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Analysis of dust exposure during chainsaw forest operations

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In 1999, the European Union proclaimed hardwood dust carcinogenic based on the classification of the International Agency for Research on Cancer (IARC) issued in 1995. The operational exposure limit (OEL) for inhalable wood dust has been set to 5 mg m^{-3} by EU directives, though in different countries the OEL ranges from 1 to 5 mg m^{-3}. The objective of this study was to determine the exposure to wood dust of forest workers in chainsaw cutting and processing and suggest possible countermeasures. The study took into consideration different silvicultural treatments (coppice clear cut, conifer thinning, conifer pruning, and sanitary cut) and chainsaw fuel (normal two-stroke gasoline mix and two alkylate fuels). All the forest operations were carried out in forests located in Central Italy, on the Apennine mountain range. During the tests, 100 samples were collected by means of personal SKC Button Sampler (one sample per worker per day). The results showed that exposure to wood dust varied widely with forest operation type, while no significant difference were found for different type of chainsaw fuel. The average wood dust concentration was about 1.5 mg m^{-3} for all operations except coppicing, which showed a mean level of about 2.1 mg m^{-3}. About 93% of the samples showed a concentration lower than 3 mg m^{-3}, and in only two samples (one in conifer pruning and one in clear cut in coppice), the concentration was slightly higher than 5 mg m^{-3}.

Keywords: Forest Operation, Chainsaw, Inhalable Wood Dust, Wood Dust Exposure, Cancer

Introduction

Motor-manual tree felling and processing (*i.e.*, by chainsaw) is still very common in many countries (Montorselli et al. 2010, Picchio et al. 2010, Caliskan 2012, Albizu-Urionabarrenetxea et al. 2013, Vusić et al. 2013). Motor-manual forest operations are inherently dangerous (Wang et al. 2003, Lindroos & Burström 2010, Tsioras et al. 2011) and cannot benefit from the safety improvements offered by high mechanization (Bell 2002). Steep terrain, ownership fragmentation and close-to-nature management criteria slow down the introduction of mechanized harvesting in mountainous conditions (Spinelli et al. 2009). Workers engaged in forest cutting who use chainsaws are exposed to noise and vibration stresses and to the hazardous effects of exhaust gases as well as floating particles of mineral oil and airborne wood dust (Neitzel & Yost 2002, Jazbec et al. 2007).

Potential health effects from exposure to wood dust have been studied and include pulmonary function changes, allergic respiratory responses (asthma) and cancer of nasal cavity and paranasal sinuses. The irritant effects of wood dust are well documented (Senear 1933, Woods & Calnan 1976, ILO 1983, Innocenti 2008). Respiratory, nasal and eye symptoms are the most common effects reported by woodworkers (Holness et al. 1985, Li et al. 1990, Pisaniello et al. 1991, Shamssain 1992, Liou et al. 1996). However, not all studies agree. A recent US study has shown fewer or no symptoms from typical exposures (Glindmeyer et al. 2008). Other studies have addressed the relationship between exposure to wood dust and skin pathologies (Innocenti & Del Monaco 1980) or asthma (Hessel et al. 1995, Malo et al. 1995). The most serious problem araising from wood dust exposure is the risk of developing cancer, mainly nose and sinus adenocancer (Pisati et al. 1982, Kubel & Weiflmann 1988, Klein et al. 2001). Nasal cavity adenocancer was diagnosed much more frequently in woodworking industry operators (saw mill, joinery, furniture, etc.) than in the rest of the human population, where this malignant disease is very rare and only accounts for 0.25% (Hausen 1981). Hausen (1981) also pointed out that wood chemical components can have serious biological effects on human health even at low concentrations, if long-term exposure occurs.

The International Agency for Research on Cancer (IARC) classified hardwood dust as a human carcinogen (IARC 1995), estimating that at least 2 million people worldwide are exposed to the noxious effect of wood dust. According to the dimension of component particles (International Organization for Standarization – ISO 1995), wood dust can be classified into inhalable, thoracic and respirable dust (ACGIH 2016). According to the Scientific Committee on Occupational Exposure Limits (SCOEL) recommendation, the inhalable fraction "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" (SCOEL 2003).

