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Review

Forestry Ergonomics Publications in the Last Decade: A Review

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Abstract: Compiling the research on forestry ergonomics, which is still a marginal field in terms of the sheer volume of published forestry-related articles, gives a good foundation and guidance for future research and publishing. This review aims to compile, classify, and analyze forestry ergonomics publications in JIF (Journal Impact Factor) journals regarding their spatial and temporal distribution, observed operations, machines and tools, and risk factors. A reference period from 2014 to 2023 was observed in this study. The Web of Science Core Collection database was used to filter publications in the field of forestry and ergonomics. A total number of 102 articles were selected. After selection, data regarding publishing year, journal name, main field, country of origin, forest operation, machine/tool, and risk factor were noted. The number of articles is ever-increasing with the last four years having above average numbers of articles. Countries from Europe and South America (Brazil) have the most publications. Most of the journals are ranked in the top 50%. Harvesting, wood extraction, and pre-harvesting operations have the highest number of records. Chainsaw, skidder, and pre-harvesting tools are the most observed means of work. The risk factors with the highest percentage of records are workload (23%), noise (20%), vibration (20%), postural load (16%), and MSD (Musculoskeletal Disorder) occurrence (7%).

Keywords: forestry; forestry ergonomics; ergonomics; publishing dynamics; risk factors; workload; noise; vibration; postural load; MSD

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1. Introduction

There are two major aspects of forestry work concerning which ergonomics can make important contributions. The first addresses problems of adaptation to heavy manual labor. In these labors, men are using simple tools to provide the most important part of the energy required to carry out given work. This can be critical when other factors are added, such as environmental heat. The second aspect is represented by mechanized work, where human energy is replaced by machinery. The workers become more sedentary, limiting their activities to perceive and interpret information and execute their decisions with actions that demand little muscular effort but require high participation of their mental processes [1]. This summarizes the focal point of forestry ergonomics and can be observed in all articles published on this topic.

According to previous research [2], forestry ergonomics will have to face challenges like dissemination of the existing knowledge of classic ergonomics, adjustments of standards to specific local conditions and workers, development of cognitive ergonomics, and adjustments in the organization of work and people to fast-developing technologies and production processes.

Risk factors included in forestry ergonomics publications are substantial and their dynamic appearance is observed in this review. Regardless of time period or harvesting systems, "traditional" risk factors like noise [3–7], vibration [8–11], and workload [12–14] remain relevant. Postural load [15–17] and MSD (Musculoskeletal Disorders) occurrence [18,19] are being increasingly researched and assessed via standardized evaluation schemes and questionnaires like REBA (Rapid Entire Body Assessment) [20], OWAS (Ovako Working Posture Analysis System) [21], or Nordic questionnaire [22]. Meanwhile, comprehensive research of multiple risk factors [23,24] via checklists, like the European ergonomic and safety guidelines for forest machines [25], remains scarce.

Compiling research on forestry ergonomics, which is still a marginal field in terms of the sheer volume of published forestry-related articles, gives a good foundation and guidance for future research and publishing. This statement is backed up by the prediction made in a first compilation–review article on forestry ergonomics by Potočnik and Poje [26], which is a highly cited article. The main prediction by those authors is that the number of publications in journals with the journal impact factor (JIF) will increase in the future due to an increasing number of forestry and ergonomics journals with JIF, uniformity of the evaluation of research performance, and the development of technologies and measurement techniques.

This review aims to compile, classify, and analyze forestry ergonomics publications in JIF journals regarding their spatial and temporal distribution, observed operations, machines and tools, and risk factors. The results should point to key questions and challenges faced and observed by countries worldwide regarding forestry ergonomics.

2. Materials and Methods

The reference period from 2014 to 2023 was observed in this study. Web of Science Core Collection (WOS CC) database was used to filter publications (articles) in the field of forestry and ergonomics. The intention of limiting this review to articles published in journals indexed in WOS CC was to ensure, to some extent, the quality and originality of the reviewed content, as perceived by the scientific community. It should be noted that the journals indexed in AHCI (Arts and Humanities Citation Index) and ESCI (Emerging Sources Citation Index) have received JIF since JCR 2022 (Journal Citation Report), while their quartiles will be visible in JCR 2023. Review articles were excluded from this study. Keywords used in the forestry field included "ergonomics", "noise", "vibration", "postural", "workload", and "MSD", while in the ergonomics field "forestry" and "forest" were used. After filtering the articles, the presented summary was reviewed to establish the validity of the article to be included in the study. The condition was that the presented studies be partially or entirely conducted in the broader field of forestry work. This, along with traditional forestry operations, included biomass production, measuring and managing, and controlled tests conducted on forestry workers. A total number of 102 articles regarding forestry ergonomics were selected.

