Assessing chainsaw operators' exposure to wood dust during timber harvesting

Vasiliki Dimou¹ · Chrisovalantis Malesios² · Vasiliki Chatzikosti³

Received: 6 August 2020 / Accepted: 19 October 2020 / Published online: 26 October 2020
© Springer Nature Switzerland AG 2020

Abstract

Exposure to wood dust during logging operations is generally associated with a variety of adverse health effects. The aim of the present study is to determine the exposure of forestry workers to wood dust during timber harvesting tasks in a cutover. The concentrations of inhalable hardwood dust produced from *Fagus sylvatica* and *Quercus petraea* as well as softwood dust from *Pinus brutia* stands were examined. In total, 24 samples were collected with the use of a Personal SKC Button Sampler. Dust collection was performed every working day. The study also took into account the duration of each work phase in which the chainsaw was used (*running time*) as well as the delays, during which the chainsaw was either at idle or not running at all (*downtime*). Measurements were carried out throughout the daily work of the logger, which lasted from June to September. Mean concentration of inhalable dust for an 8 h exposure was found to be approximately 4.84 mg m^{-3} . Fifty per cent of the samples showed dust concentrations lower than 3.00 mg m^{-3} , while in approximately 20.8% of the samples, dust levels were higher than 5 mg m^{-3} . Results also revealed that the concentration of inhalable dust is in inverse proportion to the increase in breast height diameter, implying that larger trees generated lower dust amounts. Furthermore, timbering activities in *Quercus petraea* stand were found to result in higher dust concentrations.

Keywords OEL · Inhalable wood dust · Wood dust exposure · SKC · Cancer

1 Introduction and Literature Review

Motor-manual felling and on-site timber processing is for a lot of countries, Greece included, the exclusive harvesting methodology [1–5]. More specifically, in Greece, due to features such as intense slopes, coupled with insufficient knowledge and training on the part of forestry workers, skidding is performed by means of cable yarding and tractors or mules, whereas harvesters are never used.

It is well documented that lumberjacks are, as a rule, exposed to wood dust during logging operations. Generally speaking, motor-manual harvesting is considered particularly hazardous since it fails to offer the safer conditions that highly mechanized forestry work can ensure [6].

Exposure to dust can result in a variety of health issues including skin irritation caused by contact with wood dust, bark, bark lichens or bark extracts. Skin problems, which on average take 15 days to emerge, may develop either after direct contact with wood or due to cross-contamination

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s42452-020-03735-6>) contains supplementary material, which is available to authorized users.

✉ Vasiliki Dimou, vdimou@fmenr.duth.gr; Chrisovalantis Malesios, malesios@aua.gr; Vasiliki Chatzikosti, xkosti@hotmail.com | ¹Laboratory of Forest Technology, Department of Forestry and Management of the Environment and Natural Resources, Democritus University of Thrace, 193 Pandazidou, 68200 Orestiada, PC, Greece. ²Department of Agricultural Economics and Rural Development, Agricultural University of Athens, 75 118 Athens, PC, Greece. ³Department of Forestry and Management of the Environment and Natural Resources, Democritus University of Thrace, 193 Pandazidou st, 68200 N. Orestiada, Greece.

SN Applied Sciences (2020) 2:1899 | <https://doi.org/10.1007/s42452-020-03735-6>

from other parts of the body by hand. They usually disappear when contact with the irritant is removed [7]. Wood dust exposure can also give rise to eye problems such as soreness, watering and conjunctivitis. Furthermore, it has long been associated with respiratory and other related problems such as rhinitis, violent sneezing, blocked nose and nose bleeds. Respiratory problems also include lung diseases such as asthma, impairment of lung function and, rarely, extrinsic allergic alveolitis caused by dust from certain forest species such as *Thuja plicata* and *Iroko* [7, 12, 19–21]. The majority of these problems last for as long as the patient remains in contact with the irritant dust, whose concentrations are above the recommended exposure limits (3 mg m^{-3}). However, it has been reported that some individuals eventually develop a kind of sensitivity to dust and cannot keep working in dusty environments irrespective of concentrations, even if these are kept below recommended limits. In such cases, they must make use of respiratory protective equipment (RPE), such as a breathing apparatus (BA) with a supply of breathing-quality air and their health ought to be monitored on a regular basis [7].

Apart from respiratory, pulmonary and skin problems, occupational exposure to wood dust is also associated with carcinogenicity. In fact, there is a large volume of published studies suggesting that the most serious health concern associated with exposure to wood dust is the risk of developing cancer, especially in the nose, as well as adenocarcinoma (a cancer that develops in the glandular tissues of the body) [8–10]. The International Agency for Research on Cancer [11] has already since 1995 classified hardwood dust as carcinogenic to humans [11]. More specifically, in a research paper by Kauppenen et al. [12] it is reported that the dust from certain hardwoods, such as *Fagus sylvatica* and *Quercus sp.*, is more hazardous as it is considered carcinogenic. It has also been confirmed that exposure to oak-wood and beech wood dusts in the workplace is carcinogenic, too [13, 14].

The dust produced from each particular wood type causes specific problems to the workers exposed to it; for instance, the dust from *Fagus sylvatica* can lead to dermatitis, decrease in lung function, and eye irritation (possibly from bark lichens). *Quercus sp.* can cause asthma, sneezing, and eye irritation, whereas employees exposed to *Pinus sp.* dust may develop skin irritation (due to photosensitisation) and decrease in lung function [7]. The Canadian Centre for Occupational Health and Safety [15] provides a comprehensive list of health effects that have been associated with various types of woods.