In 1999, the European Union published Directive 99/38/EC, setting the legal limit for the exposure to inhalable wood dust at 5 mg m^{-3}, as an average of a 8-h working day (European Commission 1999). This limit is defined as occupational exposure limit (OEL) and is valid for exposure to hard-

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wood dust or to any mix of hardwood and softwood dust. This OEL is not applied for exposure to pure softwood dust, which is not yet a legally recognized as a noxious substance. The EU OEL, was confirmed in Directive 2004/37/EC (European Commission 2004) and is applied in Italy and Finland. In countries like Spain and the United Kingdom, the OEL is the same but includes both hardwood and softwood inhalable dust. In still other countries, the OEL, referred to inhalable fraction, is lower and usually without distinction between softwood and hardwood: 3 mg m^{-3} in Belgium, 2 mg m^{-3} in Austria, Germany and Sweden, and 1 mg m^{-3} in France. Symptoms in the upper respiratory system have been reported also at much lower exposure levels, from 1 mg m^{-3} (Foà et al. 2008).

In 2003, SCOEL suggested applying a lower value between 1 and 1.5 mg m^{-3}, without distinction between softwood and hardwood (SCOEL 2003). Moreover, in 2012, the Advisory Committee on Safety and Health at Work (ACSHW 2012) of the European Commission proposed amendment of Directive 2004/37/EC, including an OEL for wood dust of 3 mg m^{-3}, measured as inhalable dust, with a review period of 3-5 years.

In United States, the American Conference of Governmental Industrial Hygienists (ACGIH 2016) and the National Institute for Occupational Safety and Health (NIOSH) set a Threshold Limit Value (TLV®) of 1 mg m^{-3} for most wood species, without distinction between softwood and hardwood, or lower for the western red cedar (0.5 mg m^{-3} – Lee et al. 2011, Chirila et al. 2014).

In relationship to wood dust exposure and its effect on health, many studies have been carried out taking into consideration woodworking industry workers (sawmill, joinery, etc.). Moreover, epidemiological studies have examined exposure to wood dust deal in the furniture industry, which employs many workers and is much easier to reach (Alwis 1998).

Even though it is well known that the working environment in logging operations can be dusty (Mitchell 2011), very few studies have addressed forest operators' exposure, mainly taking into account the respirable wood dust fraction in chainsaw operation (Horvat 2005, Jazbec et al. 2007) or chipping operation (Magagnotti et al. 2013).

To fill the gap in knowledge and have a comprehensive framework on the exposure of forest workers to wood dust, field surveys during motor-manual felling and processing of trees (*i.e.*, with chainsaw) were carried out in central Italy. The objectives of this study were to evaluate exposure to inhalable wood dust among forest workers and highlight significant differences among: (i) different silvicultural treatments (clear cut in coppice and thinning, pruning and sanitary cut in high stand); and (ii) chainsaw fuel. In addition, the different tasks performed by the workers were timed to highlight relationship between wood dust concentration and chainsaw running time.

Materials and methods

All study areas were located in Tuscany, on the Apennine mountain range. Four silvicultural treatments were considered (Tab. 1).

(i) *Clear cut in coppice with standards in two pure stands and one mixed stand*. Coppice forests represent about 60% of the total forest area of Italy (INFC 2005). Coppicing operation consists of cutting all the shoots growing from suckering stumps, leaving only standards (30-60 per hectare, depending on species). Shoots were felled, debranched, and cross-cut into 1-metre length logs by chainsaw, then the logs were more finely cleaned of twigs using a billhook and were manually piled. The main assortment obtained was firewood. During data collection, the operators worked singly at a safe distance from each other.

(ii) *Thinning from below in two mixed stands and one pure stand*. This operation consisted of removing a percentage of the trees (25-30%) to improve growing conditions. Usually, small, badly formed or failing trees were cut. Trees were felled, debranched and cross-cut into 5 to 6 metre length logs by chainsaw. The operators worked singly at a safe distance from each other.