After selection, data regarding publishing year, journal name, main field (WOS category), and country of origin for each article were noted. Some articles had international authorship; however, as a decision factor for noting country of origin, the location where studies were conducted was used. Furthermore, all articles were classified according to categories: forestry operation(s) observed in the study, machine(s) or tool(s) used by the worker(s), and ergonomic risk factor(s) (Table 1).

If the article dealt with several forestry operations, machines, and tools, or risk factors, it was classified into multiple fields within a category and stats were given as a number of records.

The database was constructed using Microsoft Excel® (v16.0, Microsoft, Redmond, WA, USA), which was also used for the presentation of the results through graphs and tables. A free platform MapChart (v5.0.0, Minas, Greece) was used for spatial presentation of the results.

Table 1. Article classification.

Operation	Machine/Tool	Risk Factor
Pre-harvesting	Pre-harvesting tools	Vibration
Harvesting	Manual work/tools	Noise
Wood extraction	Chainsaw	Workload [1]
Wood transport	Harvester	Postural load
Biomass production	Feller buncher	MSD
Measuring/managing	Processor	Thermal comfort
Controlled tests	Farm tractor	Fatigue
	Crawler tractor	Human factors
	Slash grapple	Gases and particulates
	Skidder	Repetitive motion
	Forwarder	Illumination
	Tower yarder	Visibility
	Loader	Cab
	Animal	Controls
	Timber truck	Seat
	Chipper	
	Debarker	
	Fire wood processor	

[1] cardiovascular, physical, aerobic, mental, psychophysical.

3. Results

3.1. Publishing Year, Country, Journal, and Field Overview

One hundred and two forestry-ergonomics-related articles in the last decade (Table A1) make an average of 10 articles per year (Figure 1). The majority (61) of articles were published in the second half of the decade.

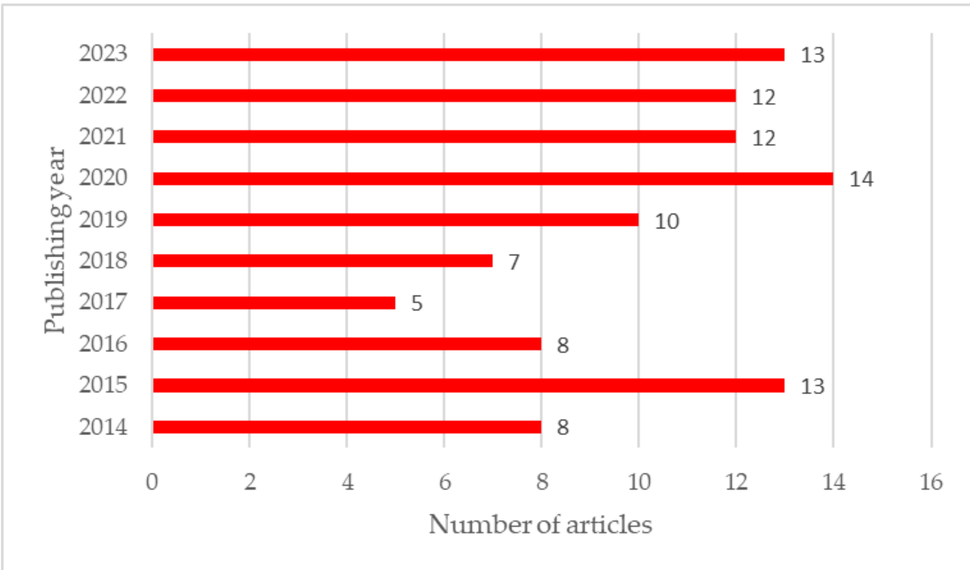

Figure 1. Number of articles in the last decade.

A total number of 25 countries on six continents published articles observed in this study (Figure 2).

