	H	PB	RW	W	cycle (s)	$a\mathit{exp}^{bV_1}$
	4	CTL	H	PB	RW	W	cycle (s)	$a+bV_1$
	5	CTL	H	PB	RW	PV	(m^3 h^{-1})	aV_1^b
Berendt et al. (2020)	1	CTL	H	PB	RW	PV	(m^3 PMh$_0^{-1}$)	aV_1^b
Berg et al. (2014)	1	CTL	H Sim	PB	RW	PV	(m^3 PMh^{-1})	$a+bD_5-cD_5^d-e\mathit{ln}(D_5)$
	2	CTL	H Sim	PB	RW	PV	(m^3 PMh^{-1})	$a+bV_1+cV_1^d+e\mathit{ln}(V_1)$
	3	*FT	FB Sim	PB	RW	PV	(m^3 PMh^{-1})	$-a+bD_5-cD_5^d$
	4	*FT	FB Sim	PB	RW	PV	(m^3 PMh^{-1})	$a+bV_1-cV_1^d+e\mathit{ln}(V_1)$
Bergström & Di Fulvio (2014)	1	CTL	H	PB	RW	TV	(PMmin$_0$ m$^{3\ -1}$)	$a+b/V_2$
	2	FT	FB	PB	RW	TV	(PMmin$_0$ m$^{3\ -1}$)	$a+b/V_2+c/I_3$
Bergström et al. (2016)	1	B (FT)	FB	PB	RW	TU	(PMmin$_0$ bundle^{-1})	$-a+bN_5$
	2	B (FT)	FB	PB	RW	PW	(ODton PMh$_0^{-1}$)	$a+bV_2$
	3	B (FT)	FB	PB	RW	PU	(bundles PMh$_0^{-1}$)	$a+bV_2$
Bergström et al. (2022)	1	*FT	FB	PB	RW	PW	(dry ton PMh^{-1})	$a+bB_2$
	2	*FT	FB	PB	RW	PW	(dry ton PMh^{-1})	$a+bB_2$
	3	*FT	FB	PB	RW	PW	(dry ton PMh^{-1})	$a+bD_2$
	4	*FT	FB	PB	RW	PW	(dry ton PMh^{-1})	$a+bD_2$
	5	*FT	FB	PB	RW	PW	(dry ton PMh^{-1})	$a+bD_3$
	6	*FT	FB	PB	RW	PW	(dry ton PMh^{-1})	$a+bD_3$
	7	*FT	FB	PB	RW	PW	(dry ton PMh^{-1})	$a+bH_2$
	8	*FT	FB	PB	RW	PW	(dry ton PMh^{-1})	$a+bH_2$
Bilici et al. (2019)	1	FT	FB	EB	CT	PV	(m^3 h^{-1})	$-a+bD_1+cH_1$
	2	*FT	FB	EB	CT	PV	(m^3 h^{-1})	$-a+bD_1+cH_1$
	3	FT	FB	EB	CT	PV	(m^3 h^{-1})	$-a+bD_1$
	4	*FT	FB	EB	CT	PV	(m^3 h^{-1})	$-a+bD_1$

	5	FT	FB	EB	CT	PV	$(m^3\ h^{-1})$	$a+bV_1$
	6	*FT	FB	EB	CT	PV	$(m^3\ h^{-1})$	$a+bV_1$
Brewer et al. (2018)	1	CTL	H	PB	RW	PV	$(m^3\ PMh^{-1})$	$a+bV_1$
	2	CTL	H	PB	RW	PV	$(m^3\ PMh^{-1})$	$a+bV_1$
	3	CTL	H	PB	RW	PV	$(m^3\ PMh^{-1})$	$a+bV_1$
	4	CTL	H	PB	RW	PV	$(m^3\ PMh^{-1})$	$a+bV_1$
	5	CTL	H	PB	RW	PV	$(m^3\ PMh^{-1})$	$a+bV_1$
	6	CTL	H	PB	RW	PV	$(m^3\ PMh^{-1})$	$a+bV_1$
	7	CTL	H	PB	RW	PV	$(m^3\ PMh^{-1})$	$a+bV_1$
	8	CTL	H	PB	RW	PV	$(m^3\ PMh^{-1})$	$a+bV_1$
Brown et al. (2013)	1	FT	FB	PB	CT	PV	$\surd(m^3\ PMh_0^{-1})$	$a+b\mathit{ln}(V_1)$
	2	FT	FB	PB	CT	PV	$\surd(m^3\ PMh_0^{-1})$	$a+b\mathit{ln}(V_1)$
Carter et al. (2017)	1	FT	FB	PB	CT	W	cycle (centi-min)	$a+bA_1+cN_1+dA_3$
Chakroun et al. (2016)	1	*FT	FB	EB	CT	PV	$(m^3\ PMh^{-1})$	$(a+bE_{10})V_1^c$
	2	*FT	FB	EB	CT	PV	$(m^3\ PMh^{-1})$	$(a+bE_{10})V_1^c$
	3	*FT	FB	EB	CT	PV	$(m^3\ PMh^{-1})$	$(a-bE_{10})V_1^c$
	4	*FT	FB	EB	CT	PV	$(m^3\ PMh^{-1})$	$(a+bO_{15})V_1^c$
	5	*FT	FB	EB	CT	PV	$(m^3\ PMh^{-1})$	$(a+bO_{15})V_1^c$
Chung et al. (2022)	1	FT	FB	PB	CT	W	cycle (s)	$a+bA_2+cD_{13}+dD_{13}$
	2	FT	FB	PB	CT	W	cycle (s)	$a+bA_4+cN_2$
Di Fulvio & Bergström (2013)	1	CTL	HW	PB	RW	TV	$(PMmin\ m^{3\ -1})$	$a+bI_5-cT_1$
Erber et al. (2016)	1	CTL	H	PB	RW	M	move $(PSH_0$ dry $ton^{-1})$	$a-bT_8$
	2	CTL	H	PB	RW	E	fell $(PSH_0$ dry $ton^{-1})$	$a+bD_2^{-c}-dN_3-eT_8$
	3	CTL	H	PB	RW	E	process $(PSH_0$ dry $ton^{-1})$	$a+bD_2^{-c}-dN_3-eT_8$
	4	CTL	H	PB	RW	TW	$(PSH_0$ dry $ton^{-1})$	$a+bD_2^{-c}-dN_3-eT_8$
Eriksson & Lindroos (2014)	1	CTL	H	PB	RW	PV	$\mathit{ln}\ (m^3ub\ PMh^{-1})$	$a+b\mathit{ln}(V_3)-c(\mathit{ln}(V_3))^d$
	2	CTL	H	PB	RW	PV	$\mathit{ln}\ (m^3ub\ PMh^{-1})$	$a+b\mathit{ln}(V_3)+c\mathit{ln}(V_{13})+d\mathit{ln}(V_{14})-e(\mathit{ln}(V_3))^f$
	3	CTL	H	PB	RW	PV	$\mathit{ln}\ (m^3ub\ PMh^{-1})$	$a+b\mathit{ln}(V_3)+c\mathit{ln}(V_{13})+d\mathit{ln}(V_{14})-e(\mathit{ln}(V_3))^f-g\mathit{ln}(S_3S_2)-h\mathit{ln}(O_9)-iT_{10}$

	4	CTL	H	PB	RW	PV	ln (m^{3}ub PMh^{-1})	$a+b\mathit{ln}(V_3)+c\mathit{ln}(V_{13})+d\mathit{ln}(V_{14})-e(\mathit{ln}(V_3))^f-g\mathit{ln}(S_3S_2)-h\mathit{ln}(O_9)-iT_{10}+jS_5-kS_4-l\mathit{ln}(S_6)+mE_{11}+n\mathit{ln}(E_6)$
	5	CTL	H	PB	RW	PV	ln (m^{3}ub PMh^{-1})	$a+b\mathit{ln}(V_3)+c\mathit{ln}(V_{13})+d\mathit{ln}(V_{14})-e(\mathit{ln}(V_3))^f-g\mathit{ln}(S_3S_2)-h\mathit{ln}(O_9)-iT_{10}+jS_5-kS_4-l\mathit{ln}(S_6)+mE_{11}+n\mathit{ln}(E_6)+oE_{12}\mathit{ln}(V_3)+pE_{12}\mathit{ln}(V_3)+qE_{12}\mathit{ln}(V_3)+rE_{12}\mathit{ln}(V_3)+sE_{12}\mathit{ln}(V_3)$
	6	CTL	H	PB	RW	PV	ln (m^{3}ub PMh^{-1})	$a+b\mathit{ln}(V_3)-c(\mathit{ln}(V_3))^d$
	7	CTL	H	PB	RW	PV	ln (m^{3}ub PMh^{-1})	$a+b\mathit{ln}(V_3)+c\mathit{ln}(V_{13})+d\mathit{ln}(V_{14})$
	8	CTL	H	PB	RW	PV	ln (m^{3}ub PMh^{-1})	$a+b\mathit{ln}(V_3)+c\mathit{ln}(V_{13})+d\mathit{ln}(V_{14})-e\mathit{ln}(S_3S_2)-f\mathit{ln}(O_9)-g\mathit{ln}(S_6)$
	9	CTL	H	PB	RW	PV	ln (m^{3}ub PMh^{-1})	$a+b\mathit{ln}(V_3)+c\mathit{ln}(V_{13})+d\mathit{ln}(V_{14})-e\mathit{ln}(S_3S_2)-f\mathit{ln}(O_9)-g\mathit{ln}(S_6)+hS_5-iS_4+jE_{11}+k\mathit{ln}(E_6)-l\mathit{ln}(E_7)+mE_{12}\mathit{ln}(V_3)+nE_{12}\mathit{ln}(V_3)+oE_{12}\mathit{ln}(V_3)$
Fernandez-Lacruz et al. (2013)	1	FT	FB	PB	RW	TW	(PWmin ODton^{-1})	$\mathit{exp}^aH_2^{-b}$
Fernandez-Lacruz et al. (2021)	1	*FT	FB	PB	RW	TW	(PMmin dry ton^{-1})	$\mathit{exp}^aH_2^{-b}$
	2	*FT	FB	PB	RW	TW	(PMmin dry ton^{-1})	$\mathit{exp}^aD_2^{-b}$
George et al. (2022)	1	CTL	H	PB	RW	W	cycle (s)	$a+bN_4+cO_8+dO_8-eM_5+fM_5+gA_8+hA_1+iD_{12}$
Ghaffariyan (2013)	1	FT	FB	PB	CT	PW	(ton PMh$_0^{-1}$)	$a+b\mathit{ln}(V_1)$
	2	FT	FB	PB	CT	W	cycle (s)	aV_1^{-b}
Ghaffariyan et al. (2019)	1	CTL	H	-	-	PV	(m^3 PMh$_0^{-1}$)	aV_1^b
Ghaffariyan et al. (2013)	1	FT	FB	PB	CT	PW	(GMton PMh$_0^{-1}$)	$a+b\mathit{ln}(V_1)$
Ghaffariyan et al. (2015)	1	CTL	H	PB	CT	W	cycle (PMmin$_0$)	$a\mathit{exp}^{bD_1}$
Green et al. (2020)	1	CTL	H	PB	RW	W	cycle (s)	$-a+bD_1+cA_1+dN_4$
	2	CTL	H	PB	RW	W	cycle (s)	$-a+bD_1+cA_1+dN_4$
Grönlund & Eliasson (2019)	1	CTL	H	PB	RW	TW	(s ODton^{-1})	$a-bB_2+cI_3$
Gülci et al. (2021)	1	FT	FB	EB	CT	PV	(m^3 h^{-1})	$-a+bH_1+cD_1+dV_1$
	2	FT	FB	EB	CT	PV	(m^3 h^{-1})	$a+bH_1+cD_1+dV_1$
	3	FT	FB	EB	CT	PV	(m^3 h^{-1})	$a-bH_1+cH_1^d-eD_1+fD_1^g-hV_1-iV_1^j$
	4	FT	FB	EB	CT	PV	(m^3 h^{-1})	$a-bH_1+cH_1^d-eD_1+fD_1^g-hV_1-iV_1^j$
Han et al. (2018)	1	FT	FB	PB	CT	W	cycle (s)	$a+bN_6+cN_7+dA_1$

Hiesl & Benjamin (2013)	1	FT	FB	PB	CT	W	*log* (PMmin_{15})	$-a+bN_9+cD_4$
Hiesl & Benjamin (2015)	1	CTL	H	PB	RW	W	*log* (PMmin_{15})	$-a+bD_1-cO_8$
Hiesl et al. (2015)	1	CTL	H	PB	RW	PW	(ton PMh_{15}^{-1})	$-a+bI_5-cI_4-dO_{14}+eB_{16}+fV_1$
	2	FT	FB	PB	CT	PW	(ton PMh_{15}^{-1})	$a-bI_5-cI_4+dO_{14}+eB_{16}$
Holzleitner & Kanzian (2022)	1	CTL	H	PB	RW	PV	($\text{m}^3\ \text{PSh}_0^{-1}$)	$a+bV_1^c-dT_9$
	2	CTL	H	PB	RW	PV	($\text{m}^3\ \text{PSh}_0^{-1}$)	$a+bV_1^c-dT_9+eM_5-fV_1M_5$
	3	CTL	H	PB	RW	PV	($\text{m}^3\ \text{PSh}_0^{-1}$)	$a+bV_1^c-dT_9$
Horváth et al. (2016)	1	CTL	H	-	-	W	cycle (min)	$aO_1^bO_2^cO_3^dO_{11}^eV_1^f$
	2	CTL	H	-	-	W	cycle (min)	$aO_1^{-b}O_2^cO_3^dO_{11}^eV_1^f$
	3	CTL	H	-	-	W	cycle (min)	$aO_1^bO_2^eO_3^dO_{11}^eV_1^{-f}$
	4	CTL	H	-	-	W	cycle (min)	$aO_1^{-b}O_2^cO_3^dO_{11}^eV_1^{-f}$
	5	CTL	H	-	-	W	cycle (min)	$aO_1^{-b}O_2^cO_3^dO_{11}^eV_1^{-f}$
	6	CTL	H	-	-	W	cycle (min)	$aO_2^bO_3^cO_{11}^dV_1^e$
	7	CTL	H	-	-	W	cycle (min)	$aO_1^bO_2^cO_3^dO_{11}^eV_1^f$
	8	CTL	H	-	-	W	cycle (min)	$aO_1^bO_2^cO_3^dO_{11}^eV_1^f$
	9	CTL	H	-	-	W	cycle (min)	$aO_1^bO_2^cO_3^dO_{11}^eV_1^f$
	10	CTL	H	-	-	W	cycle (min)	$aO_{11}^{-b}V_1^c$
	11	CTL	H	-	-	W	cycle (min)	$aO_1^bO_2^cO_3^dO_{11}^eV_1^f$
	12	CTL	H	-	-	TV	($\text{min m}^{3\ -1}$)	$aO_1^bO_2^cO_3^dO_{11}^eV_1^{-f}$
	13	CTL	H	-	-	TV	($\text{min m}^{3\ -1}$)	$aO_1^{-b}O_2^cO_3^dO_{11}^eV_1^{-f}$
	14	CTL	H	-	-	TV	($\text{min m}^{3\ -1}$)	$aO_1^bO_2^cO_3^dO_{11}^eV_1^{-f}$
	15	CTL	H	-	-	TV	($\text{min m}^{3\ -1}$)	$aO_1^{-b}O_2^cO_3^dO_{11}^eV_1^{-f}$
	16	CTL	H	-	-	TV	($\text{min m}^{3\ -1}$)	$aO_1^{-b}O_2^cO_3^dO_{11}^eV_1^{-f}$
	17	CTL	H	-	-	TV	($\text{min m}^{3\ -1}$)	$aO_2^bO_3^cO_{11}^dV_1^{-e}$
	18	CTL	H	-	-	TV	($\text{min m}^{3\ -1}$)	$aO_1^bO_2^cO_3^dO_{11}^eV_1^{-f}$
	19	CTL	H	-	-	TV	($\text{min m}^{3\ -1}$)	$aO_1^bO_2^cO_3^dO_{11}^eV_1^{-f}$
	20	CTL	H	-	-	TV	($\text{min m}^{3\ -1}$)	$aO_1^bO_2^cO_3^dO_{11}^eV_1^{-f}$
	21	CTL	H	-	-	TV	($\text{min m}^{3\ -1}$)	$aO_{11}^{-b}V_1^{-c}$
	22	CTL	H	-	-	TV	($\text{min m}^{3\ -1}$)	$aO_1^bO_2^cO_3^dO_{11}^eV_1^{-f}$
	23	CTL	H	-	-	PV	($\text{m}^3\ \text{min}^{-1}$)	$aO_1^{-b}O_2^{-c}O_3^{-d}O_{11}^{-e}V_1^f$