The term ‘dust’ generally refers to solid particles whose size, measured in microns (μm), ranges from 1 to $100 \mu\text{m}$. Depending on its size, dust is deposited either in the nasal cavity ($< 100 \mu\text{m}$), or in the respiratory tract below the larynx ($< 10 \mu\text{m}$), or in the alveolar region of

the lungs ($< 4 \mu\text{m}$) [16]. Taking all the above-reported problems into consideration, in 2002, the Scientific Committee for Occupational Exposure Limits (SCOEL) of the EU stated that exposure to wood dust above 0.5 mg m^{-3} induces pulmonary effects and should be avoided [17]. A year later, the SCOEL considered a conversion factor of total dust to inhalable dust (2–3), which led to the proposal of an OEL of $1\text{--}1.5 \text{ mg m}^{-3}$ (inhalable fraction) [18]. The smaller the particles, the more dangerous they prove to be [13, 22]. Particles sized 0.08 mm tend to settle very slowly and particles sized $< 10 \mu\text{m}$ do not settle at all and they consequently keep lingering in the polluted air; as a result, they are considered particularly hazardous because they are able to penetrate deeply into the respiratory tract and in the lung alveoli [13, 22, 23].

In terms of the impact on workers’ health and safety, wood dust can be classified into two categories: (a) the inhalable fraction, which consists of suspended particles that can enter the head airways region including the nose and mouth; and (b) the respirable fraction, which consists of small-diameter particulate matter that can be deposited in the alveoli of the lung. The latter kind of dust is mainly responsible for causing pneumoconiosis [24, 25]. The inhalable fraction, according to the SCOEL is the “best convention to explain the critical effect(s) of wood dust in the upper airways and it would therefore be the most appropriate fraction to sample” [18].

In wood processing industries operating in the 25 countries of the European Union, 16% of employees are exposed on an everyday basis to dust levels in excess of 5 mg m^{-3} , which is far above the allowable exposure limits (3 mg m^{-3}) [12]. It should be noted here that the moisture content of wood dust plays an important role that must be taken into account, as the impacts from exposure to dry and wet sawdust vary considerably. In their 2016 paper, Mračková et al. [13] report that, by using mechanical dust collectors, they managed to capture the smallest sized (separation limit = $40 \mu\text{m}$) grainy wet sawdust generated from sawing wet wood as well as the smallest (separation limit = $12 \mu\text{m}$) grainy dry sawdust. Mračková et al., [13] confirm that, while wet sawdust can infect solely the nasal cavity, dry sawdust fractions can be deposited in the thorax and the lungs, and, for this reason, they are considered more hazardous.

In view of all the aforementioned health impacts, it has been observed that, in the silvicultural sector, the number of employees exposed to dust is decreasing, owing to the fact that chainsaw is being replaced by other forest machinery such as harvesters. However, this gradual change is not valid in the Greek silvicultural context [12].

The European Council Directive [26] of 29 April 1999 had set the exposure limit for inhalable wood dust at

5 mg per cubic metre of workroom air (mg m^{-3}) for an eight-hour working day [24]. This limit value is termed as *occupational exposure limit* (OEL) and it was valid for hardwood dusts or for any mixture of dust from hardwoods and softwoods. In 2002, this limit value was changed and separate exposure limits were fixed at 3 mg m^{-3} for hardwoods and 5 mg m^{-3} for softwoods [27]. According to the EU Directive, exposure to hardwood dust remains at 3 mg m^{-3} as of 17 January 2023; nevertheless, as projected from current trends, this limit is bound to drop to 2 mg m^{-3} in the future [28].

There is a large body of research on exposure to wood dust of workers employed in various woodworking industries such as sawmills, furniture factories, etc.; as these industries employ large numbers of workers, it is easier to perform exposure measurements [14, 20]. Epidemiological studies have also been conducted to assess exposure to wood dust of workers employed in these areas. However, very few published studies have addressed the exposure of forestry workers in their workplace, i.e. in the forest [29], even though it is well known that the work environment in logging operations tends to be dusty. According to Mitchell [30], most of these studies have taken into account the respirable fraction during chainsaw operation [14, 31].

1.1 Aim of research

The aim of the present study is to assess the exposure of forestry workers to the inhalable fraction of dust originating from their chainsawing activities in the forest. In addition, the study aims at pointing out the significant differences in dust concentration levels both in relation to tree dimensions and in response to the type of wood (hard or soft) considered. The various work phases were timed with a view to highlighting the relationship between wood dust concentration and chainsaw running time.

2 Materials and methods

The study area is located in the forests of Dadia-Soufli, Northeast Greece. Measurements were carried out in silvicultural operations that lasted for a total of 24 days: 12 days in a *Quercus pertaea* stand, 7 days in a mixed *Fagus sylvatica* and *Quercus petraea* stand and 5 days in a *Pinus brutia* stand. All logging was selection cut. After felling, trees were debranched inside the stump area and cross-cut into 5–6 m length logs with the use of a chainsaw.

Harvesting tasks were intermittent, which means that after felling and processing tasks had been completed, logs were left in the stump area to be skidded at a later phase. Wood dust measurements were exclusively performed during felling and processing jobs.

Data collection was carried out in summer months from June till September.

In order to collect the inhalable fraction of wood dust, throughout the logging tasks that he performed, the chainsaw operator wore a SKC Button Sampler. The main parts of the SKC Button Sampler were the IOM sampler filter receiver equipped with a binder-free GFA glass fiber filter of 25 mm diameter and the SKC Pump-Sidekick (with a flow rate of 5–3000 mL-min). The filters were placed on the IOM sampling head (Institute of Occupational Medicine) for inhalable particles. The IOM sampler, developed by IOM researchers [30], is less sensitive to wind direction and magnitude [31] moreover, it enables the user to place a new filter into its cassette in every new dust measurement.

