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Mechanized Wood Extraction: Impacts on Operators' Hearing Health

Diego Aparecido Camargo, Rafaele Almeida Munis, Ricardo Hideaki Miyajima, Roldão Carlos Andrade Lima and Danilo Simões *

Department of Forest Science, Soils and Environment, School of Agriculture, São Paulo State University (UNESP), Botucatu 18610-034, Brazil

* Correspondence: danilo.simoes@unesp.br

Abstract: The activity of the mechanized extraction of wood, carried out by means of self-propelled forest machines, consists of moving the wood cut inside the forest stand from the planted forests to the roadside. During displacements, these machines normally travel over forest residues and stumps, which can demand greater motor power from the engine, in addition to the possible increase in occupational noise levels. In this context, we evaluated whether, when operating different self-propelled forest machines in the wood extraction of planted *Eucalyptus* forests, operators are exposed to different levels of occupational noise, especially to thresholds above those established for prevention purposes. Occupational noise data were collected during the workday, weighing six self-propelled forest machine operators who performed the wood-extraction operation, performed by two forwarders, two self-loading tractors, and two grapple skidders, in three areas with *Eucalyptus* plantations located in the southeastern region of Brazil. The sound-pressure level was collected using two integrative meters following the strategic measurement criterion recommendation for the whole day in the guidelines of the acoustic determination of occupational noise exposure and analyzed according to the American Conference of Government Industrial Hygienists. Operators of forest machines for the mechanized extraction of wood were exposed to occupational noise levels above the recommended level, which can affect health and well-being; this occupation also required above-average levels of attention during the execution of work activities.

Keywords: forest operations; planted forests; *Eucalyptus*; ergonomics; wood harvesting; occupational noise

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1. Introduction

The forest sector stands out worldwide, based on the increase in the demand for wood from planted forests used as raw material for the production of multi-products. In Brazil, in the last decade, this sector was boosted by the increase in the level of mechanization of the operations intrinsic to wood harvesting; optimizing activities; and, above all, improving the working conditions of workers.

Therefore, the evolution of this operation, that is, from manual and semi-mechanized to mechanized methods, came from the need to improve the quality of the harvested wood and, later, the quality of life of the worker [1–4].

In Brazil, among the wood-harvesting systems, the cut-to-length and the full-tree systems are used, designated according to the purpose of the wood to be harvested. These systems are evaluated under the most diverse aspects, such as technical, operational, economic, environmental, and occupational [5–9].

In these systems, the wood-extraction activity is carried out, which consists of moving the wood cut inside the forest stand to the roadside, intermediate yards, or processing yards. This activity is carried out using self-propelled forest machines such as forwarders,

grapple skidders, and self-loading tractors, selected according to the type of harvesting system adopted by forestry companies [10–13].

Despite the intrinsic particularities of the technical characteristics, these machines are characterized as sources of occupational noise. Noise is characterized as any unwanted sound coming from the workplace, which interferes with the operator's productivity and health. The emergence of occupational diseases, such as hearing loss; disorders in the brain; and disorders in the nervous, circulatory, digestive, endocrine, immunological, muscular, and sexual functions [14–16], is associated with noise.

Noise also acts as an environmental stressor, and the prolonged exposure of operators to this physical agent causes effects on quality of life, well-being, and cognitive health. In addition, the stimulation of the autonomic nervous system, which can lead to an increase in stress hormones, can result in the development of depression and anxiety disorders [12,17].

Operators may suffer from permanent or temporary hearing loss, which can increase the risk of accidents and injuries in the workplace. As a consequence, hearing loss compromises communication and the identification of warning signs of productive resources, reaching the perception of the location of sounds. In addition, it can cause discomfort in the cognitive system, an increase in stress level, sleep disturbance, and a lack of attention [18–23].

In this context, self-propelled forest machines used in wood extraction can be considered important sources of occupational noise because they can affect the health of operators. Thus, we evaluated whether, when operating different self-propelled forest machines in the wood extraction of planted *Eucalyptus* forests, operators are exposed to different levels of occupational noise, especially to thresholds above those established for prevention purposes.

2. Materials and Methods

2.1. Ethical Approval

The research was approved by the Research Ethics Committee of São Paulo State University (Unesp), Medical School, Botucatu, São Paulo, Brazil, according to ID 3,492,969. All operators participated voluntarily and received clarification on the methodology and objectives of the research, becoming aware of the use of data by reading and signing the Free and Informed Consent Term (FICT).