	24	CTL	H	-	-	PV	(m^3 min^{-1})	$aO_1^{b}O_2^{-c}O_3^{-d}O_{11}^{-e}V_1^{f}$
	25	CTL	H	-	-	PV	(m^3 min^{-1})	$aO_1^{-b}O_2^{-c}O_3^{-d}O_{11}^{-e}V_1^{f}$
	26	CTL	H	-	-	PV	(m^3 min^{-1})	$aO_1^{b}O_2^{-c}O_3^{-d}O_{11}^{-e}V_1^{f}$
	27	CTL	H	-	-	PV	(m^3 min^{-1})	$aO_1^{b}O_2^{-c}O_3^{-d}O_{11}^{-e}V_1^{f}$
	28	CTL	H	-	-	PV	(m^3 min^{-1})	$aO_2^{-b}O_3^{-c}O_{11}^{-d}V_1^{e}$
	29	CTL	H	-	-	PV	(m^3 min^{-1})	$aO_1^{-b}O_2^{-c}O_3^{-d}O_{11}^{-e}V_1^{f}$
	30	CTL	H	-	-	PV	(m^3 min^{-1})	$aO_1^{-b}O_2^{-c}O_3^{-d}O_{11}^{-e}V_1^{f}$
	31	CTL	H	-	-	PV	(m^3 min^{-1})	$aO_1^{-b}O_2^{-c}O_3^{-d}O_{11}^{-e}V_1^{f}$
	32	CTL	H	-	-	PV	(m^3 min^{-1})	$aO_{11}^{b}V_1^{c}$
	33	CTL	H	-	-	PV	(m^3 min^{-1})	$aO_1^{-b}O_2^{-c}O_3^{-d}O_{11}^{-e}V_1^{f}$
Jernigan et al. (2015)	1	FT	FB	PB	CT	W	cycle (PMmin)	$a+bN_9$
Jylhä & Bergström (2016)	1	FT	FB	PB	RW	PW	(ODton E$_0$h^{-1})	aV_{12}^{b}
	2	FT	FB	PB	RW	PW	(ODton E$_0$h^{-1})	aH_2^{b}
	3	FT	FB	PB	RW	PW	(ODton E$_0$h^{-1})	aI_5^{-b}
	4	FT	FB	PB	RW	PW	(ODton E$_0$h^{-1})	aD_5^{b}
	5	FT	FB	PB	RW	PW	(ODton E$_0$h^{-1})	aB_3^{b}
	6	FT	FB	PB	RW	PW	(ODton E$_0$h^{-1})	aH_1^{b}
	7	FT	FB	PB	RW	PW	(ODton E$_0$h^{-1})	aD_6^{b}
	8	FT	FB	PB	RW	PW	(ODton E$_0$h^{-1})	aH_3^{b}
Kärhä et al. (2018a)	1	CTL	H	PB	RW	E	fell, process (s)	$a+bV_1-cV_1^{d}+eV_1^{f}+gO_{13}$
	2	CTL	H	PB	RW	E	fell, process (s)	$a+bV_1-cV_1^{d}+eV_1^{f}+gO_{13}$
	3	CTL	H	PB	RW	E	fell, process (s)	$a+bV_1-cV_1^{d}+eV_1^{f}+gO_{13}$
	4	CTL	H	PB	RW	M	moving (s)	$a+b/I_3+cO_{13}$
Kärhä et al. (2018b)	1	CTL	HW	PB	RW	PV	(m^3 E$_{15}^{-1}$)	$-a+b\mathit{ln}(V_2)$
Kärhä et al. (2019)	1	CTL	H	PB	RW	E	fell, process (s)	$a+bV_1-cV_1^{d}+eV_1^{f}-gT_2$
	2	CTL	H	PB	RW	E	fell, process (s)	$a+bV_1-cV_1^{d}+eV_1^{f}+gT_2$
	3	CTL	H	PB	RW	E	fell, process (s)	$a+bV_1-cV_1^{d}+eV_1^{f}+gT_2$
	4	CTL	H	PB	RW	E	fell, process (s)	$a+bV_1-cV_1^{d}+eV_1^{f}+gT_2$
	5	CTL	H	PB	RW	E	fell, process (s)	$a+bV_1-cV_1^{d}+eV_1^{f}+gT_2$
	6	CTL	H	PB	RW	E	fell, process (s)	$a+bV_1-cV_1^{d}+eV_1^{f}+gT_2$

	7	CTL	H	PB	RW	E	fell, process (s)	$a+bV_1-cV_1^d+eV_1^f+gT_2$
	8	CTL	H	PB	RW	PV	(m^3 E_0^{-1})	$a+bV_1-cV_1^d+eV_1^f$
	9	CTL	H	PB	RW	PV	(m^3 E_0^{-1})	$a+bV_1-cV_1^d-eV_1^f$
	10	CTL	H	PB	RW	PV	(m^3 E_0^{-1})	$a+bV_1-cV_1^d-eV_1^f$
	11	CTL	H	PB	RW	PV	(m^3 E_0^{-1})	$a+bV_1-cV_1^d-eV_1^f$
	12	CTL	H	PB	RW	PV	(m^3 E_0^{-1})	$a+bV_1-cV_1^d-eV_1^f$
	13	CTL	H	PB	RW	PV	(m^3 E_0^{-1})	$a+bV_1-cV_1^d-eV_1^f$
	14	CTL	H	PB	RW	PV	(m^3 E_0^{-1})	$a+bV_1-cV_1^d-eV_1^f$
Karpachev & Bykovskiy (2019)	1	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$a+b\mathit{ln}(M_7)$
	2	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$a+b\mathit{ln}(M_7)$
	3	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$-a+b\mathit{ln}(M_7)$
	4	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$a-bM_6$
	5	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$a-bM_6$
	6	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$a-bM_6$
	7	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$a+b\mathit{ln}(M_7)$
	8	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$-a+b\mathit{ln}(M_7)$
	9	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$-a+b\mathit{ln}(M_7)$
	10	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$-a+bV_1$
	11	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$a+b\mathit{ln}(V_1)$
	12	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$a+b\mathit{ln}(V_1)$
	13	FT	FB Sim	PB	RW	PV	(m^3 $shift^{-1}$)-D	$a+b\mathit{ln}(V_1)$
Kim et al. (2017)	1	FT	FB	PB	CT	W	cycle (s)	$a+bN_6+cN_7+dA_2$
Kizha & Han (2016)	1	FT	FB	PB	CT	W	*log* cycle (centi-min)	$a+bN_3-cM_5-dM_5+eD_1+fO_7+gO_7+hO_7$
	2	FT	FB	PB	CT	W	*log* cycle (centi-min)	$a+bN_3-cM_5-dM_5+eD_1-fO_7-gO_7$
	3	FT	FB	PB	CT	W	*log* cycle (centi-min)	$a+bN_3-cM_5-dM_5+eD_1-fO_7-gO_7-hO_7$
	4	FT	FB	PB	CT	W	*ln* cycle (centi-min)	$a-bN_3-cM_5-dM_5+eD_1+fO_7-gO_7+hO_7$
	5	FT	FB	PB	CT	W	*ln* cycle (centi-min)	$a+bN_3-cM_5-dM_5+eD_1-fO_7-gO_7-hO_7$
	6	FT	FB	PB	CT	W	*ln* cycle (centi-min)	$a-bN_3+cM_5+dM_5-eA_1-fD_1+gO_7-hO_7-IO_7$
Kormanek & Baj (2018)	1	CTL	H	PB	RW	E	fell (s)	$a+bD_1$

	2	CTL	H	PB	RW	E	delimb, buck (s)	$a+bD_1$
Kormanek & Kępa (2016)	1	CTL	H	PB	RW	E	fell (s)	$-a+bD_1$
Krč et al. (2015)	1	CTL	H	PB	RW	E	fell, process (s)	$a+bO_4+cO_5+dO_6+eD_1$
Labelle et al. (2017)	1	CTL	H	EB	CT	PV	(m^3 PMh$_0^{-1}$)	$a-bD_1+cD_1^d-eD_1^f$
	2	CTL	H	EB	CT	PV	(m^3 PMh$_0^{-1}$)	$a-bD_1+cD_1^d-eD_1^f$
	3	CTL	H	EB	CT	PV	(m^3 PMh$_0^{-1}$)	aD_1^b
	4	CTL	H	EB	CT	PV	(m^3 PMh$_0^{-1}$)	aD_1^b
Labelle et al. (2018)	1	CTL	H	PB	RW	PV	(m^3 PMh$_0^{-1}$)	$-a+bD_1-cD_1^d$
	2	CTL	H	PB	RW	PV	(m^3 PMh$_0^{-1}$)	$-a+bD_1-cD_1^d$
	3	CTL	H	PB	CT	PV	(m^3 PMh$_0^{-1}$)	$-a+bD_1-cD_1^d$
	4	CTL	H	PB	CT	PV	(m^3 PMh$_0^{-1}$)	$-a+bD_1-cD_1^d$
Labelle & Huß (2018)	1	CTL	H	PB	RW	PV	(m^{3}ub PMh$_0^{-1}$)	$aV_3-bV_3^c$
	2	CTL	H	PB	RW	PV	(m^{3}ub PMh$_0^{-1}$)	$aV_3-bV_3^c$
Labelle et al. (2016)	1	CTL	H	PB	CT	PV	(m^3 PMh^{-1})	aD_1^b
	2	CTL	H	PB	CT	PV	(m^3 PMh^{-1})	aD_1^b
Labelle et al. (2019)	1	CTL	H	PB	RW	PV	(m^3 PMh$_0^{-1}$)	$-a+bD_1-cD_1^d$
	2	CTL	H	PB	RW	PV	(m^3 PMh$_0^{-1}$)	$-a+bD_1-cD_1^d$
	3	CTL	H	PB	RW	PV	(m^3 PMh$_0^{-1}$)	$-a+bD_1-cD_1^d$
	4	CTL	H	PB	RW	PV	(m^3 PMh$_0^{-1}$)	$a+bD_1-cD_1^d$
	5	CTL	H	PB	RW	PV	(m^3 PMh$_0^{-1}$)	$a+bV_6-cV_6^d$
	6	CTL	H	PB	RW	PV	(m^3 PMh$_0^{-1}$)	$a+bV_6-cV_6^d$
	7	CTL	H	PB	RW	PV	(m^3 PMh$_0^{-1}$)	$a+bV_6-cV_6^d$
	8	CTL	H	PB	RW	PV	(m^3 PMh$_0^{-1}$)	$a+bV_6-cV_6^d$
Laina et al. (2013)	1	CTL	H	PB	RW	PW	(ODton h^{-1})	$(aD_1^b)/((-c+dD_1)e)$
	2	FT	FB	PB	RW	PW	(ODton h^{-1})	$(aD_1^bN_3)/(-c+d/N_3e)$
Laitila et al. (2016)	1	CTL	H	PB	RW	M	move (s tree^{-1})	$a-b\mathit{ln}(I_3)$
	2	CTL	H	PB	RW	M	move (s tree^{-1})	$-a+b(c/I_3)$
	3	CTL	H	PB	RW	E	fell (s tree^{-1})	$a-bN_9$
	4	CTL	H	PB	RW	E	fell (s tree^{-1})	$a-bN_9$
	5	CTL	H	PB	RW	E	process (s tree^{-1})	$a+bV_2$

	6	CTL	H	PB	RW	E	process (s tree^{-1})	$a+bV_2$
Laitila & Väätäinen (2014)	1	CTL	H	EB	CT	M	move (s tree^{-1})	$a-b\mathit{ln}(I_3)$
	2	CTL	H	EB	CT	E	fell (s tree^{-1})	$a+b(c/N_9)$
	3	CTL	H	EB	CT	E	process (s tree^{-1})	$-a+b\mathit{ln}(V_2)$
Laitila & Väätäinen (2020)	1	*FT	HW	PB	RW	M	move (s tree^{-1})	$a+b/I_3$
	2	*FT	HW	PB	RW	E	fell (s tree^{-1})	$-a+b\mathit{ln}(V_2)$
	3	*FT	HW	PB	RW	L	load (s grapple-load^{-1})	$-a+b/E_{14}$
Laitila & Väätäinen (2021)	1	FT	FB	EB	CT	M	move (s)	$a-bI_3$
	2	FT	FB	EB	CT	E	fell, bunch (s tree^{-1})	$a+bV_2$
Laitila & Väätäinen (2023)	1	FT	FB	EB	CT	E	fell, bunch (s tree^{-1})	$a-b\mathit{exp}N_9$
Laitila et al. (2013)	1	*CTL	H	PB	RW	M	move (s tree^{-1})	$a-b\mathit{ln}(I_3)$
	2	*CTL	H	PB	RW	E	fell, process (s)	$-a+bD_1-cD_1^d+eD_1^f$
	3	*CTL	H	PB	RW	E	fell, process (s)	$a+bD_1+cD_1^d$
Laitila et al. (2020)	1	CTL	H	PB	RW	E	fell, process (s)	$a+bV_2+cV_2^d$
Lazdiņš et al. (2019)	1	CTL	H	-	-	PV	(m^3 h^{-1})	aD_1^b
	2	CTL	H	-	-	PV	(m^3 h^{-1})	aD_1^b
	3	CTL	H	-	-	PV	(m^3 h^{-1})	aD_1^b
Lazdiņš (2014)	1	CTL	H	PB	RW	TU	(centi-min tree^{-1})	$a\mathit{exp}^{bD_1}$
Lazdiņš et al. (2021)	1	CTL	H	PB	RW	PV	(m^3 h^{-1})	$a+bV_1-cV_1^d+dV_1^e$
Lazdiņš et al. (2016)	1	CTL	H	PB	RW	PV	(m^3 h^{-1})	aD_1^b
	2	CTL	H	PB	RW	PU	(trees h^{-1})	aD_1^{-b}
Leszczyński et al. (2021)	1	CTL	H	EB	CT	PV	(m^3 PMh_{15}^{-1})	aV_1^b
	2	CTL	H	EB	CT	PV	(m^3 PMh_{15}^{-1})	aV_1^b
	3	CTL	H	EB	CT	PV	(m^3 PMh_{15}^{-1})	$aV_1^bI_2^c$
	4	CTL	H	EB	CT	PV	(m^3 PMh_{15}^{-1})	aV_1^b
	5	CTL	H	EB	CT	PV	(m^3 PMh_{15}^{-1})	aI_2^b
	6	CTL	H	EB	CT	PV	(m^3 PMh_{15}^{-1})	aI_2^b
Liski et al. (2020)	1	CTL	H	PB	RW	PV	(m^3 E_0h^{-1})	$a+bT_7+cE_{13}-dE_{13}-eE_{12}+fE_{12}+gE_{12}-hO_7-iO_7-jO_7-kO_7-lM_3-mM_3-nM_3+oV_1-pV_1q-rT_7V_1+sT_7V_1t$
	2	CTL	H	PB	RW	PV	(m^3 E_0h^{-1})	$a+bT_7-cO_7-dO_7-eO_7-fO_7+gV_1-hV_1i$

