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Abstract

In the present study, occupational exposure to softwood (*Pinus brutia*) and hardwood (*Fagus sylvatica* and *Quercus petraea*) wood dust was determined during forestry work in a timber yard. In the determination of inhalable wood dust, three operating parameters of the chainsaw were taken into account. The first operating parameter was the chainsaw operating under normal conditions, which means proper maintenance and infrequent throttle pressing. Measurements under normal conditions were referred to as reference measurements and were used for comparison. The experiment continued with measurements of wood dust concentration under two other chainsaw operating parameters, namely, improper chainsaw maintenance and infrequent throttle pressing. The determination of inhalable wood dust concentrations from the ambient air was performed using the Inhalable Organic Matter (IOM) sampler, manufactured by SKC Button Sampler (Dorset, United Kingdom). Out of a total of 108 concentration values of inhalable wood dust, 44 (40.74%) showed concentrations greater than 3.00 $mg \cdot m^{-3}$, while in 10 (9.26%) values, the dust concentration exceeded 5 $mg \cdot m^{-3}$. The eight-hour time-weighted average exposure to wood dust ranged from 0.99 $mg \cdot m^{-3}$ to 12.52 $mg \cdot m^{-3}$, with an average of 4.22 $mg \cdot m^{-3}$. The results indicated that the increase in wood dust concentration is dependent on improper chainsaw maintenance, while infrequent throttle pressing reduces dust concentration levels. Additionally, an increase in wood dust concentration was observed in species with thick bark *(Pinus brutia* and *Quercus petraea*).

Keywords: timber harvesting, SKC, OEL, PM 2.5-10, air pollution

1. Introduction

The highest percentage of exposed workers within the European Union is estimated to be in the construction sector and furniture factories, while only 4% (150,000) of employees are engaged in forestry. This percentage continues to decrease in the countries of Central and Northern Europe due to the mechanization of harvesting operations (Kauppinen et al., 2006). In Greece, 100% of forestry workers use chainsaws during wood felling and shaping, with most of the shaping taking place within the timber yard. Motor-manual wood harvesting remains the primary method of work for many Southern European countries (Montorselli et al., 2010; Picchio et al., 2010; Caliskan, 2012; Albizu-Urion-abarrenetxea et al., 2013; Vusić et al., 2013).

Wood dust has been classified as a human carcinogen (IARC, 1995). Several epidemiological studies have also identified wood dust as a risk factor for causing asthma or asthma-related symptoms (Chan-Yeung et al., 1978; Bohadana et al., 2000; Douwes et al., 2001; Schlünssen et al., 2004a; Schlünssen et al., 2004b; Jacobsen et al., 2009), acute or chronic lung damage (Holness et al., 1985; Noertjojo et al., 1996; Mandryk et al., 1999; Jacobsen et al., 2008), and nasal damage (Åhman et al., 1996; Holness et al., 1985; Schlünssen et al., 2002). All these conditions can have both allergic and non-allergic origins.

The European Union Directive (EU) (1999/38) has classified hardwood dust as a carcinogen and set an Occupational Exposure Limit (OEL) for hardwood dust at 5 $mg \cdot m^{-3}$ in the workplace (European Commission, 1999; Kauppinen et al., 2006). In 2017, a European directive (2017/2398) further reduced the OEL to 2 $mg \cdot m^{-3}$ (3 $mg \cdot m^{-3}$ until January 17, 2023). The American Conference of Governmental Industrial Hygienists (ACGIH) has also classified dust from Fagus and Quercus species as carcinogens for humans and included them in the TLV list (Carrieri et al., 2016). In Greece, the exposure limit for hardwood dust was established in 2003 at 5 $mg \cdot m^{-3}$, in accordance with the EU Directive (1999/38). This limit also applies in cases of mixed softwood and hardwood dust, while exposure limits for softwood dust have not yet been defined (PD 42/2003).