Most articles (84) were published by countries from Europe (57) and South America, where Brazil alone published 27 articles—it is also the country with the most published articles. Of the European countries, Italy has the most publications (12). Other countries with five or more articles include Poland (8), Romania (7), and Croatia (5).

Articles were published in 25 journals (Figure 3), of which 20 were in the field of forestry and the rest in the field of ergonomics. Likewise, 85 articles were published in journals of the forestry field and 17 in the journals of the ergonomics field.

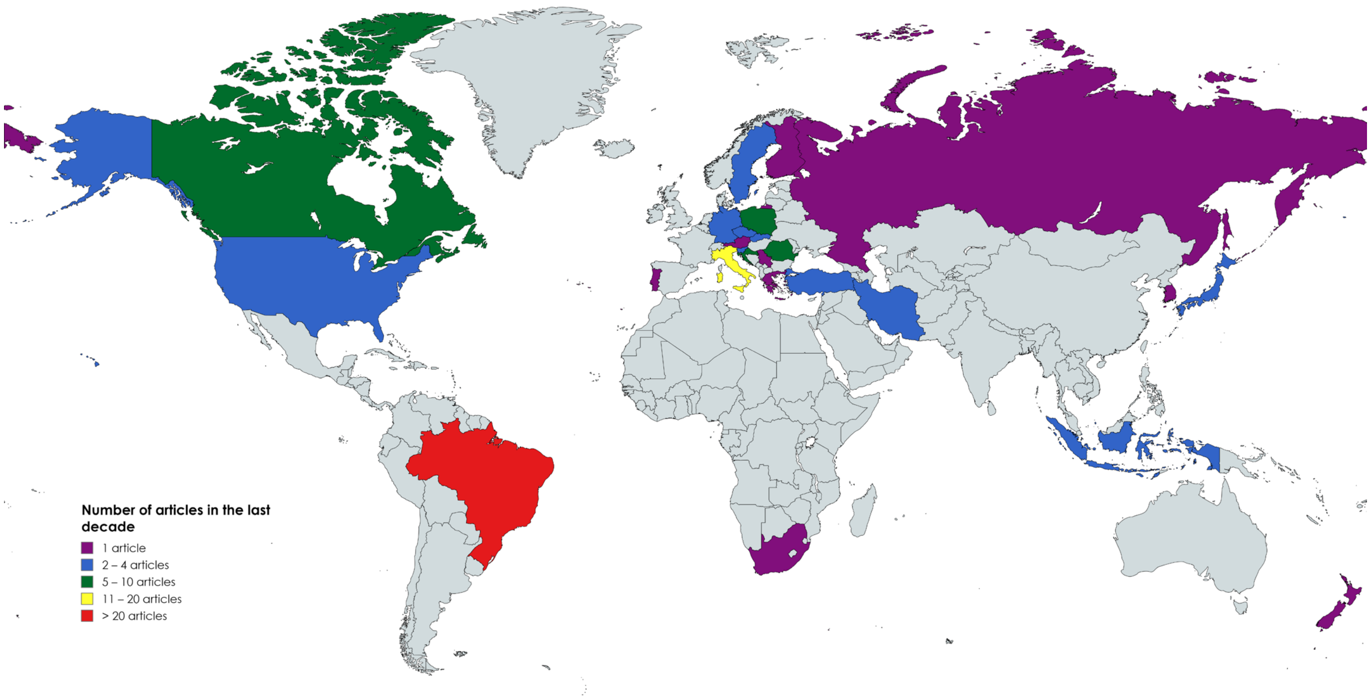

Figure 2. World map presenting spatial distribution of published articles (Source: MapChart).