2.2. Study Overview

Data were collected in three areas with planted *Eucalyptus* forests located in southeastern Brazil, characterized as follows:

Area 1: first rotation management system, with planting carried out at a spacing of 3.3 m × 1.8 m, age of 11 years, relief with a slope of 10.0 to 15.0% (wavy), and mechanized extraction with a forwarder;

Area 2: coppice management system, with planting carried out in a spacing of 3.1 m × 1.8 m, age of 7 years, relief with a slope of 5.0 to 8.0% (smooth undulating), and mechanized extraction with a self-loading tractor;

Area 3: high forest management system, with planting carried out at a spacing of 3.3 m × 1.8 m, age of 9 years, relief with a slope of 5.0 to 8.0% (smooth undulating), and mechanized extraction with a grapple skidder.

The mean relative humidity in the study area ranged from 66.8% to 69.2%, with wind speeds from 3 m s^{-1} to 4.29 m s^{-1} and mean air temperature from 16 °C to 22.2 °C, according to National Institute of Meteorology [24].

2.3. Features of Self-Propelled Forest Machines

Six self-propelled forest machines used for the mechanized extraction of wood were considered specifically for the activities of forwarding the wood and for the skidding of wood (Table 1).

Table 1. Characteristics of self-propelled forest machines used in mechanized wood extraction in *Eucalyptus* planted forests.

Brand	Model	Type	Accumulated Hours of Use (h)
Ponsse	Elephant king	Forwarder 1	15,155
	Elephant king	Forwarder 2	15,880
Valmet	118	Self-loading tractor 1	90,521
	128	Self-loading tractor 2	33,215
Tigercat	635 D	Grapple skidder 1	12,892
	635 E	Grapple skidder 2	8359

In the forwarding activity, were evaluated two Ponsse forwarders, with a cabin of forestry machines (Elephant king models), with a rated power of 205 kW, a load capacity of 20,000 kg, and equipped with a crane with a useful area of 0.36 m^2; these systems had tire wheels and a traction of 8 × 8 and could extract wood 7 m in length that was destined for the production of cellulose.

In addition to these, were evaluated two Valmet self-loading tractors with a roll-over protection structure (models 118 and 128, respectively), with a rated power of 118 and 128 kW, tire systems, and 4 × 4 traction. The forestry implements had a load capacity of 6000 kg, equipped with cranes of the TMO brand with 0.25 m^2 of useful area; they could extract wood 2 m in length that was destined for energy purposes.

In the skidding activity, two Tigercat grapple skidders, with a cabin of forestry machines, models 635D and 635E, were evaluated, both with a rated power of 194 kW, equipped with grapples of a useful area of 1.95 m^2, systems with tire wheels and a traction of 6 × 6, which could extract wood 25 m in length that was destined for the production of cellulose.

2.4. Operator Characteristics

Six self-propelled forest machine operators were evaluated during the eight-hour working day (Table 2). The operators had a mean age of 45.3 ± 8.2 years and a mean time of professional experience of 11.2 ± 7.8 years.

Table 2. Characteristics of self-propelled forest machine operators who performed mechanized wood-extraction operations.

Operator	Age	Experience Time (Years)	Type
1	51	20	Forwarder 1
2	50	8	Forwarder 2
3	41	12	Self-loading tractor 1
4	48	23	Self-loading tractor 2
5	29	2	Grapple skidder 1
6	50	4	Grapple skidder 2

2.5. Occupational Noise Analysis Procedure and Criteria

Occupational noise data were collected during the daily workday, considering breaks taken due to physiological needs; lunch breaks; and mechanical interruptions. Operators wore personal protective equipment and, during operations, kept the machine's cabin door closed.

Sound pressure levels were collected using integrator meters for personal use (brand Instrutherm, models DOS-500 and DOS-600, both calibrated and certified). Measurements took an average of 7 h and 33 min for each operator, with criteria for assessing occupational noise exposure recommended according to the International Organization for Standardization [25].

The sound-pressure level (Equation (1)), responsible for the perception of the noise level at the auditory threshold, measured in a measurement range of 50 to 130 dB, was estimated according to Kuehn [26].

$$SPL = 20 \log\left(\frac{P}{P_0}\right) \quad (1)$$

where SPL is the sound-pressure level, P is the sound pressure being measured, and P_0 is the reference sound pressure (standardized at 2×10^{-5} Pascal).