More than 1,000 tree species are used for commercial purposes (IARC, 1995). Regardless of the species, the majority (about 95%) of wood consists of cellulose, hemicellulose, and lignin. The uniqueness of a wood species is determined by the types of wood extractives it contains, which can be numerous organic and some inorganic compounds. Terpenes and their derivatives, such as abietic acid, are characteristic of conifers (Schlünssen et al., 2012), while they are rarely found in hardwoods. Phenolic compounds, including tannins, stilbenes, and flavonoids, are concentrated in the heartwood of certain species and many of them have known sensitizing and irritative properties (Hausen et al., 1990; Woods and Calnan, 1976). *Quercus* species contain large quantities of tannins, while *Pinus brutia* contains phenolic compounds mainly in the bark (Philippou, 2014).

In this study, wood dust refers to the inhalable fraction of dust originating from green wood harvesting, including the bark.

The aim of this study was to assess the exposure of forest workers to inhalable wood dust during chainsaw operations in the forest. Furthermore, significant differences in dust concentration related to the tree species and the chainsaw's operating conditions were noted. Additionally, the various work phases have been dated to emphasize the relationship between wood dust concentration and chainsaw operating time.

1. Materials and Methods

The measurements were taken under real working conditions in the forests of Derio-Dadia-Loutron Northeast Greece. The research design included measurements of wood dust concentration during work in the operator's breathing zone throughout the wood harvesting process within the forest. Additionally, the measurements of wood dust concentration were correlated with thre operating parameters of the chainsaw. The operating parameters included the use of the chainsaw under normal operating conditions, which means proper chainsaw maintenance and regular gas pedal operation. This parameter was used as a comparison for the other two operating parameters. The other two operating parameters were improper chainsaw maintenance (clogged filter) and infrequent gas pedal operation of the chainsaw. In this research effort, two chainsaws of approximately the same technical characteristics from Husqvarna were used (table 2). Also, the measurements were taken on three different forest tree species. Specifically, measurements were taken for 36 days from pure stands of *Fagus sylvatica*, 36 days from pure stands of *Quercus petraea*, and another 36 days from pure stands of *Pinus brutia* (table 1). The felling, delimbing, and cutting of the trees were carried out within the logging area, following a typical Short-wood system. The logging operations were selective. The wood dust measurements were only related to the felling and processing of the stem sections and not the forwarding, which took place at a different time (intermittent harvesting work). Data collection for the measurements occurred from February to October and included 108 sampling days. Additionally, three more measurements of dust concentration in the logging area were conducted for each forest tree species on days when the logger was not working for a time equal to the logger's average daily working time.

Table 1

Table 2

The chainsaw operator had an air sampling device, an SCK (Sidekick) equipped with a Button Sampler (with a flow rate range of 5-3000 ml/min), and a glass fiber (binder-free GFA filter) with a 25 mm diameter, integrated into their belt throughout the work. This setup allowed for the collection of inhaled wood dust. In a special IOM sampler head (Institute of Occupational Medicine), filters for inhalable dust were placed. For each new dust measurement, corresponding to a new working day, a new filter could be installed in the IOM sampler cassette (www.hse.gov.uk). Under these conditions, each filter represented the collection of inhalable dust for one working day.

The pump (SCK Button Sample) was calibrated at the beginning of each sampling day with the help of a field rotameter to operate at a flow rate of 4 l/min (www.hse.gov.uk, Marchi et al., 2017). Calibration took place at the start of each measurement, and at the end of the measurement, an additional flow rate control measurement was conducted to verify potential changes in the airflow rate. The average of these two measurements was used for flow rate calculation.

The determination of the mass of airborne particles in the inhaled dust fraction was carried out by weighing the filters before and after sampling using a high-precision balance (±0.0001 mg). Before each weighing, the filters were equilibrated for 24 hours at a temperature of 20 ±1 ºC and a relative humidity of 48 ±2% (Chrysikou et al., 2008; Dimou et al., 2020).

The duration of all work phases within the timber yard was also recorded. The work phases included: i. Chainsaw engine in operation. ii. Chainsaw engine not in operation (including phases when the engine was idling or stopped).

It was assumed that work in the first category of work phases (i. chainsaw engine in operation) resulted in the creation of wood dust. These work phases included felling, delimbing, and bucking. Work phases in the second category (ii. chainsaw engine not in operation) encompassed work-related delays (preparation time, refueling the chainsaw, maintenance, sharpening, breaks with the chainsaw at idle, pauses, searching for the next tree – walk to tree), as well as preparation time (Björheden et al., 1995; Dimou et al., 2019).