(iii) *Sanitary cut in two pure stands and two mixed stands*. This silvicultural treatment consisted of removing dead, damaged or diseased trees to avoid spread of parasites and to prevent forest fires. An operator with chainsaw felled and processed the trees to obtain logs of 5 to 6 metre length. The operators worked singly at a safe distance from each other.

(iv) *Pruning in three pure stands and two mixed stands*. Pruning consisted of removing the lower dead branches of live trees by chainsaw, up to a height of around 2 m. Dead or uprooted trees were also felled and cut into logs. The operators worked singly at a safe distance from each other.

In total, the study included 100 forest operator working days: 20 in coppice clear cut, 28 in pruning, 23 in thinning and 29 in sanitary cut.

All the forest operators who performed the activity had long experience in this kind of felling operations. During the study, the workers used their usual chainsaws (Tab. 2). All the chainsaws were in good condition and carefully maintained.

Three different fuels were used during the study: normal two-stroke gasoline mix (NG, a mixture of 2% oil and lead-free gasoline) and two alkylate fuels (Alk1 and Alk2, as usual already mixed with motor lubricating oil) sold by two major international chainsaw manufacturers. Each operator used only one type of fuel during the same sampling day.

To collect inhalable fraction of wood

Tab. 1 - Main characteristics of the sampling sites. (Ab): *Abies alba Mill*; (Ar): *Picea abies* (L.) Karst; (Ca): *Ostrya carpinifolia* L.; (Ce): *Quercus cerris* L.; (Cs): *Castanea sativa* Miller; (Du): *Pseudotsuga menziesii* (Mirb.) Franco; (Pm): *Pinus pinaster* Aiton; (Pn): *Pinus nigra* Arnold; (Ps): *Pinus sylvestris* L.; (Alk1): alkylate fuel 1; (NG): normal fuel oil/lead-free gasoline; (Alk2): alkylate fuel 2.

ID	Yard	Operation	Species	Trees processed (n)	Average DBH (cm)	Number of workers (n)	Number of samples (n)	Fuel Type
A	Rincine Mato Grosso 1	Clear cut in coppice	Cs	349	12.11	2	6	Alk.1 Alk.2 NG
B	Rincine Mato Grosso 2	Clear cut in coppice	Cs / Ca	411	9.5	2	6	Alk.1 Alk.2 NG
C	Rincine Rincine 1	Clear cut in coppice	Ce	507	10.5	3	8	Alk.1 Alk.2 NG
D	Casentino Poggio Corbello	Thinning	Ab / Pn	130	22.9	5	8	Alk.2 NG
E	Vallombrosa Soglio	Thinning	Ab	357	15.8	3	10	Alk.1 Alk.2 NG
F	Vallombrosa Metato 2	Thinning	Ab / Pn	111	20.8	3	5	Alk.1 NG
G	Rincine Colla 3 faggi	Pruning	Ar / Pn	382	13.6	2	4	Alk.2 NG
H	Rincine Faggio Tondo	Pruning	Ps	1020	23.4	3	7	NG
I	Rincine Rincine 1	Pruning	Ar / Ps	1089	19.2	2	7	Alk.1 Alk.2 NG
L	Rincine Rincine 2	Pruning	Pn	3051	21.3	3	10	Alk.1 Alk.2 NG
M	Vallombrosa Metato 1	Sanitary cut	Ab / Ps / Du	326	26.8	4	11	Alk.1 NG
N	Vallombrosa Pozzacce 2	Sanitary cut	Du	429	16.2	2	10	Alk.1 Alk.2 NG
O	Vallombrosa Masso dal Monte	Sanitary cut	Ab	262	27.8	3	6	Alk.2
P	Vallombrosa Pozzacce 1	Sanitary cut	Ab / Cs	57	24.4	2	2	Alk.1

dust, during chainsaw operation, each forest workers wore a SKC Button Sampler with binderless fibreglass membrane (Sartorius) of 25 mm in diameter (Fig. 1).