The IOM sampler and the SKC Sidekick Pump were connected to each other by means of a flexible tube (Tygon tube). The portable pump, which operated at a flow rate of 4 l min^{-1} [20], was attached to the belt of the chainsaw operator, and the IOM sampler was placed at a distance of 10 cm from the operator's face. The pump is designed to simulate the human breath; this means that the filter received all the airborne workplace particles inhaled through the lumberjack's nose and mouth. The pump, calibrated at the start of each sampling day with the use of a field rotameter ($400 \text{ mL}–5 \text{ L/min}$), recorded the total air flow and the duration of the sampling session. At the end of the sampling procedure another measurement of the flow rate was carried out, as pump performance was likely to be affected after prolonged operation as a result, the average of the two flow rate measurements was taken into consideration. Daily dust exposure was then determined by a gravimetric method of inhalable aerosols [7].

Prior to the sampling tests, filters were conditioned in a climatic cabinet at a temperature of $20 \pm 1^\circ \text{C}$ and moisture of $48 \pm 2\%$ for 24 h. The filters were subsequently weighed by means of a precision scale accurate to the microgram (model: Adam NBL 164e Analytical Balance); the IOM sampler was weighed, too, without a filter. Each filter was then placed into a separate bag and each bag was identified with its individual code number. Before the start of each sampling, the filter was carefully placed into the IOM sampler using clean tweezers to avoid contamination. At the end of the tests, the filters were sent with the use of special filter transport cases back to the laboratory, where they were reconditioned in the same climatic conditions ($20 \pm 1^\circ \text{C}$ and moisture of $48 \pm 2\%$ for 24 h). After conditioning, filters were weighed again and placed in their respective coded bags.

The concentration of wood dust was measured using the following formula:

$$C = \frac{P_2 - P_1}{V} \quad (1)$$

where C is the wood dust concentration in mg m^{-3} ; P_2 is the weight of the filter in mg after the test; P_1 is the weight of the filter in mg before the sampling; and V is the air volume in m^3 .

The air volume was calculated with the use of the following formula:

$$V = \frac{T \times F}{1000} \quad (2)$$

where T is the duration of the sampling in min ; F the effective air flow in $\text{litre} \cdot \text{min}^{-1}$.

For the calculation of the effective air flow, we took into account the average value of the initial air flow and final air flow after the end of the sampling procedure. Each filter served as a dust sampler for the whole working day, which lasted approximately 5 to 6 h. At the end, sampling data was expressed as a time-weighted average (TWA) over 8 h of daily work.

2.1 Time study

All work phases of the chainsawing process were timed and recorded. These phases fall under two main categories: (a) those in which the chainsaw engine was running (running time), and (b) those in which the chainsaw was at idle or not running at all (downtime). The first category included felling, delimbing and cross-cutting jobs, and was the work phase during which dust was generated. The second category, with the chainsaw at idle or stopped, included all kinds of work-related delays (preparation time, refueling, maintenance tasks, sharpening, breaks, searching for next tree to be felled, walking to tree etc.) [34, 35]. The timing method followed was continuous timing, in which the timer was set at the start of the logger's daily work and turned off when it was finished (i.e. after 5 or 6 h). Every time a particular task was completed, the exact time was noted down. All timing was recorded in minutes. The time difference between the separate work phases yielded the net duration of each phase.

In all measurements the same lumberjack was used so that there would be no differences whatsoever as far as the

method adopted and the rate of work is concerned. The worker chosen had the required work experience. During the study, the logger on a daily basis alternatively used two common chainsaws, namely a Husqvarna 385XP and a Husqvarna 372XP (Table 1). Both saws, equipped with similar-length blades (50 cm) and chains (3/8") recommended by the manufacturer, were regularly maintained and in good working condition. Prior to tree felling, breast height diameter was measured and recorded in centimeters for each tree along with other characteristics such as forest species. The logger worked alone and, at a safe distance, a member of the research team recorded the time measurements, the breast height diameter and the tree species. For each sampling, temperature and humidity measurements were also performed and recorded (per sampling day).

2.2 Statistical methodology

2.2.1 Regression modeling

In order to effectively examine the combined effects on wood dust of factors such as forest species, breast height diameter, type of work (i.e., felling, debranching and cross-cutting), as well as environmental factors in the form of relative temperature and relative humidity, a multiple linear regression approach was followed. In this way, it is possible to derive the statistically significant factors affecting wood dust, taking into account the inherent correlations in the covariates. In particular, the following regression model was fitted to the collected data:

$$y_i = \beta_0 + \beta_1 \cdot (Fagus - Quercus) + \beta_2 \cdot Pinus + \beta_3 \cdot (Debranching) + \beta_4 \cdot (Cross - cut) + \beta_5 \cdot (Felling) + \beta_6 \cdot (SDM) + \beta_7 \cdot (\#trees) + \beta_8 \cdot (temperature) + \beta_9 \cdot (humidity) + \varepsilon_i \quad (3)$$

where y_i ($i = 1, 2, \dots, 24$) denotes the daily total concentration of inhalable wood dust, β_0 is the intercept, β_1, β_2 are the regression coefficients for the "Fagus & Quercus" and "Pinus" types of trees, respectively, β_3, β_4 and β_5 denote the coefficients for the covariates of debranching, cross-cutting and felling time, respectively, β_6 is the coefficient of breast

Table 1 Characteristics of the chainsaws used in the study

Brand	Model	Engine size (cm^3)	Power Hp	Max rpm	Capacity		Weight (empty, kg)
					Tank volume	Oil tank volume	
Husqvarna	385XP	84.7	5.2	9600	0.70	0.40	7.0
Husqvarna	372XP	70.7	5.5	6600	0.77	0.42	6.5

height diameter, β_7 the coefficient for the number of trees per day, and finally β_8, β_9 are the regression coefficients for the relative temperature and humidity, respectively. With ε_i is denoted the error term in the regression equation.