Louis & Kizha (2021)	1	FT	FB	PB	CT	W	cycle (s)	$a+bA_1+cN_3$
	2	FT	FB	PB	CT	W	cycle (s)	$a+bA_3+cN_3$
Magagnotti et al. (2021)	1	CTL	H	PB	RW	PV	(tot above-ground m^3 SMH^{-1})*	$-a+bV_7+cT_8$
	2	CTL	H	PB	RW	PV	(m^3 SMH^{-1})*	$-a+bV_4+cT_8$
	3	CTL	H	PB	RW	PV	(m^3 SMH^{-1})*	$-a+bV_5+cT_8$
	4	CTL	H	PB	RW	PV	(m^3 SMH^{-1})*	$-a+bV_5+cT_8V_5$
Manner et al. (2023)	1	CTL	H	PB	RW	TV	(s m$^{3\ -1}$)	$a-bI_6+cI_6+dV_3+eA_1+fO_7$
	2	CTL	H	PB	RW	TV	(s m$^{3\ -1}$)	aV_3^{-b}
McEwan et al. (2016)	1	CTL	H	EB	CT	E	*ln* fell (s)	$a+bD_1^c+dP_2$
	2	CTL	H	EB	CT	E	process (s)	$a+bD_1^c+dP_2+eP_2O_{17}$
	3	CTL	H	EB	CT	E	fell, process (s)	$a+bD_1^c+dP_2+eP_2O_{17}$
Mederski et al. (2016)	1	CTL	H	PB	RW	PV	(m^3 PMh^{-1})	$-a+bD_1-cO_{16}-dO_{16}+eI_6+fI_6$
	2	CTL	H	PB	RW	PV	(m^3 PMh^{-1})	$a+bV_1+cO_{16}+dO_{16}+eI_6+fI_6$
Norihiro et al. (2018)	1	CTL	H	PB, EB	CT	PV	(m^3 PMh^{-1})	$a+bV_1$
	2	CTL	H	EB	CT	PV	(m^3 PMh^{-1})	$a+bV_1$
	3	CTL	H	PB, EB	CT	PV	(m^3 PMh^{-1})	$a+bV_1$
	4	CTL	H	EB	CT	PV	(m^3 PMh^{-1})	$a+bV_1$
	5	CTL	H	EB	CT	PV	(m^3 PMh^{-1})	$a+bV_1$
	6	CTL	H	EB	CT	PV	(m^3 PMh^{-1})	$a+bV_1$
	7	CTL	H	PB, EB	CT	PV	(m^3 PMh^{-1})	$a+bE_9-cO_{15}+dS_1-eN_{10}+fV_1$
	8	CTL	H	EB	CT	PV	(m^3 PMh^{-1})	$a+bO_{15}+cV_1$
	9	CTL	H	PB, EB	CT	PV	(m^3 PMh^{-1})	$a+bE_9-cO_{15}-dS_1-eN_{10}+fV_1$
	10	CTL	H	EB	CT	PV	(m^3 PMh^{-1})	$a+bV_1$
	11	CTL	H	EB	CT	PV	(m^3 PMh^{-1})	$a+bV_1$
	12	CTL	H	EB	CT	PV	(m^3 PMh^{-1})	$a+bV_1$
	13	CTL	H	PB	CT	PV	(m^3 PMh^{-1})	$a-bO_{15}-cS_1+dV_1$
	14	CTL	H	EB	CT	PV	(m^3 PMh^{-1})	$a-bO_{15}+cS_1+dV_1$
	15	CTL	H	EB	CT	PV	(m^3 PMh^{-1})	$a-bN_{10}+cV_1$
	16	CTL	H	EB	CT	PV	(m^3 PMh^{-1})	$a-bN_{10}+cV_1$

	17	CTL	H	PB, EB	CT	PV	(m^3 PMh^{-1})	$a+bV_1$
Nuutinen & Björheden (2016)	1	B (FT)	FB	PB	RW	E	fell (s)	$a+b\mathit{ln}(N_9)$
Olivera et al. (2016)	1	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	2	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	3	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	4	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	5	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	6	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	7	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	8	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	9	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	10	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	11	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	12	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	13	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
	14	CTL	H	PB	RW	PV	(m^{3}ub h^{-1})	$\mathit{exp}^{-a+b\mathit{ln}(D_5)}$
Petitmermet et al. (2019)	1	CTL	H	PB	RW	TU	(min corridor^{-1})	$a+bB_4+cA_5$
	2	CTL	H	PB	RW	TU	(min corridor^{-1})	$a+bB_5+cB_6+dA_5$
	3	CTL	H	PB	RW	TU	(min corridor^{-1})	$a+bB_4+cA_6+dA_7$
	4	CTL	H	PB	RW	TU	(min corridor^{-1})	$a+bB_5+cB_6+dA_6+eA_7$
	5	CTL	H	PB	RW	TU	(min corridor^{-1})	$a+bA_5+cB_7+dB_8$
	6	CTL	H	PB	RW	TU	(min corridor^{-1})	$a+bA_6+cA_7+dB_7+eB_8$
	7	CTL	H	PB	RW	TU	(min corridor^{-1})	$a+bA_5+cB_9+dB_{10}+eB_{11}+fB_{12}$
	8	CTL	H	PB	RW	TU	(min corridor^{-1})	$a+bA_6+cA_7+dB_9+eB_{10}+fB_{11}+gB_{12}$
Petty & Kärhä (2014)	1	CTL	H	PB	RW	E	fell, process (s)	$a\mathit{ln}(D_1-b)$
	2	CTL	H	PB	RW	E	fell, process (s)	$a\mathit{ln}(D_1-b)$
	3	CTL	H	PB	RW	E	fell, process (s)	$a\mathit{ln}(D_1-b)$
	4	CTL	H	PB	RW	E	fell, process (s)	$a\mathit{ln}(D_1-b)$
	5	CTL	H	PB	RW	E	fell, process (s)	$a\mathit{ln}(D_1-b)$
	6	CTL	H	PB	RW	E	fell, process (s)	$a\mathit{ln}(D_1-b)$

	7	CTL	H	PB	RW	M	move (s)	$a-b\mathit{ln}(I_3)$
	8	CTL	H	PB	RW	PV	$(m^3\ PMh_0^{-1})$	$-a+bD_1+cD_1^d$
	9	CTL	H	PB	RW	PV	$(m^3\ PMh_0^{-1})$	$-a+bD_1+cD_1^d$
	10	CTL	H	PB	RW	PV	$(m^3\ PMh_0^{-1})$	$a+bD_1+cD_1^d$
	11	CTL	H	PB	RW	PV	$(m^3\ PMh_0^{-1})$	$a+bD_1+cD_1^d$
	12	CTL	H	PB	RW	PV	$(m^3\ PMh_0^{-1})$	$a+bD_1+cD_1^d$
	13	CTL	H	PB	RW	PV	$(m^3\ PMh_0^{-1})$	$-a+bD_1+cD_1^d$
Polowy & Molińska-Glura (2023)	1	CTL	H	PB	RW	PV	$(m^3\ h^{-1})$	$-a+bV_1+cE_{15}+dE_4+eE_5$
	2	CTL	H	PB	RW	PV	$(m^3\ h^{-1})$	aV_1+bE_{15}
	3	CTL	H	PB	RW	PV	$(m^3\ h^{-1})$	$-a+bV_1+cE_{15}+dE_5$
Prinz et al. (2021)	1	CTL	H	PB	RW	E	fell (ms)	$a\mathit{exp}^{bD_5}$
	2	CTL	H	PB	RW	E	fell (ms)	$a\mathit{exp}^{bD_5}$
	3	CTL	H	PB	RW	E	crosscut (ms)	$a+bD_5-cD_5^d+eD_5^f$
	4	CTL	H	PB	RW	E	crosscut (ms)	$a-bD_5+cD_5^d-eD_5^f$
Ramantswana et al. (2013)	1	CTL	H	EB	CT	PV	$(m^3\ PMh_0^{-1})$	$a+bV_1-cV_1^d$
	2	CTL	H	EB	CT	PV	$(m^3\ PMh_0^{-1})$	$a+bV_1-cV_1^d$
	3	CTL	H	EB	CT	PV	$(m^3\ PMh_0^{-1})$	$a+bV_1-cV_1^d$
	4	CTL	H	EB	CT	PV	$(m^3\ PMh_0^{-1})$	$a+bV_8+cV_9-dV_8^e-fV_9^g-hT_6^i+jV_8T_6$
	5	CTL	H	EB	CT	PV	$(m^3\ PMh_0^{-1})$	$a+bV_8+cV_9$
	6	CTL	H	EB	CT	PV	$(m^3\ PMh_0^{-1})$	$aV_8+bV_9-cV_8^d$
	7	CTL	H	EB	CT	PV	$(m^3\ PMh_0^{-1})$	$a+bV_8-cV_9+dV_9^e-fT_6$
	8	CTL	H	EB	CT	PV	$(m^3\ PMh_0^{-1})$	$a+bV_8+cV_9-dV_8^e-fV_9^g$
	9	CTL	H	EB	CT	PV	$(m^3\ PMh_0^{-1})$	$a+bV_1-cV_1^d+eO_{10}$
Rosińska et al. (2022)	1	CTL	H	PB	RW	PV	$(m^3ub\ h^{-1})$	$-a+bD_7$
	2	CTL	H	PB	RW	PV	$(m^3ub\ h^{-1})$	$-a+bD_8-cD_8^d$
	3	CTL	H	PB	RW	PV	$(m^3ub\ h^{-1})$	$a+bV_1-cD_8+dD_7$
	4	CTL	H	PB	RW	PV	$(m^3ub\ h^{-1})$	$-a+bD_9$
	5	CTL	H	PB	RW	PV	$(m^3ub\ h^{-1})$	$-a+bD_{10}$
	6	CTL	H	PB	RW	PV	$(m^3ub\ h^{-1})$	$-a+bD_7+cD_8-dD_7D_8+eD_7^f-gD_8^h$

Santos et al. (2022)	1	CTL	H	PB	CT	PV	(m^3 h^{-1})-D	$a+bV_3-cV_3^d$
Santos et al. (2021)	1	CTL	H	PB	CT	PV	(m^3 h^{-1})-D	$a+bV_1-cV_1^d$
Santos et al. (2020)	1	CTL	H	PB	CT	M	move (s)	$a+bE_1^c+dE_2^e-fE_1E_2$
	2	CTL	H	PB	CT	E	fell (s)	$a+bE_1^c+dE_2^e-fE_1E_2$
	3	CTL	H	PB	CT	E	process (s)	$a-bE_1+cE_1^d-eE_2+fE_2^g+hE_1E_2$
	4	CTL	H	PB	CT	M	move (s)	$a-bE_1^c-dE_2^e$
	5	CTL	H	PB	CT	E	fell (s)	$a-bE_1^c-dE_2^e$
	6	CTL	H	PB	CT	E	process (s)	$a+bE_1^c+dE_2^e-fE_1E_2$
	7	CTL	H	PB	CT	PV	(m^3 h^{-1})-U	$a-bE_1^c-dE_2^e+fE_1E_2$
	8	CTL	H	PB	CT	PV	(m^3 h^{-1})-U	$-a+bE_2+cE_1^d$
Schweier et al. (2015)	1	FT	FB	EB	CT	W	cycle (s)	$a+bB_{13}+cN_8$
	2	FT	FB	EB	CT	W	cycle (s)	$a+bB_{13}+cN_8$
	3	FT	FB	EB	CT	W	cycle (s)	$a+bB_{13}$
	4	FT	FB	EB	CT	W	cycle (s)	$a+bB_{13}$
	5	FT	FB	EB	CT	W	cycle (s)	$a-bB_{13}+cB_{13}^d$
Slugeň et al. (2014)	1	CTL	H	PB	RW	E	process (min)	$-a+bO_{11}$
Soman et al. (2020)	1	FT	FB	PB	CT	W	*log* cycle (min)	$a+bA_1+cN_3$
	2	FT	FB	PB	CT	W	*log* cycle (min)	$a+bO_8$
	3	FT	FB	PB	CT	W	*log* cycle (min)	$a+bA_1+cA_3+dN_3$
Soman et al. (2019)	1	FT	FB	PB	CT	W	cycle (s)	$a+bA_1+cD_{11}+dA_3+eN_3$
	2	FT	FB	PB	CT	W	cycle (s)	$a+bA_1+cD_{11}+dA_3+eN_3-fM_1$
Sperandio et al. (2021)	1	*FT	FB	EB	CT	E	fell (s)	aB_{14}^{-b}
	2	*FT	FB	EB	CT	E	fell (s)	aB_{14}^b
	3	*FT	FB	EB	CT	PW	(ton h$_{15}^{-1}$)	aB_{14}^b
	4	*FT	FB	EB	CT	PW	(ton h$_{15}^{-1}$)	aB_{14}^b
Spinelli et al. (2014)	1	FT	FB, FB DT	PB, EB	CT	PW	(ton SMH^{-1})-D	$a+bB_{15}-cT_3$
Spinelli & De Arruda Moura (2019)	1	CTL	H	EB	CT	PV	(m^{3}ub h^{-1})	$a+b\,log(V_3)+cT_4$
Spinelli et al. (2022)	1	CTL	H	PB	RW	PW	(Bone dry ton SMH^{-1})*	$a-bB_3-cE_9-dE_9$