The sampler was made of steel with a semi-spherical protective shield with conical micro-holes to avoid aspiration of non-inhalable projectile particles (Davies et al. 1999, Harper et al. 2004, Lee et al. 2011). Inclusion of these large particles would bias the sampling because they are too heavy to be inhaled (Kauffer et al. 2010). Furthermore, this multiorificed inlet reduces sensitivity to wind direction and velocity (Kalatoor et al. 1995).

The sampler used for the study was connected by a transparent flexible tubing to a Gilian 5000 portable pump (Fig. 1). The SKC Button Sampler operated at a flow rate of 4 l min^{-1}.

The pump was calibrated at the start of each day of sampling using a flow meter (Gilian Challenger). The pump recorded the total air flow and the duration of the sampling session. The portable pump was attached to the belt on the operator's back, and the sampler was placed at a distance of 10 cm from the operator's face, *i.e.*, at lapel height on the right side of operators' jackets (Fig. 1).

Daily dust exposure was then determined by a gravimetric method. Before the tests, filters were conditioned in a climatic cabinet (Activa) set at a temperature of 20 ± 1 °C and moisture of 48 ± 2 % for 24 hours together with three control filters. The filters were then weighed in the laboratory with a precision scale accurate to the microgram (Sartorius ME36S®) and placed into sealed boxes identified with code numbers. Before starting each test, a filter was carefully placed into the sampler using clean tweezers to avoid contamination. At the end of the tests, filters were removed with tweezers and placed back in their respective coded boxes. These were sent to the laboratory, where used filters were reconditioned for 24 hours in the same climatic cabinet. After conditioning, filters were weighed again with the same scale together with the three control filters conserved in sealed boxes at the laboratory.

Finally, the concentration of wood dust was measured using the following formula (eqn. 1):

$$C=\frac{P2-P1}{V}$$

where C is the wood dust concentration in mg m^{-3}; $P2$ is the weight of the filter after the test in mg; $P1$ is the weight of the filter before the test in mg; and V is the air volume in m^3, calculated as (eqn. 2):

$$V=\frac{T \cdot F}{1000}$$

where T is the duration of the sampling in minutes and F is the effective air flow in l min^{-1}.

If the average value of the differences in weight of the control filters (weight after – weight before) was ≠ 0, the average difference was added (if <0) or deducted (if >0) from wood dust weight.

Tab. 2 - Characteristics of the chainsaws used in the study.

Brand	Model	Engine size (cm^3)	Power (kW/CV)	Max rpm	Capacity (l)		Weight (empty, kg)
					Tank volume	Oil tank volume	
Husqvarna	XP346	50.1	2.7 / 3.7	14700	0.50	0.28	5.1
Husqvarna	XP357	56.5	3.2 / 4.3	14000	0.68	0.38	5.5
Komatsu	G3700	37.2	1.7 / 2.3	12500	0.42	0.25	4.3
Komatsu	G5000	49.3	2.6 / 3.5	13000	0.55	0.26	5.1
Stihl	MS241C	42.6	2.2 / 3.0	14000	0.39	0.24	4.7

Fig. 1 - Personal sampler. SKC Button Sampler on the operator's jacket (left) and Gilian 5000 portable pumps (right).

Each sampling lasted the length of the work shift and ranged between 6 and 8 hours. Sampling data was expressed as a time-weighted average (TWA) over 8 hours.

At each work site, dust monitoring was personally supervised by the researchers, who also checked the proper running of the pumps and the correct position of the devices.

Timing of work tasks

Work time was split into time elements (Bergstrand 1991), recorded separately for every worker involved in these tasks to identify the incidence of chainsaw running time on gross time. We determined the various time elements of the work, with special attention to recording the duration of chainsaws' running and idling time, *i.e.*, potentially producing wood dust. During data analysis time elements were separated into: (i) chainsaw running time, including time for felling, branch removal, crosscutting, stump tidying (if necessary), moving about on site; (ii) other productive time, including time used to perform bill hook or axe tasks, evaluation of plants, moving about on site; (iii) time for transfer, including time for travelling to and from the site, if included in working hours; (iv) preparation time, including time for preparing and putting away tools; and (v) delays (refuelling, maintenance, sharpening, pauses, setbacks and other non-working events).