We took a backward elimination variable selection approach to obtain the best fitted model to the data. Specifically, this stepwise procedure starts by fitting the complete model including all covariates, as described in the regression equation presented in the current section. Then, at the following steps we remove the least statistically significant covariate and fit the reduced regression model. The final best selected model is the one that includes only statistically significant covariates. Model fit was performed through the R package [36], utilizing the *lm* function [37].

3 Results and discussion

3.1 Descriptive analysis results

3.1.1 Work time

As previously mentioned, the chainsaw operator worked on *Quercus petraea* stand for a total of 12 days, for 7 days on a mixed *Fagus sylvatica-Quercus petraea* stand and for another 5 days on *Pinus brutia* stand. The overall work time on site was 7550 min (which correspond to a total of 24 working days) and the average work time per day was 314.60 min. Total chainsaw running time was 4925.73 min, which corresponds to 65.23% of the overall work time. Preparation time and time for delays with the saw at idle or stopped were in total 499.61 min (6.61%) and 2129.05 min (28.19%), respectively.

Felling and processing tasks involved a total of 228 trees, of which 127 were felled in the *Quercus petraea* stand, 54 in the mixed *Fagus sylvatica-Quercus petraea* stand, and 47 in the pure *Pinus brutia* stand. Average breast height diameter was 34 cm and average dust concentration for all sampling days was 3.34 mg m^{-3} .

Table 2 illustrates the distribution of mean total time on site per forest species. As can be seen, the total time spent in the *Pinus brutia* stand was slightly longer (378.67 min). The table also shows the distribution of mean chainsaw running time per type of stand, the time allocated to each individual work phase (i.e., felling, debranching and cross-cutting) as well as the percentages of each work phase in relation to mean chainsaw running time. Of particular interest is the increased cross-cutting time in the mixed *Fagus sylvatica-Quercus petraea* stand (119.57 min), which corresponds to 57.11% of mean chainsaw running time. Additionally, in the column before the last one (DBH) the

Table 2 Daily average chainsaw running time in relation with the forest species

Forest species	Mean total time on site (min)	Chainsaw running time (min)			Mean cross cut t (min), SD	Min (min)	Max (min)	DBH	N
		Mean chainsaw run.t (min), SD	Mean fell. t (min), SD	Mean debranch. t (min), SD					
Hard wood									
<i>Quercus petr</i>	295.55	176.59 (59.74%)	30.41 (17.22%)	58.13 (32.91%)	88.04 (49.85%)	75.05	228.28	32.90	12
<i>Fagus syl.- Quercus p.</i>	301.45	209.34 (69.44%)	21.62 (10.32%)	68.13 (32.54%)	119.57 (57.11%)	178.94	287.87	35.86	7
Soft wood									
<i>Pinus brutia</i>	378.67	268.25 (70.84%)	36.76 (13.70)	90.64 (33.78%)	140.85 (52.50%)	255.29	291.68	33.63	5

SD Standard deviation, **N** Number of samples

Fig. 1 Percentage distribution of chainsaw running time and downtime in association with forest species

Fig. 2 Relationship between mean diameter at breast height (per day) (cm) and wood dust (mg m^{-3})

mean diameter at breast height per forest species can be seen (N stands for the number of sampling filters per day).

Figure 1 displays the percentage distribution in minutes of the various chainsaw work phases, namely felling and processing (chainsaw engine in running mode). Processing time includes debranching and cross-cutting times. The same figure also presents chainsaw idle times including preparation time and delay times (downtime).

3.1.2 Wood dust

Figure 2 illustrates the relation between daily dust concentrations and mean breast height diameter of trees felled per day. The result reveals a negative correlation between the two variables.

Table 3 shows dust concentration levels per stand for total time on site. More specifically, in hardwood *Quercus petraea* and *Fagus sylvatica*-*Quercus petraea* stands, dust concentration was on average 3.79 mg m^{-3} and 2.30 mg m^{-3} , respectively, whereas in softwood *Pinus brutia* stand it was found to be equal to 3.73 mg m^{-3} . The data appearing in the 5th column refer to an eight-hour working day, in accordance with European Commission Directive [26], and they amount to 6.15 mg m^{-3} , 3.66 mg m^{-3} and 4.72 mg m^{-3} respectively. Furthermore, Table 3 includes mean values of relative humidity and ambient temperature for each stand separately.

Table 4 shows the distribution of the dust samples in relation to the Occupational Exposure Limit (OEL 3 mg m^{-3}). More specifically, the following three classes were formed: (a) first class with dust concentrations below or equal to 3 mg m^{-3} , which can be considered as acceptable (b) second class with dust concentrations between 3 and 5 mg m^{-3} , which exceed allowable exposure limits and are considered hazardous; and (c) third class with dust concentrations over 5 mg m^{-3} , which are regarded as exceptionally hazardous as they are well above the recommended exposure limits. Overall, from all three stands, 12 samples (50%) are below the OEL (3 mg m^{-3}), 7 samples (appr. 29%) fall into the second class ($3 < x \leq 5 \text{ mg m}^{-3}$) and 5 samples (appr. 21%), all of which have been taken from the *Quercus petraea* stand, belong to the third, highly hazardous, class.