Spinelli et al. (2023)	1	CTL	H	PB	RW	PW	(Bone dry ton SMH^{-1})*	$a+bB_3-cT_5B_3$
Spinelli et al. (2020a)	1	CTL	H Sim	PB	RW	PV	(m^3 h^{-1})-U	$a+bP_1-cO_8$
	2	CTL	H Sim	PB	RW	PV	(m^3 h^{-1})-U	$a-bM_2$
Spinelli et al. (2020b)	1	FT	FB	EB	CT	W	cycle (s)	$a-bB_{14}$
	2	FT	FB	EB	CT	PU	(tree SMH^{-1})*	$a-bB_{14}$
	3	FT	FB	EB	CT	PW	(ton SMH^{-1})*	$a-bB_{14}$
Stoilov et al. (2021)	1	CTL	SH	PB	RW	W	cycle (min)	$-a+bA_9+cE_8+dN_3$
	2	CTL	SH	PB	RW	W	cycle (min)-D	aA_9
	3	CTL	SH	PB	RW	PV	(m^3 PMh^{-1})	$a-bA_9-cN_3$
	4	CTL	SH	PB	RW	PV	(m^3 PMh^{-1})-D	$a-bA_9$
Strandgard & Mitchell (2018)	1	*CTL	H	EB	CT	W	cycle (s)	$a\mathit{exp}^{a+bN_{10}+cN_4}$
	2	*CTL	H	EB	CT	W	cycle (s)	$a\mathit{exp}^{a+bN_4}$
	3	*CTL	H	EB	CT	W	cycle (s)	$a\mathit{exp}^{a+bN_4}$
	4	*CTL	H	EB	CT	E	fell (s)	$a+bN_4$
	5	*CTL	H	EB	CT	E	process (s)	$a\mathit{exp}^{a+bN_{10}+cN_4}$
	6	*CTL	H	EB	CT	E	process (s)	$a\mathit{exp}^{a+bN_{10}+cN_4}$
	7	*CTL	H	EB	CT	E	process (s)	$a\mathit{exp}^{a+bN_4}$
Strandgard & Mitchell (2019)	1	CTL	H	PB	CT	W	cycle (PMh$_0$)	$a\mathit{exp}^{bV_1}$
	2	CTL	H	PB	CT	PV	(m^3 PMh$_0$$^{-1}$)	aV_1^{b}
	3	CTL	H	PB	CT	W	cycle (PMh$_0$)	$a\mathit{exp}^{bV_1}$
	4	CTL	H	PB	CT	PV	(m^3 PMh$_0$$^{-1}$)	aV_1^{b}
Strandgard & Mitchell (2020)	1	FT	FB	EB	CT	PV	(m^3 PMh$_0$$^{-1}$)	aV_1^{b}
	2	CTL	H	PB	RW	W	cycle (min)	aV_1^{b}
	3	CTL	H	PB	RW	PV	(m^3 PMh$_0$$^{-1}$)	aV_1^{b}
Strandgard et al. (2016)	1	CTL	H	PB, EB	CT	PV	(m^3 PMh$_0$$^{-1}$)	$a+bV_1+cE_3$
	2	CTL	H	PB, EB	CT	PV	(m^3 PMh$_0$$^{-1}$)	$a+bV_1$
Strandgard et al. (2015)	1	FT	FB	PB	CT	PV	(m^3 PMh$_0$$^{-1}$)	$aV_{10}^{b}V_{11}^{c}$
Tajbos & Messingerova (2014)	1	CTL	H	PB	RW	W	cycle (min)	$a+bV_1$
	2	CTL	H	PB	RW	W	cycle (min)	$a+bV_1$
	3	CTL	H	PB	RW	M	move (min)	$a+bA_1$

	4	CTL	H	PB	RW	M	move (min)	$a+bA_1$
	5	CTL	H	PB	RW	E	process (min)	$a+bO_{11}$
	6	CTL	H	PB	RW	E	process (min)	$a+bO_{11}$
Tolosana et al. (2023)	1	B (FT)	FB	PB	RW	PW	(ODton EWH^{-1})	$-a+b\mathit{ln}(B_1)$
	2	B (FT)	FB	PB	RW	PW	(ODton EWH^{-1})	$-a+b\mathit{ln}(B_1)$
	3	B (FT)	FB	PB	RW	PW	(ODton SMH^{-1})-D	$-a+bI_1^c+dB_1^e$
Tolosana et al. (2018)	1	FT	FB DT	PB	RW	PW	(ODton PMh^{-1})	$-a+bI_1+cB_1+dO_7$
	2	FT	FB DT	PB	RW	PW	(ODton PMh^{-1})	$-a+bI_1+cB_1+dO_7$
Townsend et al. (2019)	1	FT	FB DT	PB	RW	W	cycle (min)	$a+bN_3$
	2	FT	FB DT	PB	RW	W	cycle (min)	$a+bN_3$
	3	FT	FB DT	PB	RW	W	cycle (min)	$a+bN_3$
	4	CTL	H	EB	CT	W	cycle (min)	$-a+bN_3+cA_1+dD_1+eN_4$
	5	FT	FB	PB	CT	W	cycle (min)	$a+bN_3+cA_1$
Walsh & Strandgard (2014)	1	CTL	H	PB	CT	PW	(GMton PMh$_0^{-1}$)	$a+b\mathit{ln}(V_1)$
	2	CTL	H	PB	CT	PW	(GMton PMh$_0^{-1}$)	$a+b\mathit{ln}(V_1)$
Walsh et al. (2014)	1	CTL	H	PB	CT	PV	(m^3 PMh$_0^{-1}$)	$a+b\mathit{ln}(V_1)$
	2	CTL	H	PB	CT	PV	(m^3 PMh$_0^{-1}$)	$a+b\mathit{ln}(V_1)$
Williams & Ackerman (2016)	1	CTL	H	PB	CT	PV	(m^3 PMh$_0^{-1}$)	$-a+bD_1-cS_1-dA_1$
Zimelis et al. (2020)	1	CTL	H	PB	RW	TU	(min tree^{-1})	$a-bD_1+cD_1^d$
	2	CTL	H	PB	RW	PV	(m^3 h^{-1})	$-a+bD_1-cD_1^d$
Zimelis et al. (2018)	1	CTL	H	PB	RW	PV	(m^3 h^{-1})	$-a+bD_1$
	2	CTL	H	PB	RW	E	delimb, buck (s)	$a-bD_1+cD_1^d$
Zimelis et al. (2019)	1	CTL	H	PB	RW	PV	(m^3 h^{-1})	$-a+bD_1-cD_1^d+eD_1^f$
	2	CTL	H	PB	RW	PV	(m^3 h^{-1})	$a-bD_1+cD_1^d-eD_1^f$
Zimelis et al. (2017a)	1	CTL	H	PB	RW	E	feed roller operation (s tree^{-1})	$-a+b\mathit{ln}(D_1)$
	2	CTL	H	PB	RW	E	feed roller operation (s tree^{-1})	$-a+b\mathit{ln}(D_1)$
	3	CTL	H	PB	RW	E	feed roller operation, delimb (s tree^{-1})	$-a+bD_1-cD_1^d$

	4	CTL	H	PB	RW	E	feed roller operation, delimb (s tree⁻¹)	$-a+bD_1+cD_1^d$
Zimelis et al. (2017b)	1	CTL	H	PB	RW	PV	(m³ h⁻¹)	$-aD_1+bD_1^c-dD_1^e$
	2	CTL	H	PB	RW	PV	(m³ h⁻¹)	$a-bD_1+cD_1^d-eD_1^f$
	3	CTL	H	PB	RW	PV	(m³ h⁻¹)	$-a+bD_1$
Zimelis & Spalva (2022)	1	CTL	H	PB	RW	PV	(m³ h⁻¹)	$-a+bD_1-cD_1^d$
	2	CTL	H	PB	RW	PU	(trees h⁻¹)	$a-bD_1$
Zimelis et al. (2016)	1	CTL	H	EB	CT	PV	(m³ h⁻¹)	aD_1^b

Appendix 9. Independent variables

Variables are presented in alphabetical order according to their abbreviations. Hence, related variables are presented in several places of the table. For instance, variables describing the work output are presented in two places since it has been described by both weight and volume in the models.

An asterisk (*) indicates a dummy variable, and a lowercase letter followed by a colon (:) in the unit column specifies the specific parameter it is associated with in the model.

Abbreviation	Unit	Independent variable
Movement and distances travelled		
A_1	m	Movement to trees/movement per cycle
A_2	ft	Movement to trees/movement per cycle
A_3	m	Movement to bunch
A_4	ft	Movement to bunch
A_5	m	Total distance traversed in the corridor
A_6	m	Untethered distance traversed in the corridor
A_7	m	Tethered distance traversed in the corridor
A_8	m	Movement to deck
A_9	m	Skidding distance
Weight of handled unit and/or output (trees/stems/logs/biomass)		
B_1	ODkg/tree	Dry weight of tree
B_2	dry ton/ha	Biomass removal
B_3	ODton/ha	Biomass per hectare
B_4	green tons	Weight of material produced in the corridor
B_5	green tons	Weight of material produced while untethered

B_6	green tons	Weight of material produced while tethered
B_7	green tons	Weight of saw-log material produced in the corridor
B_8	green tons	Weight of biochar feedstock produced in the corridor
B_9	green tons	Weight of saw-log material produced while untethered
B_{10}	green tons	Weight saw-log material produced while tethered
B_{11}	green tons	Weight of biochar feedstock produced while untethered
B_{12}	green tons	Weight of biochar feedstock produced while tethered
B_{13}	kg	Dry weight of all stems on the stump
B_{14}	kg	Weight of tree
B_{15}	ton/km	Stocking
B_{16}	tons	Wood removal
Diameter/DBH of harvested trees/stems/logs		
D_1	cm	Diameter at breast height
D_2	cm	Basal area weighted diameter at breast height
D_3	cm	Removed basal area weighted diameter at breast height
D_4	cm	Sum of diameter at breast height in accumulation
D_5	mm	Diameter at breast height
D_6	mm	Basal area weighted diameter at breast height
D_7	cm	Diameter at breast height under bark
D_8	cm	Diameter of top log under bark
D_9	cm	Diameter at breast height of trees from which logs were processed from tree crowns
D_{10}	cm	Diameter at breast height of trees from which logs were not processed from tree crowns
D_{11}	cm	Diameter per cycle
D_{12}	cm	Butt end diameter
*D_{13}	c: 36 cm $\leq$ DBH $\leq$ 51 cm 1/0, d: DBH $>$ 51 cm 1/0	Diameter at breast height class
Machine data		
E_1	revolutions/min	Engine speed
E_2	liters/min	Hydraulic pump flow
E_3	kW	Engine power
E_4	%	Proportion of engine time operating at the medium load

E_5	%	Proportion of engine time operating at the high load
E_6	kg	Harvester head weight
E_7	cm	Max cutting diameter
E_8	m^3	Load volume
*E_9	1: Purpose built, 2: Excavator - Norihiro et al. (2018) 1: Beaver, 0: Bear - Ackerman et al. (2021) c: Agama 1/0, d: Vimek 1/0 - Spinelli et al. (2022)	Machine type
*E_{10}	1: C360, 0: S350	Head model
*E_{11}	1/0	Accumulating harvesting head
*E_{12}	Model 5: XXXL is baseline, o: S 1/0, p: M 1/0, q: L 1/0, r: XL 1/0, s: XXL 1/0 Model 9: XXXL is baseline, m: S 1/0, n: M 1/0, o: L 1/0 - Eriksson & Lindroos (2014) M is baseline, e: L 1/0, f: XL 1/0, g: XXL 1/0 - Liski et al. (2020)	Harvester head size
*E_{13}	M is baseline, c: L 1/0, d: XL 1/0	Harvester size
E_{14}	m^3	Grapple load size
E_{15}	%	Proportion of processing time
Height of trees harvested		
H_1	m	Height
H_2	m	Basal area weighed height
H_3	m	Dominant height
Harvesting intensity/density		
I_1	%	Harvested basal area
I_2	%	Thinning intensity
I_3	trees/ha	Harvested trees
I_4	m^2/ha	Basal area
I_5	trees/ha	Stand density
*I_6	b: Light (15%), c: Medium (30%) and Heavy (45%) - Manner et al. (2023) $X<30$ m^3/ha is baseline, e: $30≤X≤60$ 1/0, f: $X>60$ 1/0 - Mederski et al. (2016) Miscellaneous	Harvest intensity
Miscellaneous variables		

*M_1	Skill of researcher, however, it could not be ascertained when this variable should take on the value of 1. Presumably it should take on the value of 1 when a more skilled researcher collects data.	Researcher
M_2	score	NASA Task Load Index
*M_3	Quarter 1 is baseline, l: Quarter 2 1/0, m: Quarter 3 1/0, n: Quarter 4 1/0	Quarter of year
M_4	m	Cumulative log length
*M_5	Site B 1/0 - Holzleitner & Kanzian (2022) Model 1-5: c: Unit 2 1/0, d: Unit 3 1/0 - Holzleitner & Kanzian (2022) Model 6: c: Unit 1, d: Unit 3 1/0 - Kizha & Han (2016) e: S1T2 1/0, f: S2T1 1/0 - K. George et al. (2022)	Site/Unit
M_6	number	Total number of small trees in the working zone
M_7	number	Total number of trees in the working zone
Work cycle-based observations		
N_1	number	Cuts per cycle
N_2	number	Number of swings
N_3	number	Trees per cycle
N_4	number	Number of logs per cycle
N_5	sec	Time per crane cycle
N_6	number	Number of standing trees per cycle
N_7	number	Number of downed trees per cycle
N_8	number	Number of stems on the stump per cycle
N_9	number	Number of trees per accumulation
N_{10}	number	Number of processing passes per cycle
Miscellaneous features of harvested trees		
O_1	score/tree	Crookedness
O_2	score/tree	Limbiness
O_3	score/tree	Forkedness
O_4	1/2 or 1/3 or 1/4 of tree height (unclear how these values should be interpreted in model)	Crown class
O_5	Single, Double or Multi (unclear how these values should be interpreted in model)	Stem form
O_6	≤5 or 5-10 cm (unclear how these values should be interpreted in model)	Branch thickness