The daily noise dose (Equation (2)), which refers to the amount of actual exposure relative to the amount of exposure allowed, was calculated following the precepts of the National Institute for Occupational Safety and Health [27].

$$D = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \ldots + \frac{C_n}{T_n} \quad (2)$$

where D is the daily noise dose, C_n is the total time of exposure at a specified noise level, and T_n is the exposure duration for which noise at this level becomes hazardous.

The standardized exposure level (Equation (3)), which configures the exposure level to which the auditory system is exposed during the 8-h working day, was weighted according to Masioli et al. [28].

$$SEL = EL + 10 \log\left(\frac{D_w}{480}\right) \quad (3)$$

where SEL is the standardized exposure level, EL is the exposure level, and D_w is the duration of the workday.

The maximum exposure daily permissible (Equation (4)), which expresses the maximum time of exposure to noise during the day, was estimated according to the National Institute for Occupational Safety and Health [27].

$$MEDP = \frac{480}{2(SEL - A_l)/q} \quad (4)$$

where $MEDP$ is the maximum exposure daily permissible, SEL is the standardized exposure level, A_l is the action level, and q is the dose increment factor.

The noise level (Equation (5)) indicates the estimated noise level that the operator's ear picked up after the attenuation provided by the correct use of hearing protectors; it was measured in accordance with Schulz [29].

$$NL = L_{avg} - NRR_{sf} \quad (5)$$

where NL is the estimated noise level that reaches the worker's ear, L_{avg} is the average level of daily exposure to occupational noise, and NRR_{sf} is the noise reduction rate subject fit.

The measurements followed as a strategic criterion for measuring the complete daily journey, in which the recommendations of the International Organization for Standardization [25] were recommended. The integrating meters were configured with an "A" weight and a dose increment factor of 5, as proposed by the American Standards Institute [30].

The results obtained were compared with an action level of 80 dB(A) and an exposure limit of 85 dB(A) for an 8-h working day, following the recommendations of the American Conference of Government Industrial Hygienists [31].

Hearing loss estimation was based on Portuguese Norm N. 1733, Annex N. 6 [32], considering that exposure to thresholds above 80 dB(A) and professional experience of more than five years indicate the onset of hearing loss resulting from work activities.

The normality of sound-pressure level data was analyzed using the test of Lilliefors [33] and the homoscedasticity of variance with the test of Bartlett [34]. The nonparametric test of Kruskal and Wallis [35] was adopted to establish if the samples originated from the same

distribution as the adjustment by the test of Dunn [36]. Statistical analyzes were analyzed at a 5% significance level using the R Development Core Team [37] programming language.

3. Results

When analyzing the hypotheses of normality and the homogeneity of the variances of sound-pressure levels, the assumptions at a significance level of 5.0% were rejected. Therefore, submitted to the Kruskal–Wallis test, *p*-value = 0.00 differed statistically; thus, through the Dun test, the different behaviors were evidenced (Figure 1) between the sound-pressure levels collected from the self-propelled forest machines, limiting the equivalence to Operator 5 and Operator 6.