A continuous timing method was used throughout the measurements. A stopwatch was started at the beginning of the work and stopped at the end of the working day. The time for each work phase was recorded at the end of each phase. The same forest worker was used throughout the measurements to ensure consistency in work rate and method. This worker had the required expertise for the job. Prior to each tree felling, the tree's stump diameter and tree species were measured and recorded. Additionally, for each daily sampling, three environmental temperature measurements and three humidity measurements were taken.

1.1 Statistical Methodology

A regression modeling approach to examine associations between inhalable wood dust of forestry operation and forest species/operating parameters

Methods

A regression-type modeling approach has been followed in order to examine and assess the potential effects, in a combined way, of factors such as the forest species and operating parameters of chainsaws on the inhalable wood dust of forest workers.

Prior to the fit of the regression model, regression analysis assumptions have been tested. In particular, the response variable of wood dust has been tested for normality assumption with the use of the non-parametric Kolmogorov-Smirnov (KS) test for normality. The results indicated a deviation of the response variable from the Normal distribution, whereas the transformed response through log transformation resulted in a Normal distribution.

Hence, subsequently, we fit a log-linear regression model of the following form (equation 1):

$$\begin{aligned} \log(\textit{Wood Dust})_i &= \beta_0 + \beta_1 \times (\textit{Species} = \text{Fagus Sylvatica})_i + \beta_2 \times (\textit{Species} = \text{Quercus Sp})_i + \\ &+ \beta_3 \times (\textit{Operation} = \text{Normal conditions})_i + \beta_4 \times (\textit{Operation} = \text{Improper maintenanc e})_i + \\ &+ e_i \qquad (i = 1, 2, \ldots, 108) \end{aligned} \tag{1}$$

where β_0 is the intercept, β_j $(j = 1,\ldots,4)$ the regression coefficients of the categorical explanatory variables of "Forest Species (reference category: *Pinus brutia*)" (β_1, β_2) and "Operating parameters (ref. category: Infrequent Accelerator)" (β_3, β_4), respectively. With e_i we denote the error term, assumed to follow a Gaussian distribution with zero mean and constant variance σ^2, i.e. $e_i \sim \mathrm{N}(0, \sigma^2)$.

In addition, we have included in the regression equation (1) all two-way interaction terms for the association between the two categorical explanatory variables of "Species" and "Operation".

In order to estimate the regression model parameters, the maximum likelihood method was utilized, whereas the selection of the best-fitted model that includes only statistically significant explanatory variables was performed by utilizing a backward stepwise selection technique. Goodness-of-fit for both models was assessed by the coefficient of determination, R^2.

Data were fitted to the log-linear regression model via the use of SPSS 21.0 statistical software (IBM Corporation, 2012).

1. Results and Discussion

In Table 3, the main characteristics of all sampling points are presented. Specifically, for each tree species, 12 dust concentration measurements were conducted for each operating parameter. The table also includes the number of trees by tree species and chainsaw operating parameter, as well as the corresponding average stump diameter.

Please note that specific values or data from Table 3 are not provided in your previous text, so I've translated the description of the table's content. If you need the translation of specific data from Table 3, please provide that information.

Table 3

Working Time

The distribution of working time is shown in Table 4. The total working time was 37,616.66 minutes, which corresponds to 108 working days, with an average daily working time of 348.30 minutes, approximately 6 working hours per day. The net working time of the chainsaw was 26,080.84 minutes, equivalent to 69.22% of the total working time.

The phases during which the chainsaw was not in operation (preparation time 2,229.02 minutes and delays 9,306.80) accounted for 5.92% and 24.74% of the total working time (total time on site), respectively. The time measurements for harvesting operations were conducted on a total of 1,069 trees, with an average stump diameter of 43.56 cm, while the average dust concentration was 3.07 mg·m^{-3}.

From dust concentration measurements conducted in all three forest species on days when harvesting operations did not take place and during a time duration equivalent to the average daily working time (6 hours), the concentration was 0.23 mg·m^{-3}.

Please note that specific numerical values have been translated as requested.