*O_7	Model 1: f: Douglas fir 1/0, g: Redwood 1/0, h: Western hemlock 1/0	Tree species
	Model 2: f: Redwood 1/0, g: Western hemlock 1/0	
	Model 3: f: Redwood 1/0, g: Douglas fir 1/0, h: Western Hemlock 1/0	
	Model 4: f: Redwood 1/0, g: Western hemlock 1/0, h: Tanoak 1/0	
	Model 5: f: Tanoak 1/0, g: Redwood 1/0, h: Western hemlock 1/0	
	Model 6: g: Douglas fir 1/0, h: Redwood 1/0, i: Western hemlock 1/0 - Kizha & Han (2016)	
	1: Spruce, 0: Pine - Manner et al. (2023)	
	1: *Quercus ilex*, 0: *Quercus pyrenaica* - Tolosana et al. (2018)	
	Model 1: Pine is baseline, h: Spruce 1/0, i: Birch 1/0, j: Other broadleaved 1/0, k: Mixed removal 1/0	
	Model 2: Pine is baseline, c: Spruce 1/0, d: Birch 1/0, e: Other broadleaved 1/0, f: Mixed removal 1/0 - Liski et al. (2020)	
*O_8	c: Hardwood 1/0, d: Softwood 1/0 - George et al. (2022)	Wood type
	1: Softwood, 0: Hardwood - Hiesl & Benjamin (2015)	
	1: Hardwood, 0: Softwood - Soman et al. (2020)	
	Mixwood 1/0 - Spinelli et al. (2020a)	
O_9	1%	Difficult trees
*O_{10}	1/0	Poor tree form
O_{11}	number	Number of assortments per tree
*O_{12}	1/0	Forking
*O_{13}	1/0	Wind damage
O_{14}	%	Hardwood percentage
*O_{15}	1: High forest, 0: Coppice - Chakroun et al. (2016)	Stand type
	1: Planted, 2: Coppice - Norihiro et al. (2018)	
*O_{16}	41-60 is baseline, c: 61-80 1/0, d: 81-100 1/0	Age class
*O_{17}	1: Double stem, 0: Single stem	Stem type
Operator features		
P_1	years	Operator experience
*P_2	1: Operator B (less experienced), 0: Operator A	Operator

Features related to terrain and work conditions		
S_1	%	Slope
S_2	1-5, Berg (1992)	Slope
S_3	1-5, Berg (1992)	Terrain roughness
*S_4	1/0	Expected snow limitation
*S_5	1/0	Expected daylight limitation
S_6	trees/ha	Undergrowth
Treatment/execution of harvest		
*T_1	1: Energywood, 0: Pulpwood or integrated harvest of energywood and pulpwood	Type of harvest
*T_2	1/0	Cross-cutting practice
*T_3	1/0	Small scale chain of harvest
*T_4	1/0	Adaptation kit treatment
*T_5	1/0	2 m log length treatment
*T_6	1/0	Larger stem felled first
*T_7	1/0	Regeneration felling
*T_8	1/0	Multi-tree handling
*T_9	1/0	Debarking
*T_{10}	1/0	Logging residue recovery adaptation
Volume of handled unit and/or output (tree/stem/log)		
V_1	m^3	Stem volume over bark
V_2	dm^3	Stem volume over bark
V_3	m^3	Stem volume under bark
V_4	m^3	Volume of logs per tree irrespective of them matching set quality specifications
V_5	m^3	Volume of logs per tree matching set quality specifications
V_6	m^3	Estimated recovered volume per stem with a reduction factor of volume
V_7	m^3	Whole tree volume
V_8	m^3	Stem one volume
V_9	m^3	Stem two volume
V_{10}	m^3	Accumulated volume of trees in the head
V_{11}	m^3	Mean tree volume in an accumulation

V_{12}	dm^3	Whole tree volume
V_{13}	m^3	Total harvested volume under bark
V_{14}	m^3/ha	Harvested volume under bark per ha

Appendix 10. Parameters in models

Parameters in models. nr = model number. Note: Parameters marked with an asterisk (*) are not the original values from publications. The original values yielded infeasible values of productivity. For instance, in Ackerman et. al (2018), the original value a = 0.0072 in model 1 when used with the average volume of 0.161 m³ yielded a productivity of 0.00102 m³ PMh⁻¹. This value does not align with Figure 2.b in Ackerman et. al (2018), which shows that the productivity should be approximately 12 m³ PMh⁻¹ when the average volume is around 0.15 m³. After contact with the author of Ackerman et. al (2018), the author supplied the correct model for model 2. However, model 1 was not supplied and is therefore probably incorrect.

At a certain threshold, when the decimal value for a parameter is exceedingly small, it is presented as 10^{-x}. For example, 10^{-6} = 0.000001.

Author(s)	**nr**	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**
Ackerman et al. (2018)	1	*72	1.0702	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	*4.971	*76.865	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	4.89822	57.38591	0.04803	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	4.790967	76.864974	0.005877	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	4.73667	58.44977	0.0413	0.04403	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	4.47612	79.14764	0.01787	0.08686	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ackerman et al. (2021)	1	102.10662	1	92.52183	25.48385	0.16874	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	102.10662	92.52183	1	25.48385	0.16874	0.05249	0.08296	-	-	-	-	-	-	-	-	-	-	-	-	-
Ackerman et al. (2022)	1	*68.5909	0.5505649	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	*30.26950014	0.5505689	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acosta et al. (2021)	1	0.5278	43.5612	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acuna et al. (2017)	1	3.848	0.301	0.668	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alam et al. (2014)	1	74.58	71.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	70.59	48.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	118.34	93.92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	4	119.16	44.92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apăfăian et al. (2017)	1	3.8978	0.1124	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	8.7284	2.6289	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	30.405	1.218	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	28.243	57.12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	55.189	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Berendt et al. (2020)	1	42.51	0.637	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Berg et al. (2014)	1	335.25	1.09357	0.000763	2	92.842	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	36.068	19.918	3.4251	2	10.2956	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	72.303	0.75805	0.0007375	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	30.778	67.028	14.6016	2	8.8462	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bergström & Di Fulvio (2014)	1	3.45	68.85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	1.76	58.72	2902.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bergström et al. (2016)	1	1.95	0.136	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	1.3865	0.10556	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	7.3805	0.48205	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bergström et al. (2022)	1	1.8	0.0608	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	2.8	0.0608	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	1.5	0.2782	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	2.3	0.2782	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	1.5	0.3336	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	2.3	0.3336	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	0.1	0.4028	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	0.8	0.4028	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bilici et al. (2019)	1	192.147	*8.817	*6.294	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	172.087	*4.93	*6.233	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	141.55	10.527	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	85.946	4.8334	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	8.0535	134.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	4.9022	60.207	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brewer et al. (2018)	1	51.1	37.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	50.61	35.57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	3	34.29	43.89	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	36.79	40.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	43.69	37.87	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	41.44	39.51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	33.51	58.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	33.36	57.64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brown et al. (2013)	1	12.3	3.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	10.8	3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carter et al. (2017)	1	8.766	1.852	8.816	1.066	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chakroun et al. (2016)	1	70.77	8.5	0.79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	86.47	6.64	0.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	42.16	7.37	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	72.31	19.75	0.82	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	77.86	12.52	0.84	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chung et al. (2022)	1	17.69	0.75	4.42	12.18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	2.49	0.714	14.79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Di Fulvio & Bergström (2013)	1	5.4043	0.000874	1.1512	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Erber et al. (2016)	1	0.048	0.014	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.004	1.264	0.7	0.014	0.108	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	0.209	0.362	0.7	0.023	0.046	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	0.228	1.823	0.7	0.043	0.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eriksson & Lindroos (2014)	1	3.704	0.134	0.161	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	3.135	0.378	0.066	0.056	0.072	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	3.148	0.379	0.077	0.06	0.071	2	0.079	0.038	0.044	-	-	-	-	-	-	-	-	-	-	-
	4	2.371	0.365	0.075	0.061	0.072	2	0.076	0.033	0.042	0.026	0.031	0.004	0.073	0.109	-	-	-	-	-	-
	5	2.704	0.353	0.075	0.062	0.067	2	0.077	0.034	0.042	0.027	0.032	0.004	0.079	0.061	0.112	0.027	0.039	0.024	0.022	-
	6	3.466	0.211	0.112	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	3.592	0.693	0.037	0.039	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	3.514	0.665	0.051	0.047	0.037	0.035	0.008	-	-	-	-	-	-	-	-	-	-	-	-	-
	9	2.822	0.638	0.051	0.057	0.039	0.033	0.007	0.021	0.045	0.051	0.281	0.314	0.041	0.02	0.018	-	-	-	-	-
Fernandez-Lacruz et al. (2013)	1	5.4935	1.379	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fernandez-Lacruz et al. (2021)	1	6.1603	1.6144	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	2	5.1033	1.0267	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
George et al. (2022)	1	0.91	0.03	0.11	0.11	0.12	0.06	0.05	0.02	0.11	-	-	-	-	-	-	-	-	-	-	-
Ghaffariyan (2013)	1	242.94	83.012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.115	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ghaffariyan et al. (2019)	1	48.971	0.6245	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ghaffariyan et al. (2013)	1	182.078	57.585	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ghaffariyan et al. (2015)	1	0.29	0.003	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Green et al. (2020)	1	0.112	0.023	0.022	0.076	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.2	0.039	0.056	0.037	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grönlund & Eliasson (2019)	1	1442	25.82	224	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gülci et al. (2021)	1	17.519	2.438	1.616	50.013	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	25.754	0.645	0.118	95.87	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	864.76	96.626	3.957	2	26.508	0.929	2	145.631	470.935	2	-	-	-	-	-	-	-	-	-	-
	4	540.134	62.527	2.768	2	15.339	0.678	2	376.775	171.468	2	-	-	-	-	-	-	-	-	-	-
Han et al. (2018)	1	10.14	3.709	13.082	0.989	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hiesl & Benjamin (2013)	1	0.888	0.136	0.007	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hiesl & Benjamin (2015)	1	1.129	0.041	0.246	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hiesl et al. (2015)	1	1.115	0.01	0.635	0.095	0.045	125.48	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	4.379	0.001	0.052	0.029	0.172	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Holzleitner & Kanzian (2022)	1	6.95	42.09	0.46	8.94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	5.49	48.49	0.46	9.08	4.62	13.85	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	8.97	39.47	0.46	8.68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Horváth et al. (2016)	1	1.9825	0.052	0.1368	0.5607	0.0867	0.491	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.3151	0.2748	0.2456	0.3984	0.8871	0.0616	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	0.107	0.0194	0.2618	0.392	1.3301	0.4159	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	0.1357	0.047	0.37	0.2522	1.0769	0.3307	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	0.2727	0.0405	0.2531	0.4363	0.8549	0.1226	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	0.0602	0.9065	0.4419	0.9142	0.0953	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	0.7827	0.1676	0.1907	0.919	0.1823	0.2021	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	0.3004	0.1275	0.5283	0.3881	0.7773	0.2332	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	9	0.3005	0.1436	0.3523	0.5618	0.6433	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	2.8238	0.2766	0.6936	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	11	0.3215	0.1762	0.4083	0.4968	0.6769	0.1613	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12	1.9614	0.0526	0.1364	0.5575	0.0937	0.5109	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	13	0.3157	0.2755	0.2457	0.3986	0.8862	0.938	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	14	0.1072	0.0195	0.2616	0.3921	1.3296	1.415	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	15	0.1358	0.0475	0.3698	0.2524	1.0765	1.3304	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	16	0.2725	0.0403	0.2532	0.4359	0.8557	1.1221	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	17	0.0603	0.9065	0.441	0.9138	0.9039	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	18	0.7835	0.168	0.1906	0.9192	0.182	0.7969	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	19	0.3013	0.1277	0.5283	0.3883	0.776	0.7664	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	20	0.301	0.1436	0.3526	0.5618	0.6433	0.9283	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	21	2.8176	0.2758	0.3071	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	22	0.3216	0.1763	0.4084	0.4971	0.677	0.3831	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	23	0.5257	0.0519	0.1372	0.5517	0.1064	0.521	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	24	3.1404	0.275	0.2441	0.3942	0.8826	0.9343	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	25	9.4062	0.0179	0.2626	0.3921	1.3334	1.4181	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	26	7.2354	0.0484	0.3652	0.2543	1.0715	1.3225	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	27	3.681	0.0418	0.2525	0.4351	0.8577	1.123	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	28	16.5662	0.9025	0.432	0.9167	0.9054	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	29	1.2789	0.1668	0.1898	0.9189	0.1834	0.7975	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	30	3.3738	0.1278	0.5388	0.3856	0.7826	0.7699	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	31	3.318	0.1406	0.3519	0.563	0.6422	0.9283	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	32	0.3548	0.2759	0.3079	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	33	3.1242	0.1764	0.4108	0.4974	67.884	0.84	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jernigan et al. (2015)	1	0.3	0.144	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jylhä & Bergström (2016)	1	3.552	0.279	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.48	1.167	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	230.777	0.361	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	0.869	0.572	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	0.085	0.994	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	1.57	0.793	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	0.152	0.876	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	0.0202	1.382	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Kärhä et al. (2018a)	1	14.021	45.175	24.798	10.603	14.603	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	12.35	46.046	26.661	10.138	4.975	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	6.782	93.455	47.707	12.397	10.122	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	1.752	2138.466	4.935	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kärhä et al. (2018b)	1	1.877	1.641	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kärhä et al. (2019)	1	23.845	53.895	26.6	2	9.054	3	7.758	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	16.847	59.369	32.974	2	11.3	3	0.946	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	16.004	61.287	35.309	2	12.054	3	5.815	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	17.25	56.882	30.429	2	10.358	3	11.151	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	16.834	59.125	32.747	2	11.15	3	16.107	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	17.412	56.572	29.45	2	9.964	3	15.547	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	16.882	59.942	34.017	2	11.669	3	17.457	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	8.219	72.262	21.442	2	0.837	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	9	7.778	65.628	15.578	2	0.841	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	6.588	60.14	11.858	2	1.551	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	11	4.838	57.384	11.946	2	0.88	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12	4.213	52.46	9.251	2	1.339	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	13	4.067	54.003	11.002	2	0.74	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	14	4.053	51.003	8.208	2	1.612	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Karpachev & Bykovskiy (2019)	1	178.43	44.748	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	31.593	97.129	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	232	197.44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	297.87	15.576	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	296.44	21.689	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	298.45	34.882	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	89.923	93.932	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	257.42	186.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	9	232	197.44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	0.0009	603.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	11	416.8	157.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12	384.92	157.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	13	353.29	157.88	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Kim et al. (2017)	1	11.936	2.67	5.89	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kizha & Han (2016)	1	1.26	0.07	0.02	0	0.01	0.1	0.15	0.09	-	-	-	-	-	-	-	-	-	-	-	-
	2	1.27	0.04	0.27	0.21	0.01	0.03	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	1.36	0.11	0.27	0.21	0.00	0.08	0.13	0.18	-	-	-	-	-	-	-	-	-	-	-	-
	4	3.42	0.12	0.09	0.06	0.01	0.05	0.01	0.00	-	-	-	-	-	-	-	-	-	-	-	-
	5	3.15	0.12	0.09	0.06	0.01	0	0.05	0.01	-	-	-	-	-	-	-	-	-	-	-	-
	6	3.58	0.00	0.70	0.43	0.22	0.01	0.007	0.12	0.07	-	-	-	-	-	-	-	-	-	-	-
Kormanek & Baj (2018)	1	3.1977	0.5927	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	70.727	1.7313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kormanek & Kępa (2016)	1	5.2944	0.9046	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Krč et al. (2015)	1	0.688	0.028	0.093	0.04	0.037	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labelle et al. (2017)	1	27.67	5.1784	0.3017	2	0.0039	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	7.2145	2.3227	0.1802	2	0.0023	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	0.0071	2.4652	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	0.005	2.629	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labelle et al. (2018)	1	15.15	2.53	0.02	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	42.42	3.61	0.04	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	61.26	4.56	0.047	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	42.72	3.68	0.04	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labelle & Huß (2018)	1	48.204	9.4579	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	44.683	9.3722	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labelle et al. (2016)	1	1.0273	0.8319	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.7976	0.8588	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labelle et al. (2019)	1	70.18	5.301	0.06052	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	7.87	2.638	0.04544	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	22.24	1.482	0.00433	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	1.12	0.891	0.00783	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	2.938	54.87	16.56	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	18.17	31.92	20.63	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	5.573	20.18	1.835	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	4.743	17.44	2.445	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laina et al. (2013)	1	0.012	3.05	0.1	0.8	0.001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	2	0.083	2.47	9.24	4.67	0.001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laitila et al. (2016)	1	6.873	0.605	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.023	2375.177	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	12.456	1.667	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	12.599	2.455	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	4.628	0.116	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	1.799	0.09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laitila & Väätäinen (2014)	1	9.163	0.859	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	4.542	6.176	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	10.592	3.857	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laitila & Väätäinen (2020)	1	0.168	4351.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	4.571	3.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	8.222	7.237	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laitila & Väätäinen (2021)	1	1.133	0.583×10^{-5}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	2.683	0.073	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laitila & Väätäinen (2023)	1	11.025	0.099	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laitila et al. (2013)	1	10.868	1.328	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	1.707	3.69	0.228	2	0.007	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	8.778	0.623	0.01	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laitila et al. (2020)	1	15.514	0.051	0.000105	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lazdiņš et al. (2019)	1	0.07073	2.03535	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.14166	1.76499	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	0.17848	1.74966	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lazdiņš (2014)	1	39.13	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lazdiņš et al. (2021)	1	0.3874	110.18	368	2	619.99	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lazdiņš et al. (2016)	1	0.29742	1.24747	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	629.48165	0.82643	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Leszczyński et al. (2021)	1	20.572	0.7283	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	16.7	0.7224	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	3.0486	0.6034	0.2021	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	3.2387	0.8093	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	5.6721	0.3855	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	6	3.6664	0.0886	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Liski et al. (2020)	1	5.188	5.445	0.261	6.168	2.241	1.775	4.504	3.574	5.159	3.496	2.224	0.424	0.948	1.215	89.39	58.62	2	24.12	36.65	2
	2	8.451	2.682	4.062	6.828	3.901	2.737	71.87	31.35	2	-	-	-	-	-	-	-	-	-	-	-
Louis & Kizha (2021)	1	13.86	0.2	9.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	17.7	0.34	4.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Magagnotti et al. (2021)	1	7.126	282.374	1.354	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.167	198.547	0.637	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	0.602	213.1	0.577	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	0.399	206.078	19.648	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manner et al. (2023)	1	42.168	20.992	4.216	17.677	3.139	16.007	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	61.2989	0.6681	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
McEwan et al. (2016)	1	2.149	0.0009389	2	0.217	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	19.672	0.057	2	4.942	6.653	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	26.516	0.074	2	9.038	7.295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mederski et al. (2016)	1	7.892	1.2494	0.8587	1.3237	3.7631	5.255	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	8.607	6.99	3.901	2.891	7.72	9.401	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Norihiro et al. (2018)	1	4.536	63.801	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	5.8	102.784	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	4.754	63.611	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	3.283	53.041	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	1.073	82.817	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	1.085	84.778	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	23.684	0.497	0.734	0.027	3.963	64.43	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	0.847	1.189	83.087	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	9	21.246	0.174	1.906	0.052	2.633	65.652	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	3.283	53.041	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	11	4.368	63.286	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12	1.052	83.114	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	13	10.559	2.3	0.094	62.286	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	14	4.979	1.455	0.003	73.665	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	15	22.427	3.196	52.717	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	16	20.197	2.064	40.857	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	17	4.0582	67.3274	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuutinen & Björheden (2016)	1	20.946	10.982	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Olivera et al. (2016)	1	8.68	2.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	8.55	2.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	8.82	2.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	9.36	2.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	9.23	2.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	9.5	2.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	9.34	2.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	10.02	2.49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	9	9.9	2.49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	10.16	2.49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	11	9.06	2.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12	8.93	2.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	13	9.2	2.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	14	9.04	2.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Petitmermet et al. (2019)	1	8.11	1.38	0.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	10.03	1.41	1.21	0.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	9.95	1.33	0.25	0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	10.14	1.38	1.25	0.24	0.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	8.12	0.24	1.38	1.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	10.02	0.25	0.22	1.35	1.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	10.17	0.24	1.43	1.24	1.28	0.97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	10.25	0.24	0.23	1.41	1.26	1.23	1.11	-	-	-	-	-	-	-	-	-	-	-	-	-
Petty & Kärhä (2014)	1	6.2767	1.1761	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	6.975	2.2988	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	7.0881	2.2207	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	6.7882	1.9506	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	7.3276	1.8173	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	6.6237	1.4486	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	13.865	1.741	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	3.678	0.494	0.072	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	9	3.225	0.487	0.065	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	0.868	0.41	0.065	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	11	0.318	0.494	0.065	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12	0.069	0.48	0.06	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	13	0.425	0.577	0.064	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polowy & Molińska-Glura (2023)	1	9.36	19.217	0.197	0.148	0.411	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	18.268	0.272	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	6.457	18.604	0.212	0.847	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Prinz et al. (2021)	1	24.922	0.004	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	17.813	0.004	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	16.408	0.199	5.046×10^{-6}	2	3.224×10^{-7}	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	32.603	0.138	0.001	2	4.196×10^{-7}	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ramantswana et al. (2013)	1	1.6472	38.33	15.3379	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	2.494	61.9498	26.5277	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	1.5782	83.9645	56.0942	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	2.0316	39.2977	31.1302	22.5507	2	32.9884	2	0.7631	2	4.3548	-	-	-	-	-	-	-	-	-	-
	5	6.63929	18.28758	22.57935	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	55.0268	18.7607	42.3987	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	7.874	23.5913	34.0938	317.7122	2	3.1287	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	1.5565	40.5616	32.6461	17.5555	2	46.3467	2	-	-	-	-	-	-	-	-	-	-	-	-	-
	9	1.498	62.6611	26.0416	2	0.9736	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rosińska et al. (2022)	1	15.1335	1.6846	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	25.3302	5.7387	0.1191	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	6.004	45.722	0.507	0.329	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	18.1448	1.8201	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	12.449	1.5411	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	19.2	0.623	2.79	0.019	0.026	2	0.092	2	-	-	-	-	-	-	-	-	-	-	-	-
Santos et al. (2022)	1	10.43	57.07	62.96	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Santos et al. (2021)	1	15	0.5845	0.1969	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Santos et al. (2020)	1	7.72	5.691×10^{-6}	2	2.56×10^{-4}	2	7.986×10^{-5}	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	3.97	4.97×10^{-6}	2	2.339×10^{-4}	2	6.867×10^{-5}	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	215.54	0.0905	1.80×10^{-5}	2	0.764	0.00109	2	5.857×10^{-5}	-	-	-	-	-	-	-	-	-	-	-	-