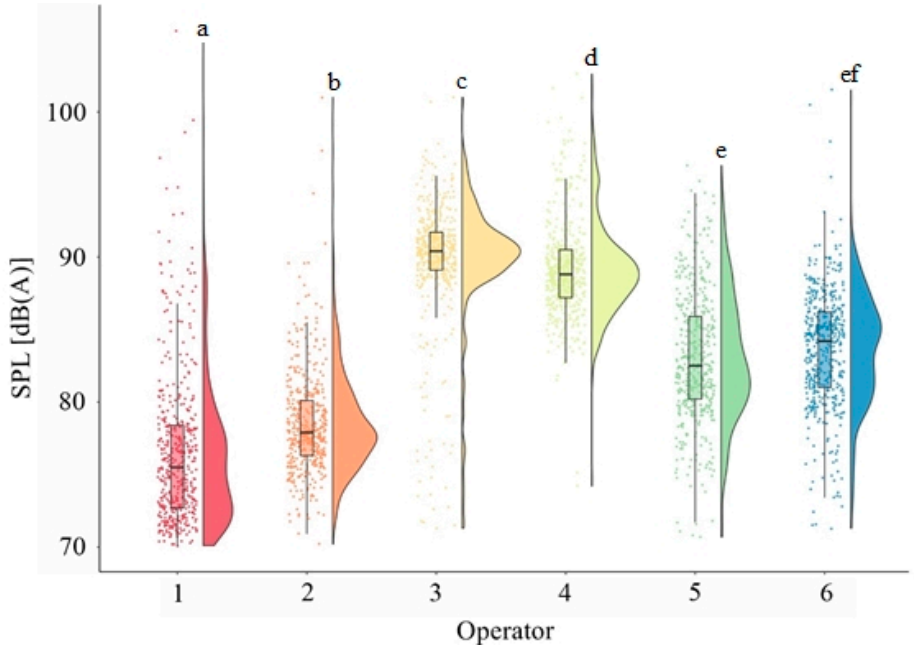

Figure 1. Analysis of sound-pressure levels in mechanized wood-extraction operations in southeastern Brazil. The slashes followed by distinct letters differ from each other by the Dunn test.

In addition to providing the implementation of mitigating measures, the study of the noise levels emitted by self-propelled forest machines promotes the identification of the excess threshold between observed emissions and reference values recommended by norms, laws, and guidelines aimed at the occupational safety of operators. Therefore, based on the occupational noise analysis variables in a mechanized wood-extraction operations in southeastern Brazil (Table 3), a comparison was made between the reference values of the American Conference of Government Industrial Hygienists.

Table 3. Occupational noise analysis variables in mechanized wood-extraction operations in southeastern Brazil.

Operator	D (%)	SEL [dB(A)]	MEDP (h)	NL [dB(A)]
1	32.0	76.8	24 h 59 min	59.8
2	34.1	77.2	23 h 28 min	60.2
3	212.8	90.4	3 h 45 min	70.4
4	196.1	89.9	4 h 4 min	69.9
5	96.5	84.7	8 h 29 min	67.7
6	102.7	85.2	7 h 47 min	68.2

Where D is the daily noise dose, SEL is the standardized exposure level, MEDP is the maximum exposure daily permissible, and NL is the estimated noise level that reaches the worker's ear.

Operator 1 and Operator 2 were exposed to a daily noise dose of 32.0% and 34.1%, respectively, with these values being lower than those recommended for the daily working day. These operators had a standardized exposure level of 0.4% and 3.5% below the action level, allowing for 313.3% and 293.3% of maximum daily exposure.

Operator 3 was exposed to a dose 112.8% higher than recommended for the daily working day, with a standardized exposure level 6.0% higher than the recommended exposure limit. Thus, the maximum permissible daily exposure for this operator was 46.9%. The daily noise dose to which Operator 4 was exposed exceeded 96.1% of the tolerable, with 5.5% of the standardized exposure level above the recommended limit, inferring 50.8% of the maximum permissible daily exposure.

Operator 5 had a daily noise dose exposure of 96.5%, presenting a standardized exposure level 5.5% above the action level, allowing for 106.0% of maximum daily exposure. Operator 6 was exposed to 2.7% above the daily noise dose, with a standardized exposure level exceeding 0.2% of the exposure limit, reflecting 97.3% of maximum permissible daily exposure.

In the analysis of hearing loss, Operator 1 and Operator 2 had exposures below the upper threshold; thus, there was no risk of hearing loss in the short term. Operator 3 and Operator 4, who presented exposure above the upper threshold, had experience in the role of 12 and 23 years, respectively, with a risk of hearing loss of 11.0% and 115.9%. The risks of hearing loss for Operator 5 and Operator 6 were 0.7% and 0.9%, with respect to the time of experience in the role of 3 and 4 years, respectively.

4. Discussion

The sound-pressure levels emitted by self-propelled forest machines in the mechanized extraction of wood can compromise the health and safety of operators. Hundy et al. [38] and Patil et al. [39] add that these levels are crucial for the acceptability of the workplace and for the preservation of workers' hearing. In cases of inadequacy of the workplace, they can corroborate in damages caused to the health of the operators.

In this perspective, the workplaces of Operator 3 and Operator 4, who performed the wood extraction with a self-loading tractor, and Operator 6, who performed the extraction operation with a grapple skidder, were the only ones to present sound-pressure levels above 85 dB(A), therefore characterizing the workplace as unhealthy. In addition, they can result in burnout syndrome; difficulty concentrating; stress; fatigue; or cardiovascular disease [40–43].

When analyzing the daily noise dose to which Operators 1, 2, and 5 were exposed, it was found that they did not exceed the limit of 100.0% recommended by the National Institute for Occupational Safety and Health [27]. Thus, Operators 3, 4, and 6 were exposed to doses above the stipulated dose for the daily working day. Thus, the adoption of methods associated with the management of occupational noise, such as hearing conservation programs, should be implemented, as recommended by Camargo et al. [44] and Moroe and Khoza-Shangase [45] to decrease the daily dose of noise.