Table 4

In Table 5, the distribution of the mean total time on site and the chainsaw working time per forest species is presented, and they are almost identical. The subsequent columns display the averages and the percentage relative to the mean chainsaw running time for the individual work phases. There is an increased felling time in the *Fagus sylvatica* stand (9.32 minutes), as well as an increase in the time of delimbing in the *Quercus sp*. stand (66.63 minutes), corresponding to 3.98% and 27.85% of the mean chainsaw running time, respectively.

Table 5

Figure 1. Distribution of chainsaw running time and downtime in association with forest Species

In Fig. 1, the distribution of the main non-working and working times of the chainsaw is shown in relation to the three examined forest species.

Table 6 presents the dust concentration levels per forest species (including all three chainsaw operation parameters) and per chainsaw operation parameter (the average of the three forest species is also included for each operation parameter). These measurements pertain to the exposure to dust concentrations of the forest worker for approximately 6 hours of work. Since the occupational exposure limits (OEL) for wood dust are referred to on an 8-hour basis (European Commission, 1999), the corresponding results for wood dust concentration have been extrapolated to an 8-hour basis and are presented in the sixth column. Additionally, the last two columns display measurements of average environmental temperature and humidity.

Table 6

In Diagram 2, the concentrations of inhalable dust are shown by forest species and operational parameters. In total, each measurement corresponded to 12 sampling filters (12 days of measurement).

Figure 2. Wood dust per forest species and operating parameters

Table 7

In Table 7, the number of sampling filters (N) is shown in the three concentration classes of dust. The classes were established based on the occupational exposure limit (OEL) of 3 $mg \cdot m^{-3}$. The first class (≤ 3 $mg \cdot m^{-3}$) is considered the acceptable concentration class below the exposure limit (OEL), the second class ($3 < x \leq 5$ $mg \cdot m^{-3}$) is the high concentration class above the exposure limit, and the third class (>5 $mg \cdot m^{-3}$) is the very high concentration class of dust. Overall, it is observed that approximately 40% of the sampling filters (44 filters out of 108) exceed the occupational exposure limit for wood dust (3 mg·m^{-3}).

The separation of the number of sampling filters (Table 7) was done by forest species and operational parameters of the chainsaw. The percentage in relation to the total number of samples per forest species and operational parameter is also shown. For each dust concentration class, the mean tree diameter, temperature, humidity, and chainsaw working time have been measured.

Table 8 shows the number of sampling filters belonging to the very high concentration class of dust, which is over 5 mg·m^{-3}, per forest species and operational parameter.

Table 8

Figure 3. Mean distribution in min of a chainsaw running time and downtime in association with dust classes

Figure 3 depicts the distribution in minutes of chainsaw felling and processing time (work time) and non-work time (preparation time and delays) in relation to the distribution of the three classes of wood dust concentration.

3.1 Results of statistical regression modeling

Prior to fitting the regression model that examines the potential effects of the variables of "Forest Species" and "Operating Parameters" on the Wood dust, the latter was examined for the Normality assumption through the Kolmogorov-Smirnov test.

The results indicated a deviation of the variable from the Normal distribution (see results ~~of~~ the first column of Table 1). The KS statistic is 1.485 and the corresponding p-value of the test is $0.024<0.05$, therefore the null hypothesis of Normality is rejected at a 5% significance level. Since the response variable violates the normality assumption, we log transform the former and the KS results indicate that the resulting log wood dust follows the normal distribution (KS = 0.716; p-value=$0.685>0.05$) (Table 9).

Table 9

Figure 4 below shows the histogram plots (distributions) of both original and log-transformed wood dust variables. From the inspection of the two plots, it is evident that the log transformation alleviated the deviation from normality for the wood dust response variable.

Figure 4. Histogram plots for the wood dust and log-transformed wood dust variables

Hence, we subsequently utilize the Normally distributed log-Wood dust variable as the response and fit the log-linear regression model of equation (1).

Upon fitting the model and performing a backward elimination stepwise model selection, we obtain parameter estimates presented in Table 10.

Table 10

Goodness-of-fit of the model is measured through the R^2 which is 0.409, indicating that the specific model accounts for around 40% of the variance in wood dust concentration.

According to the parameter estimates results, it is seen that only the "Forest species" explanatory variable is a statistically significant predictor of wood dust. Specifically, more wood dust is produced under the forest species of *Quercus sp*., in comparison to the other two forest species (b=2.124; p-value=0.002<0.01). On the other hand, the modeling results did not show a direct statistically significant effect of operation on the produced wood dust.