Figure 3 shows the mean percentage distribution in min of the various work phases (felling and processing times) in which the chainsaw is used (running time) as well as chainsaw downtime (preparation time and delays) in relation to the three dust concentration classes.

Table 3 Average values of wood dust concentration ($\pm$ standard error) in relation with the forest species

Forest species	Mean wood dust (mg m^{-3})	Min (mg m^{-3})	Max (mg m^{-3})	Mean Wood dust /8 h (mg m^{-3})	Mean Humidity	Mean Temperature
<i>Quercus petr</i>	$3.79 (\pm 4.73)$	0.82	6.78	6.15	49.83	25.98
<i>Fagus syl.- Quers p.</i>	$2.30 (\pm 0.39)$	1.09	3.19	3.66	44.00	27.84
<i>Pinus brutia</i>	$3.73 (\pm 1.06)$	2.10	4.69	4.72	49.46	26.50

Table 4 Distribution of the wood dust samples in relation with OEL (N: number of samples)

Wood dust	$\leq 3 \text{ mg m}^{-3}$ N %	$3 < x \leq 5 \text{ mg m}^{-3}$ N %	$> 5 \text{ mg m}^{-3}$ N %
<i>Quercus petr.</i> (12N)	5 (41.67%)	2 (16.67%)	5 (41.67%)
<i>Fagus syl.- Quercus p.</i> (7N)	6 (85.71%)	1 (14.28%)	0 (0.00%)
<i>Pinus br.</i> (5N)	1 (20.00%)	4 (80.00%)	0 (0.00%)
St. D (cm)	36.67	32.60	28.90
Temperature (°C)	26.98	26.22	26.36
Moisture (%)	49.11	48.00	45.60
Chainsaw run.t (min)	185.24	239.35	205.44

3.2 Results of statistical regression modeling

In our attempt to estimate in a unified way the potential relative effects of the previously presented factors on wood dust, multiple regression modeling was applied, the results of which are presented in the current section.

Frequency plots of the response variable and the continuous-type covariates of the multiple linear regression model are presented in Fig. A1 and A2 in the Appendix.

In the following table (Table 5), the covariate selection results from the backward elimination stepwise procedure are presented. The final best selected regression model (Model F) includes only statistically significant covariates, namely those of chainsaw running time, forest species and diameter. The selected model explains approximately the 54.5% of the total variability in the response variable ($R^2 = 0.545$, adjusted $R^2 = 0.449$), indicating a moderate fit to the data.

Table 5 Results of model fit for the various candidate models (backward elimination)

Model	Covariates removed	R^2	Adjusted R^2
A (full model)	--	0.612	0.364
B	Felling time	0.607	0.397
C	Relative temperature	0.597	0.421
D	Relative humidity	0.587	0.442
E	Debranching time	0.580	0.463
F	Number of trees	0.545	0.449

To test the quality of the fit of the best fitted model (F) we look at the normal probability plot (QQ-plot) of the residuals (see Fig. 4), which ideally should look like a straight line if errors are normally distributed. Inspection of Fig. 4 indicates that there are few moderate deviations from normality.

In Table 6, the estimates of the regression coefficients of the final selected model, along with their statistical significance, are shown. As is seen, the "*Fagus & Quercus*" type of trees generates reduced wood dust concentrations in comparison to the other two types of trees (beta coefficient = -1.572 ; p value < 0.1). Also, we observe that the longer cross-cutting time increases the levels of wood dust at a 10% significance level (beta coefficient = 0.021 ; p value < 0.1), when compared with the other two types of chainsaw running time (debranching, felling). Finally, the smaller the diameter of the tree, the higher the levels of wood dust inhaled by the worker, according to the regression analysis results (beta coefficient = -0.193 ; p value < 0.05). Tree diameter seems to be the most important factor affecting the response, as indicated by the higher level of statistical significance,

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

Fig. 4 Normal probability plot of the residuals of the best fitted model

Table 6 Parameter estimates, along with corresponding significance (p-value)

Parameter	Estimate	P value
β_0	8.285	0.007***
β_1	-1.572	0.051*
β_4	0.021	0.062*
β_6	-0.193	0.013**
R^2	0.545	
Adjusted R^2	0.449	

(*): parameter is significant at the 10% significance level

(**): parameter is significant at the 5% significance level

(***): parameter is significant at the 1% significance level

in comparison to the other two statistically significant covariates.

4 Discussion

There has been a major change in the field of forest technology over time: in many countries, chainsawing has been replaced by forest harvesters that do not entail massive exposure to wood dust. This means that lumberjacks and other forest workers are exposed to dust to a lesser degree than in the past and in an indirect manner [12]. This fact can account for the relatively few research papers published in relation to wood dust exposure of chainsaw operators [14, 20, 31, 38]. In Greece, although timber harvesting is exclusively motor-manual carried

out by means of chainsaws, there is no research published in the field, with the exception of a review paper by Mantanis et al. [21].

In most countries, however, separate OELs for hardwoods (at 3 mg m^{-3}) have been set since 2017 [28]. Taking these limit values into consideration, the findings of the current study can be expressed as follows:

As far as hardwood dust is concerned (produced from *Quercus petraea* stand and *Fagus sylvatica*-*Quercus petraea* mixed stands), 33.3% of the samples were found to exceed the OEL for hardwood dust (3 mg m^{-3}), whereas softwood dust samples were found to be 100% below the corresponding OEL (5 mg m^{-3}).