Operators 3, 4, and 6 were exposed to standardized exposure levels above the exposure limit of 85 dB(A). Thresholds above the pre-established maximum limits highlighted how exposed these operators were to the compromise of their occupational integrity [8,12,46,47].

It is evident that the self-loading tractors presented unfavorable results of occupational noise, that is, higher levels than the other self-propelled forest machines. This result can be attributed to the fact that they are machines adapted for the forestry activity under analysis, for example, the cabin did not have adequate sealing to mitigate noise levels. Another factor that can be considered a potentiator of noise generation was the amount of hours accumulated, exceeding 30,000 h of use.

The total hours accumulated are counted using the machine's hourmeter; thus, the useful life of self-propelled forest machines can be estimated. Because the self-loading tractor is an agricultural machine adapted for forestry operations, the estimated useful life for an agricultural tractor is considered, which is limited to 16,000 h of use [48]. This

machine configuration that operates above the hourmeter limit tends to produce higher noise levels [49].

As for the grapple skidder, the increase in the standardized exposure level can be explained since the self-propelled forestry machine operated at the limit of the grapple's maximum capacity. Visser and Spinelli [50] and Poje et al. [51] point out that, when performing the activity close to the maximum volume of technical capacity, there is a greater demand for machine power. Therefore, this indicated an increase in average noise levels, which could be avoided by the strategic involvement of forest managers, in order to eliminate cognitive biases in permanent decision-making, as exposed by McLain et al. [52] and Camargo et al. [44].

During the mechanized extraction of wood performed by forwarders, operators were exposed to a standardized exposure level close to the action level of 80 dB(A). Due to this proximity to the action level, the constant monitoring of noise levels must be maintained in order to prevent values from exceeding recommended levels. However, if these were exceeded, Oliveira et al. [53] justify the adoption of appropriate control measures.

In the operation performed by the grapple skidder, Operator 5 was exposed to the standardized exposure level of 4.7 dB(A) above the action level of 80 dB(A). Operators frequently exposed to noise levels above the action level may experience symptoms of discomfort, tinnitus, physiological disturbances, noise-induced hearing loss, etc., which intensify over time [54,55].

Ideally, the extinction of all risky and unhealthy situations in the work routines of self-propelled forest machine operators is desirable. However, eradicating the possible risks can be time-consuming or impossible. Associating measurement and quality-management tools makes it possible for the forest manager to know the sources of noise, reorganize activities, implement control measures, and check their efficiency in promoting new adjustments.

The continuous improvement routine allows the problem to be decomposed so that its resolution becomes feasible. As an example of the identification and awareness of the need to use personal protective equipment such as ear protectors, can, according to Veiga et al. [56], attenuate up to 20 dB of the occupational noise to which workers may be exposed on a daily basis.

The monitoring and evaluation of occupational noise levels as part of the work routine creates opportunities to ensure the well-being of operators during the execution of mechanized wood-extraction activities. Thus, as protective measures can be adopted, the stipulation of intervals during long hours of operation against possible damage caused by excessive noise, in addition to engineering actions to replace damaged parts and seal the cabins, is necessary.

5. Conclusions

Operators of self-propelled forest machines that work in the mechanized extraction of *Eucalyptus* wood are exposed to occupational noise levels above those recommended for prevention purposes.

Self-loading tractors and grapple skidder self-propelled forest machines stand out for their non-compliance with values higher than those recommended.

The risk of hearing loss for the operators analyzed represented 33%, as a result of the average time of experience above 12 years.

Higher levels of occupational noise than those recommended expose operators to risks and compromise their occupational health, as well as their performance in the operation of the mechanized extraction of *Eucalyptus* wood by different self-propelled machines.