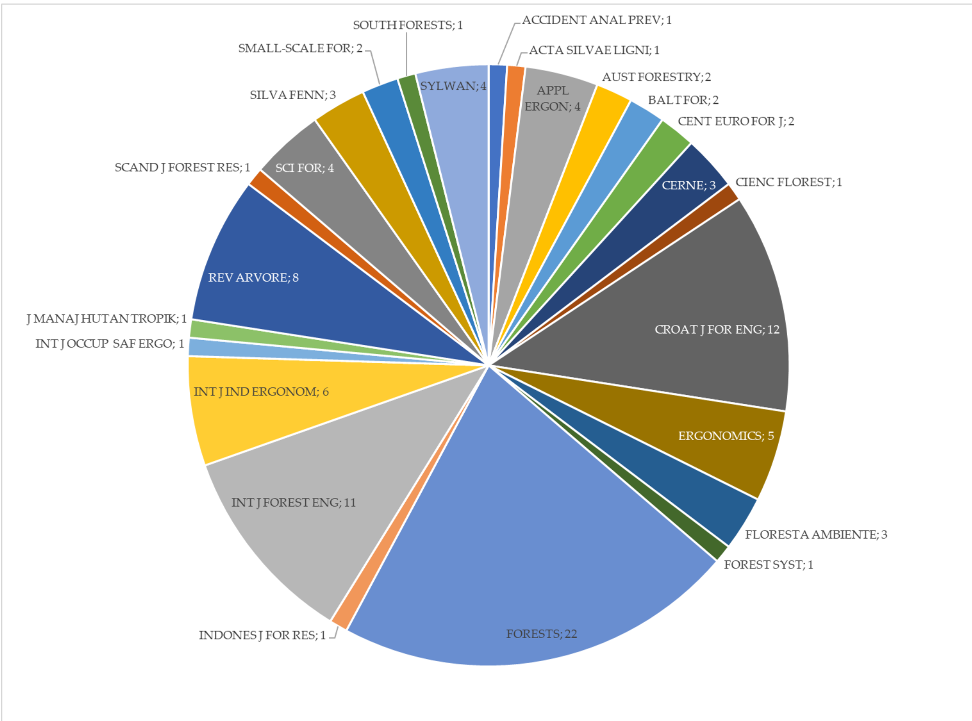

Figure 3. Number of articles per journal.

Journals with the five or more published articles include Forests (22), Croatian Journal of Forest Engineering (12), International Journal of Forest Engineering (11), Revista Arvore (8), International Journal of Industrial Ergonomics (6), and Ergonomics (5).

3.2. Article Classification

Regarding the topic of the article and its classification by the category of forest operations, a total of 127 records in seven fields were noted (Figure 4).

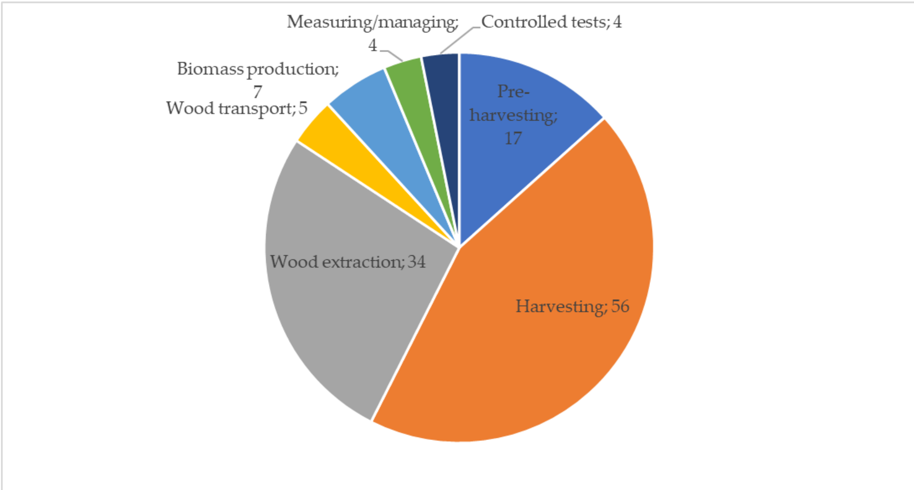

Figure 4. Number of records per forest operation category.

Harvesting operations were the most represented in this review, followed by wood extraction and pre-harvesting operations, all of which total 84% of all records in this category of classification. As expected, the most records in harvesting (16), wood extraction (13), and pre-harvesting (6) were noted in Brazilian articles (Figure A1). Other countries with five or more records in harvesting operations include Italy, Poland, and Romania. Wood transport was only mentioned in articles published by Germany, Indonesia, Türkiye, USA, and Japan with one article per country. Likewise, ergonomics in biomass production was studied the most by Italy (3) followed by Finland, Greece, Slovenia, and Türkiye with one article per country. Operations regarding measuring and managing were studied in Brazil, Japan, Poland, and Romania with one article per country. Controlled tests were conducted in Canada (3) and Slovenia (1).

A total of 152 records in 18 fields on machine/tool studied in observed articles were noted (Figure 5).