Regarding the relation between wood dust concentration per day and average breast height diameter of trees felled on a daily basis, there has been found to exist a strong correlation (see Fig. 2), a fact corroborated by the statistical study (Table 6, beta coefficient = -0.193 ; p value < 0.05) as well. As it can be seen in the table, dust concentration is inversely proportional to tree dimensions, as it tends to decrease with bigger tree sizes. This finding can be accounted for by the fact that the bigger a tree diameter is, the fewer trees can be harvested in the same time period. For the production of 1 m^3 of timber less time is required when tree diameter increases [35]. This can also be seen in Table 4 that presents the three dust classes formed; it becomes evident here that the mean breast height diameter corresponding to the $\leq 5 \text{ mg m}^{-3}$ dust class is smaller than the equivalent mean diameters corresponding to the other two classes.

Temperature and ambient humidity do not seem to affect the results as both of them were relatively constant on all sampling days (Tables 3 and 4). In relation with forest species (Table 3) the lowest dust amounts (2.30 mg m^{-3}) were generated by the mixed *Fagus sylvatica*-*Quercus petraea* stand. This is also confirmed by the statistical study (Table 6, beta coefficient = -1.572 ; p value < 0.1). However, the differences in dust concentration levels in relation to type of stand require further investigation.

The highest dust levels that the logger was exposed to were found to be produced in the *Quercus petraea* stand, amounting to 3.79 mg m^{-3} on average. If this data is expressed as a time-weighted average over 8 h of daily work, as proposed by the European Commission [26], then it corresponds to an exposure that is equal to 6.15 mg m^{-3} (Table 3), with its maximum value reaching 6.78 mg m^{-3} . Following closely is softwood dust concentration from the *Pinus brutia* stand averaging 3.73 mg m^{-3} , which corresponds to 4.72 mg m^{-3} for an 8 h working day. However, in this case, due to the different OEL (5 mg m^{-3}), this value is not particularly alarming. Taking all three forest species into consideration, mean wood concentration, expressed

as a time-weighted average over 8 h of daily work, was found to be 4.84 mg m^{-3} , a finding that is very close to the results of the study by Kauppinen et al. [12], according to which 15% of employees exposed to dusty environments work in places where sawdust exceeds 5 mg m^{-3} .

According to Demers et al. [39], exposure to fresh wood dust, as is the case in harvesting standing trees, is more hazardous to workers' health owing to the fact that exposure to monoterpenes is higher than in the processing of dry wood. This finding further underlines the tough conditions under which chainsaw operators work in the forest.

It can be seen in Fig. 1 that the chainsaw operator works with the same speed and at the same pace in all three forest species, a fact that guarantees the reliability of the findings of the current study, since dust concentration is in direct correlation with the chainsaw's running time, that is, when the engine is in operation. Moreover, average breast height diameter does not differ considerably in the three forest species, a fact that also proves that exposure results have not been effected by tree dimensions but solely by forest species.

As a whole, average dust exposure on all sampling days for both hardwoods and softwoods was 3.34 mg m^{-3} , whereas in a similar study by Marchi et al. [20] the equivalent mean exposure was found to be approximately 1.5 mg m^{-3} . In the same study by Marchi et al. [20], wood dust values, in 98% of the cases, are reported to be significantly below the EU, but these researchers used as a reference the 5 mg m^{-3} (at that time was the EU allowable wood exposure limit for hardwood). This difference can be accounted for by the different silvicultural treatments considered in their study and possibly to the differences in tree sizes; however, no data about tree dimensions are included in their research. Furthermore, in the study by Horvat et al. [14], total dust concentration was found to be 1.29 mg m^{-3} . This concentration is relatively low in comparison with the results of the present study and is due to the fact that Horvat et al. [14] conducted measurements while felling dead standing fir-trees. Added to this is the fact that the pump operated at a flow rate of 2 l min^{-1} , whereas in the present study the portable pump operated at a rate of 4 l min^{-1} [20] owing to the exceptionally difficult conditions under which the lumberjack worked. In other studies, such as by Alwis [29] and Mitchell [30], which, nevertheless, refer to chipping jobs performed by operators working inside a cabin, mean exposure results were found to be 1.9 mg m^{-3} and 1.3 mg m^{-3} respectively.

The higher concentrations found in the current study can be accounted for by the fact that operators work outdoors and not inside a cabin. Additionally, timbering tasks in Greece are performed during the summer months and this is likely to positively contribute to increased dust concentrations. Generally speaking, research referring to

dust exposure in the forest is scarce; however, there are two such studies available that refer to dust generated by chainsawing activities in the forest and were carried out in Croatia [14, 31]. Both of these studies refer to respirable and not inhalable wood dust; consequently, their results cannot be considered comparable with the results of the present research.

5 Conclusions

According to the new limit values being in effect since 2017 for hardwoods (3 mg m^{-3}) [28], then in the present study it has been found that loggers' exposure to dust is in half of the cases (50%–8 in 24 samples) higher than the EU OEL (3 mg m^{-3}).

However, it should be clarified that the OEL has been set according to research on woodworking industries and is applicable to a specific industrial environment; it is quite likely that it cannot be used in forest operations assessment [20]. Current OELs have been established for variables that are not valid in forest tasks; for instance, they are based on labour carried out for 8 h a day and around 200 days a year. The average logger works on average for about 5–6 h daily and around 120 days per year. This means that the overall working-life exposure to wood dust of forest workers is different from that of woodworking industry workers. Another factor that has to be taken into consideration is that woodworking industry employees often work in cabins, an advantage that chainsaw operators do not have. Taking all the above into consideration, we believe that the OEL is not applicable to the outdoor work environment.