Working time was recorded using a chronometric table with centesimal (1 min = 100 cmin) stopwatches.

Statistical analysis

The data were entered in a data sheet and analysed using the R open-source software (R Development Core Team, Wien, Austria – http://www.r-project.org). Correlations relevant to the aims of the study were sought, *i.e.*, the relationships between the variables measured (chainsaw running time, wood dust), the type of silvicultural treatment and fuel type. Normal distribution of the variables was checked by the Lilliefors test and homoscedasticity (homogeneity of variance) by Levene test. Wood dust exposure data were logarithmically transformed with the base 10 (*i.e.*, for wood dust in operation type and wood dust in fuel type) due to the non-normal distribution. One-way ANOVA was then used to calculate mean square error for Tukey's HSD test. By comparing pairs, this test revealed statistically significant differences between the means.

Chainsaw running time differences in relationship with silvicultural treatment were tested with the Kruskal-Wallis multiple comparison test due to the non-normal distribution of data. For this data, we did not find a satisfying normalization function, so we prefer to apply a non-parametric method.

Results

Working time

Tab. 3 summarises the distribution of the working time in the considered phases.

"Chainsaw running time" showed a statis-

Tab. 3 - Distribution of working time in the phases considered at the different working sites. (Tran): transfer time; (Prep): preparation time.

ID	Operation	Tran (min)	Prep (min)	Chainsaw running (min)	Other productive tasks		Delays (min)	Total time on site (min)	Chainsaw running (%)	Other time (%)
					bill hook (min)	other (min)				
A	Clear cut in coppice	138	199	875	517	6	530	2265	38.6	61.4
B		118	376	857	636	0	327	2314	37.0	63.0
C		299	300	912	986	11	666	3174	28.7	71.3
D	Thinning	256	327	1070	0	18	1537	3208	33.4	66.7
E		208	498	1563	0	481	831	3581	43.7	56.4
F		0	298	842	0	230	529	1899	44.3	55.7
G	Pruning	113	176	900	0	6	442	1637	55.0	45.0
H		420	216	1209	0	0	844	2689	45.0	55.0
I		264	324	1832	0	0	396	2816	65.1	34.9
L		419	372	1798	0	6	1120	3715	48.4	51.6
M	Sanitary cut	0	677	2140	0	646	714	4177	51.2	48.8
N		122	755	1742	0	458	946	4023	43.3	56.7
O		36	301	1120	0	337	589	2383	47.0	53.0
P		0	136	343	0	124	128	731	46.9	53.1

Tab. 4 - Daily average chainsaw running time in relation with the silvicultural treatment. Different letters show significant differences among medians (Kruskal-Wallis test, χ^2 = 41.7827, df = 3). (SD): standard deviation; (N): number of samples.

Chainsaw running time	Mean (minutes)	SD	Median	Min (minutes)	Max (minutes)	N
Clear cut in coppice	181.8	35.7	171^a	124	258	20
Thinning	267.8	53.5	241^b	201	370	23
Pruning	270.1	41.5	259.5^b	207	357	28
Sanitary cut	244.7	31.9	245^b	173	310	29

Tab. 5 - Distribution of the wood dust samples in relation with OEL. The EU OEL in Italy is 5 mg m^{-3}, whereas is 3 and 1 mg m^{-3} in other countries. The number of samples (N.) under each threshold limit and the percentage relative to the total (%) are shown.

Wood dust		≤ 1 mg m^{-3}		≤ 3 mg m^{-3}		≤ 5 mg m^{-3}		> 5 mg m^{-3}	
N	Operation	N	%	N	%	N	%	N	%
20	Clear cut in coppice	1	5	18	90	19	95	1	5
23	Thinning	11	48	21	91	23	100	0	0
28	Pruning	7	25	25	89	27	96	1	4
29	Sanitary cut	13	45	29	100	29	100	0	0
100	Total	32	32	93	93	98	98	2	2

tically significant difference between clear cut in coppice with standards and the other silvicultural treatments ($p < 0.001$ – Tab. 4). In particular, coppicing with standards showed the lower chainsaw running time, while no difference was recorded among the treatments performed in high forest stands. This was expected because coppicing involves many tasks, that do not involve chainsaw use.