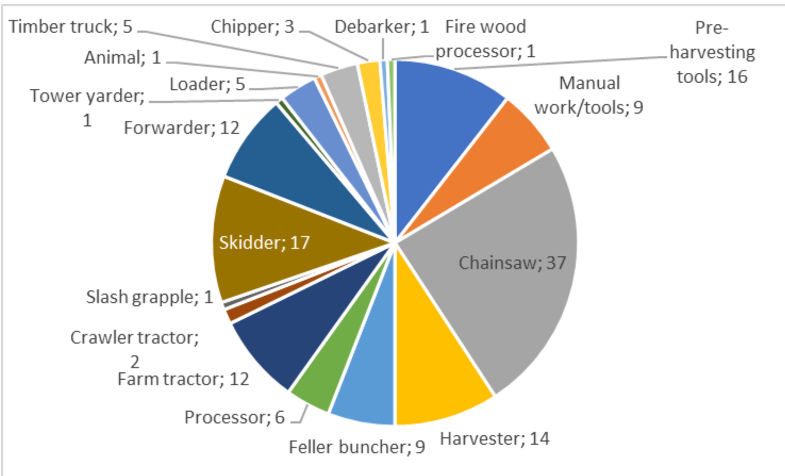

Figure 5. Number of records per machine/tool category.

The most represented machines and tools were chainsaw (37), skidder (17), pre-harvesting tools (16), harvester (14), forwarder (12), and farm tractor (12). Overall, almost one-third of all records were noted in Brazilian articles (Figure A2) where the most records were observed for skidder (8), feller buncher (7), harvester (6), pre-harvesting tools (6), chainsaw (5), and forwarder (5). Out of 25 countries, chainsaw was noted in articles from 17 countries including Brazil and Croatia with five records, Poland and Romania with four, and Iran and Italy with three records each.

Classification of articles by the risk factor category yielded 157 records in 15 fields (Figure 6).

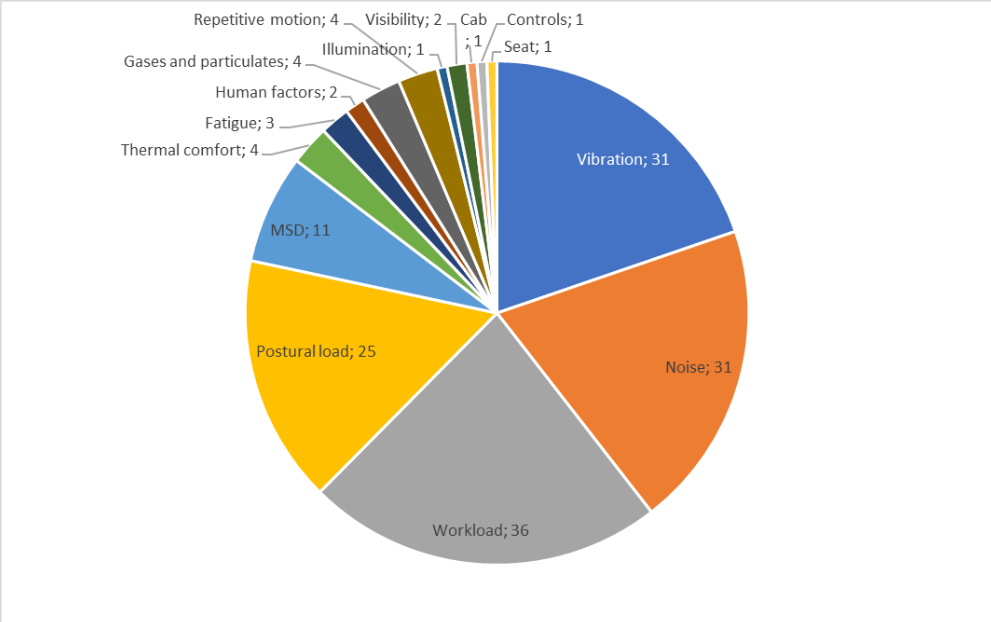

Figure 6. Number of records per risk factor category.

Workload (multiple types) is the most common risk factor with 36 records, followed by vibration and noise with 31 records each, postural load (25), and MSD (11). Again, almost one-third of all records were noted in Brazilian articles (Figure A3) with noise (11), postural load (11), vibration (9), and workload (6) as the most represented. Other countries with five or more records per field include Italy (6) and Poland (5) in the workload field and Romania (5) in the noise field.