	4	15.9922	1.058×10^{-6}	2	6.84×10^{-5}	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	8.57	2.514×10^{-7}	2	1.483×10^{-5}	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	25.72	1.42×10^{-5}	2	6.38×10^{-4}	2	2.036×10^{-4}	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	11.21	1.04×10^{-5}	2	4.53×10^{-4}	2	1.449×10^{-4}	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	38.4	0.1876	1.56×10^{-6}	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Schweier et al. (2015)	1	7.8618	0.4392	8.626	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	21.1914	0.492	13.742	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	23.1072	0.2046	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	22.5648	0.0006	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	16.4532	0.0396	0.000236	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Slugeň et al. (2014)	1	0.3342	0.273	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soman et al. (2020)	1	1.247	0.008	0.036	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	1.053	0.127	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	1.193	0.033	0.005	0.036	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soman et al. (2019)	1	0.99	1.05	0.83	1.02	4.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	19.45	0.35	0.43	0.32	3.98	2.050	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sperandio et al. (2021)	1	137.59	0.133	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	50.519	0.1596	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	0.042	1.1422	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	0.1188	0.8404	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spinelli et al. (2014)	1	21.863	0.163	31.424	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spinelli & De Arruda Moura (2019)	1	31.329	19.278	1.343	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spinelli et al. (2022)	1	34.372	0.272	7.392	4.529	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spinelli et al. (2023)	1	1.131	0.04	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spinelli et al. (2020a)	1	65.24	0.886	34.646	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	80.732	0.614	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spinelli et al. (2020b)	1	71.149	8.737	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	303.109	1.535	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	18.842	0.044	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stoilov et al. (2021)	1	13.73	0.056	3.7	5.94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.0764	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	3	14.59	0.018	2.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	12.21	0.029	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Strandgard & Mitchell (2018)	1	1.01	2.44341	0.0224328	0.281459	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	1.01	2.66535	0.192202	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	1.01	2.67646	0.20921	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	1.98179	0.532718	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	1.01	1.80586	0.0310813	0.360245	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	1.02	1.79123	0.0435792	0.290831	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	1.02	2.12057	0.261395	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Strandgard & Mitchell (2019)	1	0.0094	0.44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	68.1	0.47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	0.0114	0.39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	58.8	0.57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Strandgard & Mitchell (2020)	1	114.4	0.946	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.88	0.244	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	70.7	0.756	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Strandgard et al. (2016)	1	0.655	58.72	0.036	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	5.62	57.84	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Strandgard et al. (2015)	1	222.9	0.13	0.751	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tajbos & Messingerova (2014)	1	1.0549	2.3522	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.48	4.29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	0.1876	0.0487	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	0.0182	0.0458	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	0.2792	0.1172	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	0.017	0.2049	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tolosana et al. (2023)	1	0.711	1.328	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	1.573	1.218	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	11.77	2.73	0.233	4.93	0.124	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tolosana et al. (2018)	1	1.66	0.0464	0.105	1.105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	1.31	0.0367	0.083	0.873	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Townsend et al. (2019)	1	0.2709	0.1415	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.517	0.1079	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	3	0.4415	0.1204	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	0.2274	0.1442	0.0347	0.0228	0.1883	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	0.3864	0.0644	0.206	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Walsh & Strandgard (2014)	1	71.7	38.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	62.1	51.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Walsh et al. (2014)	1	68.66	33.617	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	63.768	35.231	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Williams & Ackerman (2016)	1	9.14	1.34	1.91	0.52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zimelis et al. (2020)	1	0.46	0.01	0	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	2.73	0.76	0	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zimelis et al. (2018)	1	1.8270908	0.7001146	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.2138	0.0274	0.0025	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zimelis et al. (2019)	1	1.06	0.98	0.12	2	0.01	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.32	0.25	0.13	2	0.01	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zimelis et al. (2017a)	1	22.271	11.398	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	19.965	9.8097	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	12.519	2.668	0.0177	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	4.4214	1.3096	0.0127	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zimelis et al. (2017b)	1	0.0626	0.0678	2	0.0014	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	0.8074	0.2731	0.0899	2	0.0021	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	0.1691	0.5005	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zimelis & Spalva (2022)	1	5.3703	1.4103	0.0191	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	141.55	4.3887	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zimelis et al. (2016)	1	0.14736	1.4508	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 11. Statistical significance and observational units

Type of observational unit, number of observations, type of equation, and coefficients of determination. nr = model number; OB = observational unit, SL = shift level, PL = plot level (includes stands as well), CL = cycle level, EL = element level; SV = statistical significance for predictors in model, but not the actual model, SS = statistically significant.

Author(s)	nr	OB	Observations	Mathematical structure	R²	R²-adj	Significance	F value
Ackerman et al. (2018)	1	EL	436	Power law model	0.7531	-	-	-
	2	EL	428	Linear Model	0.712	-	-	-
	3	EL	436	Linear model	-	-	SV	-
	4	EL	428	Linear model	-	-	SV	-
	5	EL	436	Linear model with interaction term	-	-	SV	-
	6	EL	428	Linear model with interaction term	-	-	SV	-
Ackerman et al. (2021)	1	CL	140 465	Nonlinear model with exponential terms and division operation	-	-	SV	-
	2	CL	140 465	Nonlinear model with exponential terms, division operations, and interaction effects	-	-	SV	-
Ackerman et al. (2022)	1	EL	281	Power law model	0.58	-	SV	-
	2	EL	284	Power law model	0.58	-	SV	-
Acosta et al. (2021)	1	EL	259	Linear model	0.76	-	-	-
Acuna et al. (2017)	1	EL	1048	Exponential model with logarithmic transformation	-	0.85	SV	-
Alam et al. (2014)	1	EL	153	Log-linear model	0.58	-	-	-
	2	EL	103	Log-linear model	0.33	-	-	-
	3	EL	153	Log-linear model	0.4	-	-	-
	4	EL	103	Log-linear model	0.15	-	-	-
Apăfăian et al. (2017)	1	EL	1045	Exponential model	0.46	-	P <0.001	-

	2	EL	1045	Exponential model	0.49	-	P <0.001	-
	3	EL	1045	Exponential model	0.25	-	P <0.001	-
	4	EL	1045	Linear model	0.2	-	P <0.001	-
	5	EL	1045	Power law model	0.62	-	P <0.001	-
Berendt et al. (2020)	1	EL	706	Power law model	0.515	-	P <0.05	-
Berg et al. (2014)	1	-	800	Non-linear model with quadratic term and logarithmic transformation	0.985	-	SV	-
	2	-	800	Non-linear model with quadratic term and logarithmic transformation	0.994	-	SV	-
	3	-	800	Second-degree polynomial model	0.981	-	SV	-
	4	-	800	Non-linear model with quadratic term and logarithmic transformation	0.998	-	SV	-
Bergström & Di Fulvio (2014)	1	EL	10	Linear model with division operation	-	0.47	P = 0.017	-
	2	EL	7	Linear model with division operation	-	0.78	P = 0.022	-
Bergström et al. (2016)	1	EL	26	Linear model	-	0.6	P <0.001	-
	2	EL	26	Linear model	0.7	0.68	SV	-
	3	EL	26	Linear model	0.77	0.75	SV	-
Bergström et al. (2022)	1	EL	32	Linear model	-	0.676	SV	-
	2	EL	32	Linear model	-	0.676	SV	-
	3	EL	32	Linear model	-	0.457	SV	-
	4	EL	32	Linear model	-	0.457	SV	-
	5	EL	32	Linear model	-	0.454	SV	-
	6	EL	32	Linear model	-	0.454	SV	-
	7	EL	32	Linear model	-	0.452	SV	-
	8	EL	32	Linear model	-	0.452	SV	-
Bilici et al. (2019)	1	EL	30	Linear model	0.7	-	P <0.05	30.968
	2	EL	30	Linear model	0.63	-	P <0.05	34.959
	3	EL	30	Linear model	0.6541	-	SV	-
	4	EL	30	Linear model	0.2844	-	SV	-
	5	EL	30	Linear model	0.7501	-	SV	-
	6	EL	30	Linear model	0.6814	-	SV	-
Brewer et al. (2018)	1	CL	165	Linear model	0.37	-	-	-
	2	CL	165	Linear model	0.47	-	-	-
	3	CL	158	Linear model	0.21	-	-	-