The authors of the present study would like to suggest that the OELs should be reconsidered especially for motor-manual chainsaw operators and additional variables should be taken into account in order to reflect more effectively the special conditions prevailing in this work field. Furthermore, harvesting jobs should not be performed during the summer months when dust levels are likely to be further increased due to climate factors. Besides that, research carried out in most of the Scandinavian countries has shown that health issues such as irritations and allergies are more likely to appear during the summer rather than in winter, irrespective of whether dust levels are kept below the OEL [40]. In every case, forest workers must be protected against dust by means of suitable protective equipment (i.e. headgear, such as helmets with vizors made of plexiglass), whereas employees who have become sensitive to dust must wear respiratory protective equipment (RPE), such as air fed respirators. Furthermore, the latter must have their health condition monitored on a more regular basis [7].

The results of the present study could constitute a reliable pool of data regarding dust exposure of loggers in the forest. It seems that tree size plays an important part in dust concentration; however, further research studies are desirable in order to verify the various concentration values per forest species. Finally, Greece should set limit values for softwood dust, as well, and review the current OELs based on new data.

Acknowledgements The authors wish to express their sincere gratitude for their cooperation to the members of the forest cooperatives in the Prefecture of Dadia-Soufli, Northeast Greece. This synergy between the forest cooperatives and academia contributed to a great extent to the implementation of the current research project. We hope that the research will contribute to the existing body of knowledge and raise awareness among forest managers. We wish to thank Mrs. Malivitsi Zoe for editing the paper.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Vasiliki Dimou, Chrisovalantis Malesios and Vasiliki Chatzikosti. 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.

Data availability Not applicable.

Code availability Not applicable.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

- Montorselli NB, Lombardini C, Magagnotti N, Marchi E, Neri F, Picchi G, Spinelli R (2010) Relating safety, productivity and company type for motor-manual logging operations in the Italian Alps. *Accid Anal Prev* 6:2013–2017. <https://doi.org/10.1016/j.aap.2010.06.011>
- Picchio R, Blasi S, Sirna A (2010) Survey on mechanization and safety evolution in forest works in Italy. In: Proceedings of the “International Conference Ragusa SHWA2010”. Ragusa (Italy) 16–18 Sep 2010. University of Catania, Catania, Italy, 173–180
- Caliskan E (2012) Productivity and cost analysis of manual felling and skidding in oriental spruce (*Picea orientalis* L.) forests. *Ann For Res* 2:297–308
- Albizu-Uriónabarrenetxea P, Tolosana-Esteban E, Roman-Jordan E (2013) Safety and health in forest harvesting operations diagnosis and preventive actions. *A rev For Syst* 3:392–400. <https://doi.org/10.5424/fs/2013223-02714>
- Vusić D, Šušnjar M, Marchi E, Spina R, Zečić Z, Picchio R (2013) Skidding operations in thinning and shelterwood cut of mixed stands work productivity, energy inputs and emissions. *Ecol Eng* 61:216–223. <https://doi.org/10.1016/j.ecoleng.2013.09.052>
- Bell JL (2002) Changes in logging injury rates associated with use of feller-bunchers in West Virginia. *J Saf Res* 4:463–471. [https://doi.org/10.1016/S0022-4375\(02\)00048-8](https://doi.org/10.1016/S0022-4375(02)00048-8)
- Health and Safety Executive HSE. Toxic woods. HSE information sheet. <https://pdf4pro.com/view/toxic-woods-wis30-health-and-safety-executive-3ab8fd.html>. Accessed on 13/4/2020
- Pisati G, Cirila AM, Zedda S (1982) Asma allergologica da esposizione professionale a polveri di legno non esotico (Faggio). Considerazioni di un caso clinico Asthma allergy from occupational exposure to non-exotic wood dust (beech). Considerations of a clinical case. In: Proceedings of the Conference “Infortunie malattie professionali nel settore del legno e del mobile” Occupational accidents and distry. OECE, Siena, [in italian] 472–478
- Kubel H, Weiflmann G (1988) Untersuchungen zur Cancero-genit it von Holzstaub. Holz als Roh und Werkstoff Studies on the carcinogenicity of wood dust. *Wood Raw Mater* 46:215–20. <https://doi.org/10.1007/BF02608116>
- Klein RG, Schmezer P, Amelung F, Schroeder HG, Woeste W, Wolf J (2001) Carcinogenicity assays of wood dust and wood additives in rats exposed by long-term inhalation. *International Archiv Occup Environ Health* 2:109–118. <https://doi.org/10.1007/s004200000199>
- IARC (1995) IARC monographs on the evaluation of carcinogenic risks to human. Wood dust and formaldehyde. IARC Press, Lyon, France, pp 35–216
- Kauppinen T, Vincent R, Liukkonen T, Grzebyk M, Kauppinen A, Welling I, Arezes P, Black N, Bochmann F, Campelo F, Costa M, Elsigan G, Goerens R, Kikemenis A, Kromhout H, Miguel S, Mirabelli D, McEneaney R, Pesch B, Plato N, Schlünssen V, Schulze J, Sonntag R, Verougstraete V, Vicente MA, Wolf J, Zimmerman M, Husgafvel-Pursiainen K, Savolainen K (2006) Occupational exposure to inhalable wood dust in the member states of the European union. *Ann Occup Hyg* 50(6):549–561. <https://doi.org/10.1093/annhyg/mel013>
- Mračková E, Krišťák L, Kučerka M, Gaff M (2016) Creation of wood dust during wood processing: size analysis, dust separation, and occupational health. *BioResources* 11(1):209–222
- Horvat D (2005) Research of fir-wood dust concentration in the working environment of cutters. HSE, Health and Safety Executive 2012. Toxic woods. Woodworking Sheet No 30 (Revision 1) 1–6.
- CCOHS Canadian Centre for Occupational Health and Safety. (https://www.ccohs.ca/oshanswers/chemicals/wood_dust.html). Accessed on 12/6/2020.
- Brown JS, Gordon T, Price O, Asgharian B (2013) Thoracic and respirable definitions for human health risk assessment. *Part Fibre Toxicol* 10(1):12. <https://doi.org/10.1186/1743-8977>
- SCOEL. (2002) Recommendation from the Scientific Committee on Occupational Exposure Limits for WoodDust. SCOEL/SUM/102B.
- SCOEL (2003) Recommendation from the scientific committee on occupational exposure limits: risk assessment for wood dust (SCOEL/SUM/102). European Commission on Occupational Exposure Limits for Chemicals in the Workplace, Bruxelles, Belgium, pp. 36, [online] URL: <https://ec.europa.eu/social/BlobServlet?docId=3876&langId=en>.
- Ayalew E, Gebre Y, De Wael K (2015) A survey of occupational exposure to inhalable wood dust among workers in small – and medium –scale wood-processing enterprises in Ethiopia. *Ann Occup Hyg* 59(2):253–257
- Marchi E, Neri F, Cambi M, Laschi A, Foderi C, Sciarra G, Fabiano F (2017) Analysis of dust exposure during chainsaw forest operations. *Biogeosci For* 10:341–347. <https://doi.org/10.3832/for2123-009>
- Mantanis G, Dalos G, Anastasis G (2005) The impact of wood dust on the health of woodworking and furniture industry workers. *Geotech Sci Issues* 16(2):74–80 (In Greek)