In terms of the interaction effects between the two independent factors on the response variable of wood dust, we observe few significant results from the parameter estimation results.

Specifically, when operating under normal conditions on the *Quercus sp*., this results in statistically significantly lower wood dust production, when compared with the other two forest species (b=-1.997; p-value=0.04<0.05).

Another important outcome from modeling is that operation under improper maintenance on *Quercus sp*. also results in reduced wood dust compared to *Fagus sylvatica* and *Pinus brutia* forest species (b=-2.297; p-value=0.019<0.05).

Overall, it is found that the increase in wood dust is mainly due to working on the *Quercus* sp. forest species. However, our results show that this can be reduced significantly if the operation on *Quercus sp*. is performed under "Normal Conditions" or "Improper Maintenance" instead of the "Infrequent Accelerator" operation.

4. Discussion

In forestry (NACE 02), forest workers and loggers (occupation code, 340) are considered to be the only ones exposed to wood dust (Kauppinen, 2006). Although in advanced forestry countries in Central and Northern Europe, individuals exposed to the forestry profession, especially loggers, are decreasing due to the use of fully mechanized harvesting systems, as they work from enclosed cabins and are less exposed to wood dust. In Greece, wood is harvested using chainsaws.

Wood dust can have different health effects on workers since different wood species have varying toxicological and allergenic potentials due to differences in their chemical composition, including protein content. For example, Pinus wood generally has a low but variable protein content (Kespohl et al., 2010; Skovsted et al., 2003). Additionally, the dust from *Quercus* and *Fagus* is considered quite toxic and classified as carcinogenic to humans (Group A1) (ACGIH, 2014; Kauppinen et al., 2006; Čavlović et al., 2022).

In the present study, an attempt was made to measure wood dust concentrations in pure stands of *Fagus sylvatica*, *Quercus sp.* and *Pinus brutia*, aiming to investigate the relationship between wood dust levels, the mentioned tree species, and chainsaw operation parameters. All measured wood dust values have been compared to the European Occupational Exposure Limit (OEL), which is set at 3 $mg \cdot m^{-3}$.

From Table 6, it is evident that the highest wood dust concentrations exceeding the OEL are found in stands of *Pinus brutia* and *Quercus sp.* (3.31 $mg \cdot m^{-3}$ and 3.11 $mg \cdot m^{-3}$, respectively), with a statistically significant difference between these wood dust concentrations for approximately 6 hours of work. The corresponding results converted to an 8-hour working basis, according to the applicable OEL, are 4.47 $mg \cdot m^{-3}$ and 4.31 $mg \cdot m^{-3}$, respectively. These results align with those from Dimou et al., (2020), where the highest concentrations were in *Pinus* and *Quercus* stands (3.73 $mg \cdot m^{-3}$ and 3.79 $mg \cdot m^{-3}$, respectively), with slightly higher concentrations in *Quercus*, a trend that is also observed in the current study based on statistical data processing (Table 10).

Moreover, lower concentrations are observed in *Fagus* stands (2.78 $mg \cdot m^{-3}$). According to Dimou et al. (2020), in the mixed *Fagus sylvatica*-*Quercus* stands, where *Fagus sylvatica* predominated, the lowest wood dust concentration was recorded (2.30 $mg \cdot m^{-3}$). These results reinforce the idea that higher concentrations are more related to the thickness of the bark of a species, as *Pinus* and *Quercus* belong to species with thick bark, while *Fagus* belongs to those with thin bark.

In a similar study measuring wood dust concentrations during chipping operations, conducted by Marchi et al., (2017), the mean exposure value was lower, approximately around 2.1 mg·m^{-3}. Since there are not many studies that have dealt with wood dust concentration measurements during logging operations, Alwis (1998) and Mitchell (2011) are mentioned, who conducted studies on chipping operations where machine operators worked from inside a cabin, reporting mean exposure values of 1.9 mg·m^{-3} and 1.3 mg·m^{-3}, respectively.