	4	CL	158	Linear model	0.25	-	-	-
	5	CL	173	Linear model	0.39	-	-	-
	6	CL	173	Linear model	0.34	-	-	-
	7	CL	125	Linear model	0.18	-	-	-
	8	CL	125	Linear model	0.2	-	-	-
Brown et al. (2013)	1	EL	124	Log-linear model	0.6	-	P <0.05	-
	2	EL	126	Log-linear model	0.61	-	P <0.05	-
Carter et al. (2017)	1	EL	84	Linear model	0.85	-	P = 0.36	-
Chakroun et al. (2016)	1	EL	-	Power law model	0.73	-	SV	-
	2	EL	-	Power law model	0.73	-	SV	-
	3	EL	-	Power law model	0.58	-	SV	-
	4	EL	-	Power law model	0.8	-	SV	-
	5	EL	-	Power law model	0.66	-	SV	-
Chung et al. (2022)	1	EL	220	Linear model	-	0.67	P <0.001	-
	2	EL	87	Linear model	-	0.89	P <0.001	-
Di Fulvio & Bergström (2013)	1	EL	9	Linear model	0.909	0.855	SV	-
Erber et al. (2016)	1	EL	598	Linear model	-	0.007	$P = 2.1\times10^{-2}$	-
	2	EL	598	Non-linear model with power law and linear terms	-	0.49	$P <2\times10^{-16}$	-
	3	EL	598	Non-linear model with power law and linear terms	-	0.21	$P <2.0\times10^{-16}$	-
	4	EL	598	Non-linear model with power law and linear terms	-	0.42	$P <2\times10^{-16}$	-
Eriksson & Lindroos (2014)	1	PL	12350	Non-linear model with quadratic term and logarithmic transformation	-	0.553	P <0.001	-
	2	PL	12350	Non-linear model with quadratic term and logarithmic transformation	-	0.6	P <0.001	-
	3	PL	12350	Non-linear model with quadratic term, interaction term and logarithmic transformation	-	0.617	P <0.001	-
	4	PL	12350	Non-linear model with quadratic term, interaction term and logarithmic transformation	-	0.625	P <0.001	-
	5	PL	12350	Non-linear model with quadratic term, interaction term and logarithmic transformation	-	0.626	P <0.001	-
	6	PL	4851	Non-linear model with quadratic term and logarithmic transformation	-	0.576	P <0.001	-
	7	PL	4851	Linear model with logarithmic transformations	-	0.581	P <0.001	-
	8	PL	4851	Linear model with logarithmic transformations and interaction terms	-	0.598	P <0.001	-
	9	PL	4851	Linear model with logarithmic transformations and interaction terms	-	0.612	P <0.001	-
Fernandez-Lacruz et al. (2013)	1	EL	13	Power law model	-	0.617	P = 0.0009	-
Fernandez-Lacruz et al. (2021)	1	EL	9	Power law model	0.952	-	P <0.001	-

	2	EL	9	Power law model	0.897	-	P <0.001	-
George et al. (2022)	1	EL	542	Linear model	0.57	-	P <0.05	-
Ghaffariyan (2013)	1	EL	59	Log-linear model	0.32	-	P = 0.05	-
	2	EL	65	Power law model	0.73	-	P = 0.05	-
Ghaffariyan et al. (2019)	1	CL	-	Power law model	-	-	-	-
Ghaffariyan et al. (2013)	1	EL	80	Log-linear model	0.402	-	P = 0.05	-
Ghaffariyan et al. (2015)	1	CL	562	Exponential model	0.519	-	P <0.01	605.45
Green et al. (2020)	1	EL	110	Linear model	0.5	-	P <0.001	35.53
	2	EL	168	Linear model	0.23	-	P <0.001	16.3
Grönlund & Eliasson (2019)	1	EL	10	Linear model	0.942	-	SV	-
Gülci et al. (2021)	1	EL	57	Linear model	0.45	0.42	SV	-
	2	EL	57	Linear model	0.49	0.46	SV	-
	3	EL	60	Second-degree polynomial model	0.48	0.42	SV	-
	4	EL	60	Second-degree polynomial model	0.5	0.44	SV	-
Han et al. (2018)	1	EL	863	Linear model	-	0.4329	P <0.01	-
Hiesl & Benjamin (2013)	1	CL	481	Linear model	-	0.4	SV	-
Hiesl & Benjamin (2015)	1	CL	1154	Linear model	-	0.2	SV	-
Hiesl et al. (2015)	1	PL	12	Linear model	-	0.36	SV	-
	2	PL	9	Linear model	-	0.14	SV	-
Holzleitner & Kanzian (2022)	1	EL	390	Power law model	-	-	SV	-
	2	EL	390	Non-linear model with power law and linear terms	0.553	0.548	SV	-
	3	EL	390	Power law model	0.521	0.518	SV	-
Horváth et al. (2016)	1	EL	392	Non-linear model with power law terms	0.58	-	P <0.05	108.614
	2	EL	135	Non-linear model with power law terms	0.54	-	P <0.05	30.61
	3	EL	593	Non-linear model with power law terms	0.48	-	P <0.05	110.199
	4	EL	275	Non-linear model with power law terms	0.57	-	P <0.05	71.622
	5	EL	1426	Non-linear model with power law terms	0.53	-	P <0.05	316.94
	6	EL	501	Non-linear model with power law terms	0.61	-	P <0.05	196.174
	7	EL	1928	Non-linear model with power law terms	0.35	-	P <0.05	207.455
	8	EL	496	Non-linear model with power law terms	0.61	-	P <0.05	150.526
	9	EL	1026	Non-linear model with power law terms	0.57	-	P <0.05	271.479

	10	EL	153	Non-linear model with power law terms	0.21	-	P <0.05	20.47
	11	EL	1675	Non-linear model with power law terms	0.61	-	P <0.05	522.7
	12	EL	392	Non-linear model with power law terms	0.25	-	P <0.05	25.645
	13	EL	135	Non-linear model with power law terms	0.19	-	P <0.05	6.152
	14	EL	593	Non-linear model with power law terms	0.12	-	P <0.05	15.813
	15	EL	275	Non-linear model with power law terms	0.31	-	P <0.05	24.361
	16	EL	1426	Non-linear model with power law terms	0.53	-	P <0.05	317.548
	17	EL	501	Non-linear model with power law terms	0.39	-	P <0.05	77.822
	18	EL	1928	Non-linear model with power law terms	0.52	-	P <0.05	423.266
	19	EL	496	Non-linear model with power law terms	0.77	-	P <0.05	319.957
	20	EL	1026	Non-linear model with power law terms	0.79	-	P <0.05	789.152
	21	EL	153	Non-linear model with power law terms	0.21	-	P <0.05	20.206
	22	EL	1675	Non-linear model with power law terms	0.8	-	P <0.05	1294.678
	23	EL	392	Non-linear model with power law terms	0.25	-	P <0.05	25.66
	24	EL	135	Non-linear model with power law terms	0.19	-	P <0.05	6.093
	25	EL	593	Non-linear model with power law terms	0.12	-	P <0.05	15.835
	26	EL	275	Non-linear model with power law terms	0.31	-	P <0.05	24.065
	27	EL	1426	Non-linear model with power law terms	0.53	-	P <0.05	317.977
	28	EL	501	Non-linear model with power law terms	0.39	-	P <0.05	77.676
	29	EL	1928	Non-linear model with power law terms	0.52	-	P <0.05	422.684
	30	EL	496	Non-linear model with power law terms	0.77	-	P <0.05	319.03
	31	EL	1026	Non-linear model with power law terms	0.79	-	P <0.05	782.738
	32	EL	153	Non-linear model with power law terms	0.21	-	P <0.05	20.205
	33	EL	1675	Non-linear model with power law terms	0.79	-	P <0.05	1287.774
Jernigan et al. (2015)	1	CL	186	Linear model	-	-	SV	-
Jylhä & Bergström (2016)	1	EL	17	Power law model	0.961	-	P <0.001	368.824
	2	EL	17	Power law model	0.956	-	P <0.001	324.558
	3	EL	17	Power law model	0.939	-	P <0.001	229.112
	4	EL	17	Power law model	0.909	-	P <0.001	150.308
	5	EL	17	Power law model	0.884	-	P <0.001	114.541
	6	EL	17	Power law model	0.863	-	P <0.001	94.485

	7	EL	17	Power law model	0.821	-	P <0.001	68.885
	8	EL	17	Power law model	0.782	-	P <0.001	53.807
Kärhä et al. (2018a)	1	EL	1088	Non-linear model with power law and linear terms	-	0.636	P <0.001	155
	2	EL	1088	Non-linear model with power law and linear terms	-	0.635	P <0.001	184
	3	EL	1088	Non-linear model with power law and linear terms	-	0.709	P <0.001	190
	4	EL	1529	Linear model with division operation	-	0.559	P <0.01	9.9
Kärhä et al. (2018b)	1	PL	-	Log-linear model	0.13	-	P <0.05	3.056
Kärhä et al. (2019)	1	EL	-	Third-degree polynomial model	-	0.561	P <0.001	634.5
	2	EL	-	Third-degree polynomial model	-	0.512	P <0.001	520.5
	3	EL	-	Third-degree polynomial model	-	0.524	P <0.001	544.6
	4	EL	-	Third-degree polynomial model	-	0.533	P <0.001	565.4
	5	EL	-	Third-degree polynomial model	-	0.528	P <0.001	554.2
	6	EL	-	Third-degree polynomial model	-	0.525	P <0.001	547.4
	7	EL	-	Third-degree polynomial model	-	0.517	P <0.001	530.0
	8	EL	-	Third-degree polynomial model	-	-	-	-
	9	EL	-	Third-degree polynomial model	-	-	-	-
	10	EL	-	Third-degree polynomial model	-	-	-	-
	11	EL	-	Third-degree polynomial model	-	-	-	-
	12	EL	-	Third-degree polynomial model	-	-	-	-
	13	EL	-	Third-degree polynomial model	-	-	-	-
	14	EL	-	Third-degree polynomial model	-	-	-	-
Karpachev & Bykovskiy (2019)	1	-	-	Log-linear model	0.9955	-	SV	-
	2	-	-	Log-linear model	0.992	-	SV	-
	3	-	-	Log-linear model	0.9856	-	SV	-
	4	-	-	Linear model	0.9946	-	SV	-
	5	-	-	Linear model	0.991	-	SV	-
	6	-	-	Linear model	0.9827	-	SV	-
	7	-	-	Log-linear model	0.929	-	SV	-
	8	-	-	Log-linear model	0.9956	-	SV	-
	9	-	-	Log-linear model	0.9856	-	SV	-
	10	-	-	Linear model	-	-	SV	-

	11	-	-	Log-linear model	0.9874	-	SV	-
	12	-	-	Log-linear model	0.9873	-	SV	-
	13	-	-	Log-linear model	0.9871	-	SV	-
Kim et al. (2017)	1	EL	185	Linear model	-	0.5406	P <0.0001	-
Kizha & Han (2016)	1	EL	approx. 200	Linear model	0.15	-	SV	-
	2	EL	approx. 200	Linear model	0.19	-	SV	-
	3	EL	approx. 200	Linear model	0.41	-	SV	-
	4	EL	approx. 200	Linear model	0.1	-	SV	-
	5	EL	approx. 200	Linear model	0.12	-	SV	-
	6	EL	approx. 200	Linear model	0.39	-	SV	-
Kormanek & Baj (2018)	1	EL	35	Linear model	0.1734	-	-	-
	2	EL	35	Linear model	0.1138	-	-	-
Kormanek & Kępa (2016)	1	EL	75	Linear model	0.3455	-	-	-
Krč et al. (2015)	1	EL	229	Linear model	0.762	0.759	P = 0.000	240.439
Labelle et al. (2017)	1	EL	338	Third-degree polynomial model	0.6854	-	-	-
	2	EL	365	Third-degree polynomial model	0.7293	-	-	-
	3	EL	42	Power law model	0.8322	-	-	-
	4	EL	55	Power law model	0.8572	-	-	-
Labelle et al. (2018)	1	EL	56	Second-degree polynomial model	0.35	-	-	-
	2	EL	67	Second-degree polynomial model	0.27	-	-	-
	3	EL	48	Second-degree polynomial model	0.24	-	-	-
	4	EL	72	Second-degree polynomial model	0.12	-	-	-
Labelle & Huß (2018)	1	EL	68	Second-degree polynomial model	0.3196	-	-	-
	2	EL	135	Second-degree polynomial model	0.4689	-	-	-
Labelle et al. (2016)	1	EL	54	Power law model	0.247	-	-	-
	2	EL	55	Power law model	0.3215	-	-	-
Labelle et al. (2019)	1	EL	15	Second-degree polynomial model	0.838	-	-	-
	2	EL	15	Second-degree polynomial model	0.295	-	-	-
	3	EL	22	Second-degree polynomial model	0.756	-	-	-
	4	EL	30	Second-degree polynomial model	0.082	-	-	-
	5	EL	15	Second-degree polynomial model	0.834	-	-	-

	6	EL	15	Second-degree polynomial model	0.259	-	-	-
	7	EL	22	Second-degree polynomial model	0.802	-	-	-
	8	EL	30	Second-degree polynomial model	0.461	-	-	-
Laina et al. (2013)	1	EL	6022	Non-linear model with power law terms and division operation	0.56	-	SV	-
	2	EL	3507	Non-linear model with power law terms and division operation	0.79	-	SV	-
Laitila et al. (2016)	1	EL	25	Log-linear model	0.141	-	P = 0.070	3.626
	2	EL	40	Linear model with division operation	0.544	-	P <0.001	44.06
	3	EL	25	Linear model	0.032	-	P = 0.400	0.738
	4	EL	40	Linear model	0.167	-	P = 0.009	7.632
	5	EL	25	Linear model	0.514	-	P <0.001	23.298
	6	EL	40	Linear model	0.738	-	P <0.001	107.174
Laitila & Väätäinen (2014)	1	EL	37	Log-linear model	0.12	-	SV	-
	2	EL	37	Linear model with division operation	0.369	-	SV	-
	3	EL	37	Log-linear model	0.775	-	SV	-
Laitila & Väätäinen (2020)	1	EL	80	Linear model with division operation	0.881	-	P <0.001	576.779
	2	EL	80	Log-linear model	0.724	-	P <0.001	204.102
	3	EL	80	Linear model with division operation	0.848	-	P <0.001	434.187
Laitila & Väätäinen (2021)	1	EL	17	Linear model	0.44	-	P = 0.004	-
	2	EL	17	Linear model	0.61	-	P <0.001	-
Laitila & Väätäinen (2023)	1	EL	16	Linear model	0.59	-	P <0.001	19.845
Laitila et al. (2013)	1	EL	-	Log-linear model	0.46	-	SV	-
	2	EL	-	Third-degree polynomial model	0.6	-	SV	-
	3	EL	-	Second-degree polynomial model	0.58	-	SV	-
Laitila et al. (2020)	1	EL	535	Second-degree polynomial model	0.46	-	P <0.001	223.174
Lazdiņš et al. (2019)	1	-	-	Power law model	0.93979	-	-	-
	2	-	-	Power law model	0.964	-	-	-
	3	-	-	Power law model	0.9784	-	-	-
Lazdiņš (2014)	1	EL	-	Exponential model	0.92	-	-	-
Lazdiņš et al. (2021)	1	PL	-	Third-degree polynomial model	0.9717	-	-	-
Lazdiņš et al. (2016)	1	EL	-	Power law model	0.91094	-	-	-
	2	EL	-	Power law model	0.79425	-	-	-