The highest value was recorded in pruning (Tab. 4), since conifer pruning does not involve any particular assessment of plants or use of other tools, as in felling, and the chainsaw is used continuously for longer periods.

A higher standard deviation suggests that the chainsaw running time during thinning varied more than during the other silvicultural treatments.

Tab. 6 - Average values of wood dust exposure (± standard error) in relation with the silvicultural treatment. Different letters indicate significant differences between treatments (data not $\log_{10}$ transformed).

Operation	Mean wood dust (mg m^{-3})	Geometric mean (mg m^{-3})	Samples (N)	Min. (mg m^{-3})	Max. (mg m^{-3})
Clear cut in coppice	2.14 ± 0.22^{a}	1.98	20	0.95	5.58
Thinning	1.27 ± 0.20^{b}	0.99	23	0.38	3.59
Pruning	1.75 ± 0.18^{ab}	1.36	28	0.11	5.40
Sanitary cut	1.20 ± 0.18^{b}	1.07	29	0.31	2.58

Wood dust

Wood dust response to type of silvicultural treatment

Tab. 5 shows that only 2 samples (2%) exceeded the European OEL (5 mg m^{-3}). One of these samples (1%) was recorded in pruning, which is a typical treatment for conifers only, *i.e.*, softwood dust that at present is not included in the OEL. Tab. 5 also shows the exceedances for the lower limits applied in some other European countries and the United States: less than 10% exceeded the limit of 3 mg m^{-3}, and more than 50% exceeded 1 mg m^{-3}.

The mean exposure to wood dust during coppicing was significantly higher than during thinning and sanitary cut, while pruning did not show statistical differences with the other treatments ($p = 0.002$ – Tab. 6).

Wood dust response to type of chainsaw fuel

To check whether the type of fuel used in the chainsaw affected the wood dust exposure, a one-way ANOVA was performed. The analysis did not show any statistical differences among the types of fuel used ($p = 0.253$ – data not shown). However, the normal fuel showed slightly higher values of mean wood dust concentration. This was probably due to the presence of unburned particles of gasoline or lubricant during combustion.

Discussion

Very few studies have tried to determine the exposure of forest operators to wood dust (Horvat 2005, Jazbec et al. 2007, Magagnotti et al. 2013), probably because of the relatively small population and the difficulty of organizing field tests in the forest (Foà et al. 2008).

The results of our study provide important indications about the exposure of forest workers to wood dust during motor-manual felling. The values of wood dust were considerably below the EU OEL in

98% of cases. The means were about 1.5 mg m^{-3} for all operations except coppicing, which showed a mean value significantly higher. In detail, clear cut in coppice showed the highest average exposure to wood dust, and one sample exceeded the EU OEL of 5 mg m^{-3}. Moreover, 10% of the data recorded were higher than 3 mg m^{-3}, and only 5% of the data recorded were lower than 1 mg m^{-3} (Tab. 3, Tab. 4, Tab. 6). These results contrast with the chainsaw running time recorded in clear cut in coppice, which was significantly lower than in the other silvicultural treatment, thus suggesting a lower wood dust exposure.

In pruning operation, one sample exceeded the EU OEL, 11% of the data recorded were higher than 3 mg m^{-3}, and only 25% of the recorded data were lower than 1 mg m^{-3}. Moreover, if we consider the OEL applied in other countries, which are usually lower than the EU OEL, the recorded exposures highlighted critical situations. The results recorded in clear cut in coppice and in pruning may be explained by these facts: (i) In coppicing mainly hardwood species are cut, and this may cause a higher production of wood dust compared with softwood cutting (IARC 1995, Puntarić et al. 2005); and (ii) in coppicing and pruning, it is quite common for the operator to have his/her face very close to the cutting area when the bottom of the guide bar is used for cutting. When using the bottom of the guide bar, the chain is running towards the operator, throwing shavings and dust against him/her, thus increasing exposure to wood dust. Further studies are required to support this hypothesis and explain why in coppicing and pruning higher wood dust exposure was recorded.