In this research effort, three chainsaw operation parameters have been taken into account. However, it is observed after statistical analysis (Table 10) that the mean wood dust concentration values concerning the operation parameters do not have statistically significant differences between them. When compared to the "normal conditions" operation parameter (proper maintenance and infrequent accelerator use), the "Improper maintenance" parameter (improper maintenance and frequent accelerator use) seems to have a negative impact, resulting in an increase in wood dust concentration, specifically at 3.48 mg·m^{-3} for about 6 hours of work, compared to 2.91 mg·m^{-3} for "normal conditions," although without a statistically significant difference in this increase. Conversely, when the chainsaw operates under the "Infrequent accelerator" parameter (infrequent accelerator use), this has a positive effect, namely a reduction in wood dust concentration. Specifically, compared to "normal conditions" (2.91 mg·m^{-3}), the wood dust concentration value was 2.81 mg·m^{-3} (again without a statistically significant difference in this decrease). Additionally, from Figure 2, which presents the results by tree species and operation parameters (i.e., measurements for each case from 12 sampling filters), it is evident that for the examined tree species in this study, under the "Improper maintenance" operation parameter, there was a higher wood dust concentration (except for the *Quercus sp.* species, where it appears slightly lower compared to the "Infrequent accelerator" operation parameter, again without a statistically significant difference as shown in Table 10). This can be justified by the increased pruning time observed (66.63 minutes, Table 6) for *Quercus sp.* compared to the other two tree species, *Fagus sylvatica* and *Pinus brutia* (25.11 minutes and 29.30 minutes, respectively).

Additionally, from Table 7, it is evident that the lowest number of sampling filters in the "acceptable concentration" class of wood dust (≤3 mg·m^{-3}) was achieved under the "Improper maintenance" parameter (N.18, 50%). Conversely, the majority of the sampling filters in this concentration class (≤3 mg·m^{-3}) were found under the "Infrequent accelerator" parameter (N.25, 69.44%). Moreover, regarding the tree species from the same table (Table 7), it appears that the tree species with coarse bark, such as

Quercus sp. and *Pinus brutia*, accumulate the most sampling filters in the high and very high concentration classes of wood dust (3x≤5 mg·m^{-3} and >5 mg·m^{-3}), respectively. Cumulatively, for these two concentration classes, *Quercus sp.*and *Pinus brutia* have N. 23 (63.88%) and N. 19 (53.77%) sampling filters, while *Fagus sylvatica* has N. 14 (38.88%). Moreover, most of the sampling filters (N. 5, 10.42%) in the "very high concentration" class (>5 mg·m^{-3}) are attributed to *Pinus brutia*.

From Table 7, it seems that there is a decreasing trend in the average diameter concerning the three concentration classes of wood dust, from the "acceptable concentration" class (≤3 mg·m^{-3}) to the "very high concentration" class of wood dust. Specifically, the largest average stem diameter is found in the "acceptable concentration" class of wood dust (≤3 mg·m^{-3}). This indicates that the dust concentration is proportionate to tree dimensions, showing a decreasing concentration as tree dimensions increase. This finding aligns with previous work by Dimou et al., (2020).

The ambient temperature and humidity do not appear to have contributed significantly to the results since they remained relatively stable for all the sampling days (Tables 6 and 7).

The researchers also determined productivity and chainsaw usage through appropriate time studies (Magagnotti and Spinelli, 2012). From Figure 1 and Figure 3, it is evident that the chainsaw operator maintained a consistent work rate across all three forest species and within the three wood dust concentration classes. This consistency ensures the validity of the results of this study, as wood dust concentration is directly dependent on the chainsaw's working time when the engine is in operation.

5. Conclusions

The comparison of the results in this study was not conducted in accordance with the Occupational Exposure Limit (OEL) that is in effect in Greece (5 mg·m^{-3}), considering that this exposure limit should be reduced. Following the European Directive (2017/2398), the OEL has now been lowered to 2 mg·m^{-3}. An additional reason for compliance with the current OEL of the European directive is that, according to Magagnotti et al., (2013), the toxicity of fresh wood could be more potent, particularly endotoxins, and exposure to monoterpenes, which are highly present in coniferous trees, could be more active in wood dust than fresh wood (Mandryk et al., 2000; Demers et al., 2000). With this perspective, the authors of this study consider that woodcutters exposed to wood dust are more vulnerable compared to workers in wood industries, as the existing limits are based on this specific wood industry rather than the forestry profession (Marchi et al., 2017).