Leszczyński et al. (2021)	1	EL	-	Power law model	0.91	-	SV	-
	2	EL	-	Power law model	0.82	-	SV	-
	3	EL	-	Non-linear model with power law terms	-	-	SV	-
	4	EL	-	Power law model	-	-	SV	-
	5	EL	-	Power law model	-	0.5192	P = 0.008	8.304
	6	EL	-	Power law model	-	0.0291	P = 0.367	0.84
Liski et al. (2020)	1	PL	1104	Second-degree polynomial model	0.846	-	-	-
	2	PL	1104	Second-degree polynomial model	0.822	-	-	-
Louis & Kizha (2021)	1	EL	390	Linear model	-	0.34	SV	-
	2	EL	160	Linear model	-	0.18	SV	-
Magagnotti et al. (2021)	1	PL	18	Linear model	-	0.507	P <0.05	31.1
	2	PL	18	Linear model	-	0.801	P <0.05	35.2
	3	PL	18	Linear model	-	0.757	P <0.05	27.4
	4	PL	18	Linear model	-	0.765	P <0.05	28.6
Manner et al. (2023)	1	CL	115	Linear model	0.89	-	SV	-
	2	CL	115	Power law model	0.86	-	P <0.0001	1366.7
McEwan et al. (2016)	1	EL	-	Second-degree polynomial model	-	0.428	SV	-
	2	EL	-	Second-degree polynomial model	-	0.715	SV	-
	3	EL	-	Second-degree polynomial model	-	0.75	SV	-
Mederski et al. (2016)	1	PL	56	Linear model	-	0.7168	SV	-
	2	PL	56	Linear model	-	0.3934	SV	-
Norihiro et al. (2018)	1	EL	4388	Linear model	0.64	-	P <0.001	-
	2	EL	297	Linear model	0.45	-	P <0.001	-
	3	EL	2255	Linear model	0.61	-	P <0.001	-
	4	EL	181	Linear model	0.79	-	P <0.001	-
	5	EL	1478	Linear model	0.76	-	P <0.001	-
	6	EL	177	Linear model	0.75	-	P <0.001	-
	7	EL	4388	Linear model	0.68	-	P <0.001	-
	8	EL	1655	Linear model	0.76	-	P <0.001	-
	9	EL	2552	Linear model	0.6	-	P <0.001	-
	10	EL	181	Linear model	0.78	-	P <0.001	-

	11	EL	1478	Linear model	0.65	-	P <0.001	-
	12	EL	177	Linear model	0.76	-	P <0.001	-
	13	EL	1156	Linear model	0.56	-	P <0.001	-
	14	EL	1099	Linear model	0.64	-	P <0.001	-
	15	EL	297	Linear model	0.62	-	P <0.001	-
	16	EL	181	Linear model	0.56	-	P <0.001	-
	17	EL	4388	Linear model	0.624	-	P <0.001	-
Nuutinen & Björheden (2016)	1	EL	171	Log-linear model	0.252	-	SV	-
Olivera et al. (2016)	1	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	2	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	3	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	4	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	5	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	6	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	7	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	8	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	9	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	10	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	11	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	12	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	13	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
	14	CL	42690	Exponential model with logarithmic transformation	-	-	P <0.001	-
Petitmermet et al. (2019)	1	PL	45	Linear model	-	0.9412	SV	-
	2	PL	45	Linear model	-	0.9412	SV	-
	3	PL	45	Linear model	-	0.9412	SV	-
	4	PL	45	Linear model	-	0.9399	SV	-
	5	PL	45	Linear model	-	0.9398	SV	-
	6	PL	45	Linear model	-	0.9398	SV	-
	7	PL	45	Linear model	-	0.9384	SV	-
	8	PL	45	Linear model	-	0.9368	SV	-
Petty & Kärhä (2014)	1	EL	374	Log-linear model	0.17	0.16	P <0.0001	2117.84

	2	EL	332	Log-linear model	0.34	0.33	P <0.0001	1282.24
	3	EL	366	Log-linear model	0.26	0.25	P <0.0001	1669.85
	4	EL	262	Log-linear model	0.31	0.3	P <0.0001	1458.32
	5	EL	364	Log-linear model	0.22	0.21	P <0.0001	1904.89
	6	EL	334	Log-linear model	0.21	0.2	P <0.0001	1570.91
	7	EL	22	Log-linear model	0.72	0.71	P = 0.000	53.48
	8	EL	6	Second-degree polynomial model	0.99	0.99	P = 0.000	14735.693
	9	EL	6	Second-degree polynomial model	0.99	0.99	P = 0.000	12169.468
	10	EL	7	Second-degree polynomial model	0.99	0.99	P = 0.000	7761.318
	11	EL	7	Second-degree polynomial model	0.99	0.99	P = 0.000	6176.361
	12	EL	7	Second-degree polynomial model	0.99	0.99	P = 0.000	6329.739
	13	EL	7	Second-degree polynomial model	0.99	0.99	P = 0.000	5401.736
Polowy & Molińska-Glura (2023)	1	SL	108	Linear model	-	0.897	SV	-
	2	SL	108	Linear model	0.846	-	SV	-
	3	SL	108	Linear model	0.942	-	SV	-
Prinz et al. (2021)	1	EL	165	Exponential model	0.865	-	P <0.001	1047.137
	2	EL	126	Exponential model	0.909	-	P <0.001	1241.662
	3	EL	819	Third-degree polynomial model	0.879	-	P <0.001	1980.297
	4	EL	612	Third-degree polynomial model	0.934	-	P <0.001	2860.012
Ramantswana et al. (2013)	1	CL	724	Second-degree polynomial model	0.88	-	P = 0.05	-
	2	CL	485	Second-degree polynomial model	0.87	-	P = 0.05	-
	3	CL	542	Second-degree polynomial model	0.88	-	P = 0.05	-
	4	CL	724	Second-degree polynomial model	0.884848	-	SS	-
	5	CL	33	Linear model	0.67	-	SV	-
	6	CL	70	Second-degree polynomial model	0.77	-	SV	-
	7	CL	13	Second-degree polynomial model	0.92	-	SV	-
	8	CL	246	Second-degree polynomial model	0.89	-	SV	-
	9	CL	485	Second-degree polynomial model	0.873293	-	SS	-
Rosińska et al. (2022)	1	EL	-	Linear model	0.321	0.32	P <0.0001	442.53
	2	EL	-	Second-degree polynomial model	0.16	0.158	P <0.0001	89.133
	3	EL	-	Linear model	0.359	0.357	P <0.001	169.66

	4	EL	-	Linear model	0.271	-	-	-
	5	EL	-	Linear model	0.36	-	-	-
	6	EL	-	Second-degree polynomial model with interaction terms	-	-	-	-
Santos et al. (2022)	1	PL	80	Second-degree polynomial model	-	-	SV	-
Santos et al. (2021)	1	PL	-	Second-degree polynomial model	0.86	-	SV	-
Santos et al. (2020)	1	EL	-	Second-degree polynomial model with interaction terms	0.82	-	SV	-
	2	EL	-	Second-degree polynomial model with interaction terms	0.69	-	SV	-
	3	EL	-	Second-degree polynomial model with interaction terms	0.99	-	SV	-
	4	EL	-	Second-degree polynomial model	0.82	-	SV	-
	5	EL	-	Second-degree polynomial model	0.85	-	SV	-
	6	EL	-	Second-degree polynomial model with interaction terms	0.9	-	SV	-
	7	EL	-	Second-degree polynomial model with interaction terms	0.82	-	SV	-
	8	EL	-	Second-degree polynomial model	0.89	-	SV	-
Schweier et al. (2015)	1	EL	-	Linear model	0.733	-	P <0.0001	126.511
	2	EL	-	Linear model	0.795	-	P <0.0001	104.784
	3	EL	-	Linear model	0.379	-	P <0.0001	63.573
	4	EL	-	Linear model	0.639	-	P <0.0001	232.129
	5	EL	-	Second-degree polynomial model	0.415	-	P <0.0001	103.779
Slugeň et al. (2014)	1	EL	159	Linear model	0.4915	-	P = 0.0000	-
Soman et al. (2020)	1	EL	99	Linear model	-	0.18	SV	-
	2	EL	104	Linear model	-	0.19	SV	-
	3	EL	106	Linear model	-	0.34	SV	-
Soman et al. (2019)	1	EL		Linear model	-	0.42	SV	-
	2	EL		Linear model	-	0.45	SV	-
Sperandio et al. (2021)	1	EL	-	Power law model	0.1014	-	P <0.01	-
	2	EL	-	Power law model	0.3842	-	P <0.01	-
	3	EL	-	Power law model	0.8751	-	P <0.01	-
	4	EL	-	Power law model	0.9377	-	P <0.01	-
Spinelli et al. (2014)	1	PL	24	Linear model	0.959	-	P <0.0001	270.9
Spinelli & De Arruda Moura (2019)	1	-	106	Log-linear model	-	0.858	SV	-
Spinelli et al. (2022)	1	PL	33	Linear model	-	0.944	SV	-

Spinelli et al. (2023)	1	PL	16	Linear model	-	0.918	SV	-
Spinelli et al. (2020a)	1	-	26	Linear model	-	0.649	P <0.0001	24.12
	2	-	26	Linear model	-	0.315	P = 0.0017	12.503
Spinelli et al. (2020b)	1	PL	13	Linear model	-	0.014	P = 0.3018	1.174
	2	PL	13	Linear model	-	0.602	P = 0.0011	19.167
	3	PL	13	Linear model	-	0.026	P = 0.2751	1.319
Stoilov et al. (2021)	1	EL	31	Linear model	0.93	0.92	P <0.05	69.54
	2	EL	31	Linear model	0.86	0.83	P <0.05	31.32
	3	EL	31	Linear model	0.57	0.49	P <0.05	6.5
	4	EL	31	Linear model	0.37	0.25	P <0.05	2.98
Strandgard & Mitchell (2018)	1	EL	108	Exponential model	0.73	-	SV	-
	2	EL	106	Exponential model	0.3	-	SV	-
	3	EL	101	Exponential model	0.5	-	SV	-
	4	EL	101	Linear model	0.13	-	SV	-
	5	EL	108	Exponential model	0.73	-	SV	-
	6	EL	106	Exponential model	0.4	-	SV	-
	7	EL	136	Exponential model	0.36	-	SV	-
Strandgard & Mitchell (2019)	1	EL	107	Exponential model	0.59	-	-	-
	2	EL	107	Power law model	0.53	-	-	-
	3	EL	104	Exponential model	0.41	-	-	-
	4	EL	104	Power law model	0.6	-	-	-
Strandgard & Mitchell (2020)	1	EL	321	Power law model	-	0.88	SV	-
	2	EL	378	Power law model	-	0.32	SV	-
	3	EL	378	Power law model	-	0.72	SV	-
Strandgard et al. (2016)	1	-	47	Linear model	0.8	-	SV	-
	2	-	47	Linear model	0.79	-	SV	-
Strandgard et al. (2015)	1	CL	116	Non-linear model with power law terms	0.75	-	SV	-
Tajbos & Messingerova (2014)	1	EL	187	Linear model	0.35	-	P = 0.0000	100.48
	2	EL	68	Linear model	0.23	-	P = 0.0001	18.52
	3	EL	96	Linear model	0.52	-	P = 0.0000	101.63
	4	EL	32	Linear model	0.9	-	P = 0.0000	255.77

	5	EL	189	Linear model	0.25	-	P = 0.0000	62.38
	6	EL	64	Linear model	0.48	-	P = 0.0000	56.14
Tolosana et al. (2023)	1	EL	-	Log-linear model	0.84	-	SV	-
	2	EL	-	Log-linear model	0.27	-	SV	-
	3	EL	-	Non-linear model with power law terms	0.73	0.52	SV	-
Tolosana et al. (2018)	1	CL	17	Linear model	0.901	0.878	P = 0.0000	39.31
	2	CL	17	Linear model	-	-	-	-
Townsend et al. (2019)	1	EL	-	Linear model	0.52	-	SV	-
	2	EL	-	Linear model	0.51	-	SV	-
	3	EL	-	Linear model	0.51	-	SV	-
	4	EL	-	Linear model	0.48	-	SV	-
	5	EL	-	Linear model	0.54	-	SV	-
Walsh & Strandgard (2014)	1	EL	48	Log-linear model	0.33	-	-	-
	2	EL	55	Log-linear model	0.61	-	-	-
Walsh et al. (2014)	1	EL	70	Log-linear model	0.39	-	-	-
	2	EL	76	Log-linear model	0.47	-	-	-
Williams & Ackerman (2016)	1	EL	500	Linear model	0.8	-	P <0.01	-
Zimelis et al. (2020)	1	EL	18	Second-degree polynomial model	0.88	-	SV	-
	2	EL	18	Second-degree polynomial model	0.91	-	-	-
Zimelis et al. (2018)	1	EL	9985	Linear model	0.85	-	$P = 2.82\times10^{-21}$	372
	2	EL	-	Second-degree polynomial model	0.73	-	-	-
Zimelis et al. (2019)	1	EL	-	Third-degree polynomial model	0.96	-	-	-
	2	EL	-	Third-degree polynomial model	0.72	-	-	-
Zimelis et al. (2017a)	1	EL	-	Log-linear model	0.5444	-	-	-
	2	EL	-	Log-linear model	0.695	-	-	-
	3	EL	-	Second-degree polynomial model	0.6551	-	-	-
	4	EL	-	Second-degree polynomial model	0.9091	-	-	-
Zimelis et al. (2017b)	1	EL	-	Third-degree polynomial model	0.98	-	-	-
	2	EL	-	Third-degree polynomial model	0.93	-	-	-
	3	EL	-	Linear model	0.5	-	-	-
Zimelis & Spalva (2022)	1	-	-	Second-degree polynomial model	0.9048	-	-	-

	2	-	-	Linear model	0.9236	-	-	-
Zimelis et al. (2016)	1	EL	-	Power law model	0.94734	-	-	-