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References

1. Obi, O.F.; Visser, R. Influence of the operating environment on the technical efficiency of forest harvesting operations. *Int. J. For. Eng.* **2017**, *28*, 140–147. [CrossRef]
2. Kaakkurivaara, N.; Stampfer, K. Assessment for Improvement: Harvesting Operations in Small-Scale Forest on Thai Steep Terrain. *Small-Scale For.* **2018**, *17*, 259–276. [CrossRef]
3. Štěrbová, M.; Stojanovski, V.; Weiss, G.; Šálka, J. Innovating in a traditional sector: Innovation in forest harvesting in Slovakia and Macedonia. *For. Policy Econ.* **2019**, *106*, 101960. [CrossRef]
4. Bilici, E. Investigation of feller-buncher performance using weibull distribution. *Forests* **2021**, *12*, 284. [CrossRef]
5. Camargo, D.A.; Munis, R.A.; Simões, D. Investigation of exposure to occupational noise among forestry machine operators: A case study in Brazil. *Forests* **2021**, *12*, 299. [CrossRef]
6. Munis, R.A.; Almeida, R.O.; Camargo, D.A.; Barbosa, R.; Wojciechowski, J.; Sim, D. Machine Learning Methods to Estimate Productivity of Harvesters: Mechanized Timber Harvesting in Brazil. *Forests* **2022**, *13*, 1068. [CrossRef]
7. Pagnussat, M.B.; da Silva Lopes, E.; Robert, R.C.G. Machine availability and productivity during timber harvester machine operator training. *Can. J. For. Res.* **2021**, *51*, 433–438. [CrossRef]
8. Schettino, S.; Minette, L.J.; Andrade Lima, R.C.; Pedroso Nascimento, G.S.; Caçador, S.S.; Leme Vieira, M.P. Forest harvesting in rural properties: Risks and worsening to the worker's health under the ergonomics approach. *Int. J. Ind. Ergon.* **2021**, *82*, 103087. [CrossRef]
9. Spinelli, R.; Magagnotti, N.; Visser, R.; O'Neal, B. A survey of the skidder fleet of Central, Eastern and Southern Europe. *Eur. J. For. Res.* **2021**, *140*, 901–911. [CrossRef]
10. Han, S.-K.; Han, H.-S.; Page-Dumroese, D.S.; Johnson, L.R. Soil compaction associated with cut-to-length and whole-tree harvesting of a coniferous forest. *Can. J. For. Res.* **2009**, *39*, 976–989. [CrossRef]
11. Smirnov, M.; Shirnin, Y.; Shirnin, A.; Andrianov, Y. Research into the process of loading wood assortments by a tractor-mounted hydraulic manipulator of a tractor-trailer train. *J. Appl. Eng. Sci.* **2019**, *17*, 373–378. [CrossRef]
12. Lima, C.F.; Lima, R.C.A.; de Souza, A.P.; Minette, L.J.; Schettino, S.; Vieira, M.P.L.; Nascimento, G.S.P. Occupational Noise and Vibration Assessments in Forest Harvesting Equipment in North-eastern Brazil. *J. Exp. Agric. Int.* **2019**, *40*, 1–9. [CrossRef]
13. Miyajima, R.H.; Fenner, P.T.; Batistela, G.C.; Simões, D. The impact of felling method, bunch size, slope degree and skidding area on productivity and costs of skidding in a *Eucalyptus* plantation. *Croat. J. For. Eng.* **2021**, *42*, 381–390. [CrossRef]
14. Jankovský, M.; Merganič, J.; Allman, M.; Ferenčík, M.; Messingerová, V. The cumulative effects of work-related factors increase the heart rate of cabin field machine operators. *Int. J. Ind. Ergon.* **2018**, *65*, 173–178. [CrossRef]
15. Poje, A.; Grigolato, S.; Potočnik, I. Operator Exposure to Noise and Whole-Body Vibration in a Fully Mechanised CTL Forest Harvesting System in Karst Terrain. *Croat. J. For. Eng.* **2019**, *40*, 139–150.
16. Iftime, M.D.; Dumitrascu, A.E.; Dumitrascu, D.I.; Ciobanu, V.D. An investigation on major physical hazard exposures and health effects of forestry vehicle operators performing wood logging processes. *Int. J. Ind. Ergon.* **2020**, *80*, 103041. [CrossRef]
17. Clark, C.; Paunovic, K. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Quality of Life, Wellbeing and Mental Health. *Int. J. Environ. Res. Public Health* **2018**, *15*, 2400. [CrossRef]
18. Estill, C.F.; Rice, C.H.; Morata, T.; Bhattacharya, A. Noise and neurotoxic chemical exposure relationship to workplace traumatic injuries: A review. *J. Saf. Res.* **2017**, *60*, 35–42. [CrossRef]
19. Jacobs, N.; Roberts, B.; Reamer, H.; Mathis, C.; Gaffney, S.; Neitzel, R. Noise exposures in different community settings measured by traditional dosimeter and smartphone app. *Appl. Acoust.* **2020**, *167*, 107408. [CrossRef]
20. Picard, M.; Girard, S.A.; Simard, M.; Larocque, R.; Leroux, T.; Turcotte, F. Association of work-related accidents with noise exposure in the workplace and noise-induced hearing loss based on the experience of some 240,000 person-years of observation. *Accid. Anal. Prev.* **2008**, *40*, 1644–1652. [CrossRef]
21. Simpson, S.A.; Wadsworth, E.J.K.; Moss, S.C.; Smith, A.P. Minor injuries, cognitive failures and accidents at work: Incidence and associated features. *Occup. Med.* **2005**, *55*, 99–108. [CrossRef] [PubMed]