Exceeding the Occupational Exposure Limit (OEL) value of 3 $mg \cdot m^{-3}$ for wood dust concentration poses health risks for workers, including various respiratory diseases. In this study, it was found that approximately 40% (44 out of 108 sampling filters) exceeded the OEL for wood dust concentration (3 $mg \cdot m^{-3}$). Concerning forest species, those with thick bark appear to contribute to higher levels of wood dust concentration. Wood dust concentration is more dependent on the tree species rather than the chainsaw operation. High wood dust concentration was found in *Quercus* species; however, this can be significantly reduced when the chainsaw operation is under normal conditions, meaning proper chainsaw maintenance with infrequent accelerator use. It was also observed that tree dimensions tend to affect wood dust concentration levels, showing a decreasing trend as tree dimensions increase.

The results of this study can serve as a valid database for assessing the exposure of forest workers in the forest. Future research in the field of harvesting may also focus on examining the current safety culture to improve safe working practices in forestry. Awareness among forest workers regarding the health problems posed by environmental dust concentrations would be the first essential step in voluntary prevention measures, either through personal protective equipment or by improving their working practices, particularly concerning chainsaw handling and maintenance.

Statement and Declarations

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Author Contribution All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Vasiliki Dimou, Theodora Tioutiuntzi, and Chrisovalanti Malesio. The first draft of the manuscript was written by Vasiliki Dimou and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript**.**

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Fig. 1

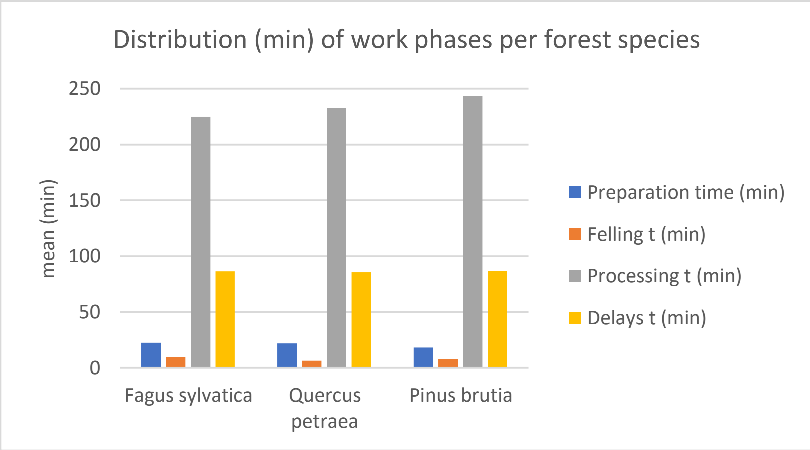

Distribution (min) of work phases per forest species
250
200
150
100
50
0
mean (min)
Fagus sylvatica
Quercus petraea
Pinus brutia
Preparation time (min)
Felling t (min)
Processing t (min)
Delays t (min)