The lower average wood dust exposure was recorded in sanitary cut, for which all the samples showed values lower than 3 mg m^{-3} (Tab. 5). These results were likely affected by the wood condition, frequently decayed (*i.e.*, lower cutting area because of heart rot) and/or extremely wet (*i.e.*, because of wetwood), which reduced the amount of dust production during cutting.

About half the data recorded in thinning were lower than 1 mg m^{-3}, and about 9% of the samples were included in the range 3 to 5 mg m^{-3}. The better conditions in terms of wood dust exposure were likely due to the type of wood that was easily cut by the chain teeth with a lower production of fine particles. However, further and specific studies are required to highlight the effect of the plant species on the production of wood dust in chainsaw cutting.

The type of fuel did not affect the cutting performance and the exposure of forest workers to wood dust.

The other few studies on wood dust exposure of forest workers during chainsaw operations were carried out in Croatia (Horvat 2005, Jazbec et al. 2007). However, respirable and not inhalable wood dust data were recorded during these studies, and thus the results are not comparable with the results of our study. Horvat et al. (Horvat 2005, Jazbec et al. 2007) recorded values lower than 1 mg m^{-3} for respirable dust both in fir wood and in oak wood cutting and processing operation with chainsaws. In Croatia, according to the proposal of the Regulatory Act on maximum permissible concentrations (MPC) of hazardous substances in the working atmospheres and biological limit values (BLV), maximum permissible concentration of wood dust of hardwood species (beech and oak) at the workplace is 1 mg m^{-3} for respirable particles and 3 mg m^{-3} for total dust.

Conclusion

According to our findings, the exposure of forest workers to wood dust was usually lower than the EU OEL, even though 2 samples exceeded that standard. Nevertheless, the average values recorded were close or higher than the OEL applied in some countries (*e.g.*, 2 mg m^{-3} in Austria, Germany and Sweden, 1 mg m^{-3} in France), and higher or included in the exposure range values suggested for the future by the SCOEL (1–1.5 mg m^{-3}).

However, in considering our results, it is important to highlight that at present, the OEL are set on the basis of studies of the woodworking industry. This means that the EU and national laws are at present designed to be effective in an industrial environment and they are probably not suitable for evaluating forest operation in the field, where additional variables affecting dust exposure and its effects on workers' health are not yet defined and assessed. A constructive criticism of the current risk assessment and OEL, designed for an industrial environment, is that they are based on labour carried on for 8 hours a day and around 200 days a year. It should be recalled that the average exposure to wood dust of forest workers is usually lower (<100 days per year) and that their overall working-life exposure is different from that of woodworking industry workers.

Specific epidemiological studies on forest operators should be developed in different countries to examine the relationship between chainsaw operations (*i.e.*, wood dust exposure) and cancer (*e.g.*, nasal cavity and paranasal sinuses cancers) or other occupational diseases.

The first results provided by this study represent a broad and valid database on exposure of chainsaw workers to wood dust. However, further studies are strongly recommended. Future developments on this topic should be: (i) to verify whether the highest values are significant and representative of a particular type of work or species under cutting, or whether they can be ignored; (ii) to investigate if different types of use of chainsaws may affect wood dust exposure (*e.g.*, reducing as much as possible the use of the bottom of the guide bar); and (iii) to review the law to ensure well designed and prudent analysis of real working conditions in forests.

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Individual contributions of authors to the manuscript: EM conceived the study and checked the final version of the manuscript; FN carried out the field measurements and draft the manuscript, MC carried out the field measurements; AL carried out the field measurements and performed the statistical analysis; CF performed the statistical analysis; GS carried out the laboratory analysis; FF carried out the field measurements.

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