22. Dabirian, S.; Han, S.H.; Lee, J. Stochastic-based noise exposure assessment in modular and off-site construction. *J. Clean. Prod.* **2020**, *244*, 118758. [CrossRef]
23. Selamat, F.E.; Tagusari, J.; Matsui, T. Mapping of transportation noise-induced health risks as an alternative tool for risk communication with local residents. *Appl. Acoust.* **2021**, *178*, 107987. [CrossRef]
24. National Institute of Meteorology. Available online: https//portal.inmet.gov.br/dadoshistoricos (accessed on 18 February 2021).
25. *ISO 9612:2009*; Acoustics—Determination of Occupational Noise Exposure—Engineering Method. BSI Standards Limited: Geneva, Switzerland, 2009.
26. Kuehn, J. Noise Measurement. In *Instrumentation Reference Book*; Elsevier: Amsterdam, The Netherlands, 2010; pp. 593–614; ISBN 978-0-7506-8308-1.
27. NIOSH (National Institute for Occupational Safety & Health). *NIOSH: Criteria for a Recommended Standard—Occupational Noise Exposure*; Center for Disease Control and Prevention: Cincinnati, ON, USA, 1998.
28. Masioli, W.; Fiedler, N.C.; da Silva Lopes, E.; de Oliveira, F.M. Exposição de trabalhadores a ruído e vibração em atividades de colheita florestal semimecanizada. *Pesqui. Florest. Bras.* **2020**, *40*, 1–7. [CrossRef]
29. Schulz, T. Individual fit-testing of earplugs: A review of uses. *Noise Health* **2011**, *13*, 152. [CrossRef]
30. *ANSI/ASA S1.25-1991*; ANSI S1.25: Specifications for Personal Noise Dosimeters. ANSI American Standards Institute: New York, NY, USA, 1991.
31. American Conference of Government Industrial Hygienists. *Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices*; American Conference of Government Industrial Hygienists: Cincinnati, OH, USA, 2021.
32. Portuguese Institute of Quality. *NP-1733 Annex 6, Estimation of Exposure to Noise during the Exercise of a Professional Activity with a View to Hearing Protection*; Portuguese Institute of Quality: Lisboa, Portugal, 1981.
33. Lilliefors, H.W. On the Kolmogorov-Smirnov test for the exponential distribution with mean unknown. *J. Am. Stat. Assoc.* **1969**, *64*, 387–389. [CrossRef]
34. Bartlett, M.S. Properties of Sufficiency and Statistical Tests. *Phys. Eng. Sci.* **1937**, *190*, 268–282. [CrossRef]
35. Kruskal, W.H.; Wallis, W.A. Use of ranks in on-criterion variance analyses. *J. Am. Stat. Assoc.* **1952**, *47*, 583–621. [CrossRef]
36. Dunn, O.J. Multiple Comparisons Using Rank Sums. *Technometrics* **1964**, *6*, 241–252. [CrossRef]
37. R Development Core Team. *R: A Language and Environment for Statistical, Statistical Computing*; R Foundation for Computing: Vienna, Austria, 2021; ISBN 3-900051-07-0.
38. Hundy, G.F.; Trott, A.R.; Welch, T.C. Noise and vibration. In *Refrigeration, Air Conditioning and Heat Pumps*; Elsevier: Amsterdam, The Netherlands, 2016; pp. 447–455.
39. Patil, V.S.; Bano, F.; Kurahatti, R.V.; Patil, A.Y.; Raju, G.U.; Afzal, A.; Soudagar, M.E.M.; Kumar, R.; Ahamed Saleel, C. A study of sound pressure level (SPL) inside the truck cabin for new acoustic materials: An experimental and FEA approach. *Alexandria Eng. J.* **2021**, *60*, 5949–5976. [CrossRef]
40. Hnilica, R.; Dado, M.; Rejf, L.; Vaniš, L.; Veverková, D. Analysis of noise impact on mental stress of employees. *Akustika* **2017**, *27*, 26–34.