Fig. 2

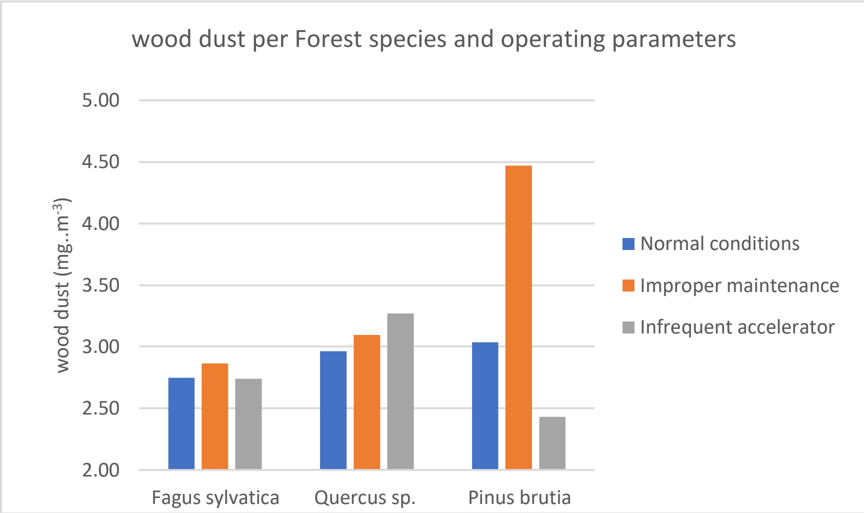
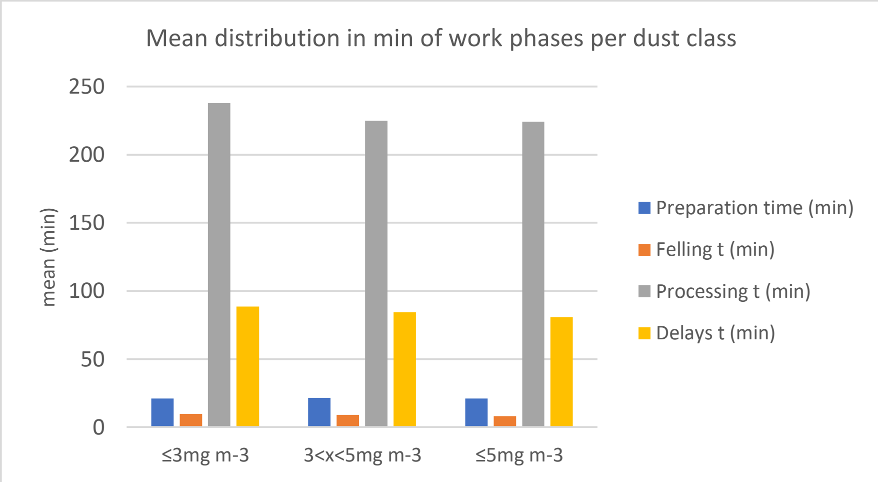
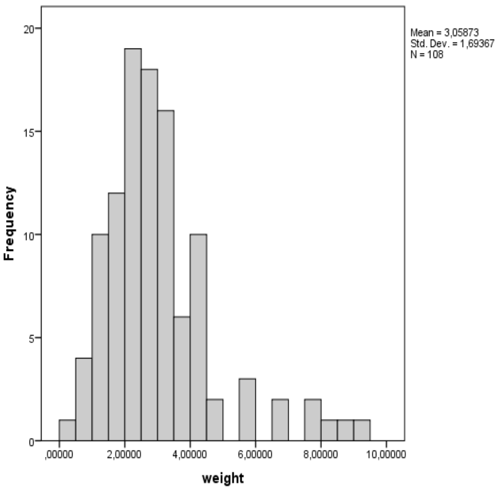

wood dust per Forest species and operating parameters
wood dust (mg..m-3)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
Fagus sylvatica
Quercus sp.
Pinus brutia
Normal conditions
Improper maintenance
Infrequent accelerator

Fig. 3

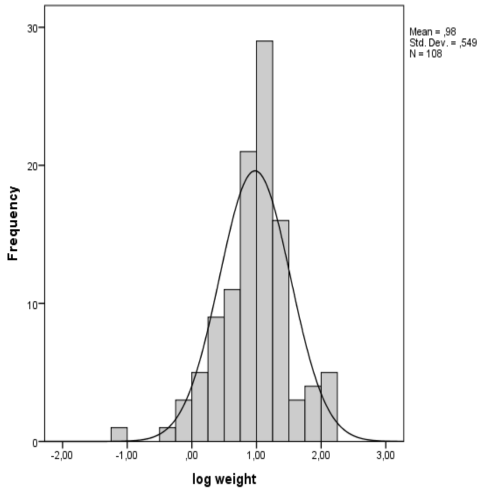


Mean distribution in min of work phases per dust class
250
200
150
100
50
0
mean (min)
≤3mg m-3
3<x<5mg m-3
≤5mg m-3
Preparation time (min)
Felling t (min)
Processing t (min)
Delays t (min)

Fig. 4



Mean = 3,05873
Std. Dev. = 1,69367
N = 108
Frequency
weight
,00000
2,00000
4,00000
6,00000
8,00000
10,00000



Mean = ,98
Std. Dev. = ,549
N = 108
Frequency
log weight
-2,00
-1,00
,00
1,00
2,00
3,00

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