22. Očkajová A, Kučerka M, Kminiak R, Krišt'ák L, Igaz R, Réh R (2020) Occupational exposure to dust produced when milling thermally modified wood. *International J Environ Res Public Health* 17:1478. <https://doi.org/10.3390/ijerph17051478>
23. Tureková I, Mračková E, Marková I (2013) Determination of waste industrial dust safety characteristics. *Int J Environ Res Public Health* 16:2103
24. ISO (1995) 7708 - Air quality particle size fraction definitions for health-related sampling. Switzerland, International Organization for Standardization, Geneva, p 9
25. Health and Safety Executive HSE (2004) Occupational health management in the quarry industry. Quarries National Joint Advisory Committee, Cutting Accidents and Ill Health
26. European Commission (1999) Council directive 1999/38/EC of 29 April 1999 amending for the second time directive 90/394/EEC on the protection of workers from the risk related to exposure to carcinogens at work and extending it to mutagens. *Off J Europ Commun* 138:66–69
27. COSHH, Control of Substances Hazardous to Health. British Statutory Instrument to protect workers from ill health when working with specific substances and materials <https://www.britsafe.org/training-and-learning/find-the-right-course-for-you/informational-resources/what-is-coshh/>
28. Directive (EU) 2017/2398 of the European Parliament and of the Council of 12 December 2017 amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work
29. Alwis KU (1998) Occupational exposure to wood dust. PhD Thesis, Department of Public Health and Community Medicine, Faculty of Medicine, University of Sydney, New South Wales, Australia, 291
30. Mitchell D (2011) Air quality on biomass harvesting operations. In: Proceedings of the "34th Council on Forest Engineering annual meeting", Quebec City (Quebec, Canada) 12–15 Jun 2011, pp. 9. [online] URL: https://www.srs.fs.usda.gov/pubs/ja/2011/ja_2011_mitchell_001.pdf
31. Jazbec A, Zečić Z, Horvat D, Šušnjar M, Cavlović AO (2007) Tree cutters' exposure to oakwood dust a case study in Croatia. *Die Bodenkultur* 4:59–65
32. www.hse.gov.uk. SKC Ltd - Workplace/Environmental Air Sampling Equipment & Accessories <https://www.skcltd.com/> Accessed on 13/4/2020
33. Kalatoor S, Grinshpun SA, Willeke K, Baron P (1995) New aerosol sampler with low wind sensitivity and good filter collection uniformity. *Atmos Environ* 10:1105–1112. [https://doi.org/10.1016/1352-2310\(95\)00044-Y](https://doi.org/10.1016/1352-2310(95)00044-Y)
34. Björheden R, Thompson AM (1995) "An International Nomenclature for Forest Work Study". Paper presented at the XX IUFRO Congress, Tampere, 6–12 August 1995. Manuscript. 16
35. Dimou V, Symeonidou M (2019) Evaluating the effectiveness productivity of motor-manual felling with a catalytic chainsaw. *J International Sci Publ Mater Methods Technol* 13:187–198. <https://doi.org/10.1093/annhyg/mes112>
36. R Core Team (2017) R: A Language and Environment for Statistical Computing. <https://www.R-project.org/>
37. Chambers, J.M. (1992) Linear models. Chapter 4 of *Statistical Models in Seds* J. M. Chambers and T. J. Hastie, Wadsworth & Brooks/Cole
38. Magagnotti N, Nannicini C, Sciarra G, Spinelli R, Volpi D (2013) Determining the exposure of chipper operators to inhalable wood dust. *The Annals of Occupational Hygiene* 6: 784–792. doi: 10.1093/annhyg/mes112
39. Demers P, Teschke K, Davies H et al (2000) Exposure to dust, resin acids, and monoterpenes in softwood lumber mills. *Am Ind Hyg Ass J* 61:521–528
40. Rosenberg Ch, Liukkonen T, Kallas-Tarpila T, Ruonakangas A, Ranta R, Nurminen M, Welling I, Jäppinen P (2002) Monoterpene and Wood Dust Exposures: Work-Related Symptoms among Finnish Sawmill Workers. *Am J Ind Med* 41:38–53

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.