41. Ramón-Fernández, A.; Ruiz-Fernández, D.; Marcos-Jorquera, D.; Gilart-Iglesias, V. A Distributed Model for Stressors Monitoring Based on Environmental Smart Sensors. *Sensors* **2018**, *18*, 1935. [CrossRef]
42. Jankovský, M.; Allman, M.; Allmanová, Z. What are the occupational risks in forestry? Results of a long-term study in Slovakia. *Int. J. Environ. Res. Public Health* **2019**, *16*, 4931. [CrossRef]
43. Dehghan, S.F.; Mehrifar, Y.; Sayedabadi, E.; Aghl, M.P.; Mirhamidi, S.M.; Motlagh, A.T.; Bahrami, M.; Mohammadi, A.D.; Balochkhane, F.A.; Golkhani, F. Investigating the relationship between Exposure Level to Sound Pressure Level (SPL) and Light Intensity with Occupational Burnout in an Automotive Parts Industry. *J. Biochem. Technol.* **2020**, *1*, 18–24.
44. Camargo, D.A.; Munis, R.A.; Rocha, Q.S.; Simões, D. Evaluation of occupational noise exposure among forest machine operators: A study on the harvest of Pinus taeda trees. *Aust. For.* **2022**, *85*, 89–94. [CrossRef]
45. Moroe, N.F.; Khoza-Shangase, K. Recent advances in hearing conservation programmes: A systematic review. *S. Afr. J. Commun. Disord.* **2020**, *67*, 675. [CrossRef]
46. Özkul, S.; Sümer, S.K. Noise Exposure in Olive Harvest Mechanization. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım Doğa Derg.* **2022**, *25*, 348–356. [CrossRef]
47. Camargo, D.A.; Munis, R.A.; Miyajima, R.H.; Lima, R.C.A.; Simões, D. An evaluation of machine operator exposure to occupational noise during harvesting and extraction operations in Brazilian *Eucalyptus* plantations. *Int. J. For. Eng.* **2022**, 1–7. [CrossRef]
48. American Society of Agricultural and Biological Engineers. *Agricultural Machinery Management Data ASAE D496.3*; American Society of Agricultural and Biological Engineers: St. Joseph, MI, USA, 2011.
49. Mileusnić, Z.; Tanasijević, M.; Miodragović, R.; Dimitrijević, A.; Urošević, M. Tractor Lifetime Assessment Analysis. *Tarım Bilim. Derg.* **2019**, *25*, 197–204. [CrossRef]
50. Visser, R.; Spinelli, R. Determining the shape of the productivity function for mechanized felling and felling-processing. *J. For. Res.* **2012**, *17*, 397–402. [CrossRef]
51. Poje, A.; Potočnik, I.; Danilović, M.; Antonić, S. A case study of the impact of skidding distance on tractor operator exposure to noise. *Balt. For.* **2016**, *22*, 357–364.

52. McLain, S.C.; Autenrieth, D.A.; Yang, X.; Brazile, W.J. Noise Exposures and Hearing Protector Use at Small Logging Operations. *Small-Scale For.* **2021**, *20*, 1–9. [CrossRef]
53. de Oliveira, F.M.; da Silva Lopes, E.; Fiedler, N.C.; Koehler, H.S. Indicator for urgency assessment in ergonomic intervention of wood harvesting machines. *Rev. Arvore* **2020**, *44*, 1–10. [CrossRef]
54. Lacerda, A.; Quintiliano, J.; Lobato, D.; Gonçalves, C.; Marques, J. Hearing Profile of Brazilian Forestry Workers' Noise Exposure. *Int. Arch. Otorhinolaryngol.* **2014**, *19*, 22–29. [CrossRef]
55. Ding, T.; Yan, A.; Liu, K. What is noise-induced hearing loss? *Br. J. Hosp. Med.* **2019**, *80*, 525–529. [CrossRef]
56. Veiga, R.K.; Gontijo, L.A.; Masiero, F.C.; Venturi, J. Analysis of spatial distribution of noise near agricultural and forestry machinery. *Ciência Florest.* **2021**, *31*, 43–65. [CrossRef]