3.3. Recent Study Results per Risk Factors Overview

3.3.1. Noise and Vibration

Exposure to a noise level of 85 dB(A) for more than 8 h can damage hearing, while raising the noise level to 95 dB(A) (chainsaw territory) reduces exposure time to less than one hour before putting hearing at risk. Repeated exposure can lead to more lasting conditions (total hearing loss). In addition, symptoms like physical and mental stress, high blood pressure, or tinnitus can occur [27]. Vibration, especially hand–arm vibration (HAV), is viewed as a risk factor that can only be mitigated via shorter exposure time through the likes of job rotation, limited working time, or entire harvesting system replacement. HAVs in forestry are generated from hand-held and hand-guided tools and machines like chainsaws, brushcutters, stump grinders, billhooks, machetes, axes, and sickles [10]. Long exposures can cause problems with blood circulation in fingertips and damage to muscles, nerves, and tendons [28]. Whole-body vibration (WBV) is mainly a concern in highly mechanized systems [29]. Occurrence of neck pain among forest machine operators is associated with exposure to shock-type vibration [30].

Out of 156 records, the most are observed in these two fields (62). Regardless of the simplicity of minimizing noise exposure through the use of PPE and other measures, it remains a high point in forestry ergonomics. The latest discoveries in chainsaw noise state that the average noise dose exceeds the maximum allowable limit of 85 dB(A) for 8 h of continuous work [31,32]. Veiga et al. [33] concluded that for the chainsaw, the maximum exposure time is one hour (without PPE). The exposure of harvester and forwarder operators to noise in karst areas does not exceed the limit for daily noise exposure defined in the EU legislation [34] but is higher than exposure in fully mechanized CTL harvesting on flat terrain [23]. Carmago et al. [4] observed that 36.4% of harvester operators were exposed to values above the exposure limit of 85 dB(A) and 63.6% to the action level of 80 dB(A). Regarding the forwarder operators, 100% were exposed to values that exceeded the action level. In full tree harvesting, the results showed that 17 self-propelled forest machines exceeded the exposure action value of 80 dB(A), of which 10 machines exceeded the exposure limit of 85 dB(A) [5].

Lately, many studies regarding vibrations have been performed on battery-powered chainsaws; the general conclusion is that hand–arm vibrations are weaker than those of similar power and weight-class petrol chainsaws [10,35,36]. Different hand tools used in forest cleaning are deemed unsafe because of high hand–arm vibrations [10]. Chainsaw vibrations, i.e., daily vibration exposure, are not affected by the years in use of the chainsaw [37,38]. Feyzi et al. [11] stated that the effect of wood species on vibration acceleration was found to be significant, while no significant influence of this factor on the vibration total value was detected. Instead, the cutting process amplified the vibration total value due to an increase in the vibration acceleration at lower frequencies. Martins et al. [8] reported higher WBV exposures by tracked harvesters in comparison to wheeled harvesters.

3.3.2. Workload

Multiple iterations of workload was the most common risk factor recorded in this study. Physical workload is the measurable portion of physical resources expended when performing a given task (manual lifting and carrying, repetitive work, and other physical strain). It is affected by various factors, including the nature of work, training, motivation, and environmental factors [39]. On the other hand, mental workload can be defined as the proportion of information processing capability used to perform a task [40,41].

As expected, manual and motor-manual work is physically the most demanding and deemed as moderate to heavy or very heavy from a physical workload standpoint [32,42–45]. Mental workload is mostly associated with a higher level of mechanization. A study by Spinelli et al. [46] confirmed the increased aggravation of mental demand, effort, and frustration experienced by the harvester operators when passing from the »pure conifer« stand to the »mixwood« stand. Furthermore, a higher slope gradient increased visual activity, indicating that the harvester operator experienced a heavier mental workload [47]. However, a study by Arman et al. [48] on tree fellers, skidder drivers, and manual loaders recorded high scores for mental workload using a NASA-TLX questionnaire. Pajek et al. [49] in their controlled study stated that there are significant differences in psychophysical load in regard to the clothing systems used by forest workers.

3.3.3. Postural Load

Methods for assessing postural load are mostly based on sampling the work instances and coding them to evaluate postures of different body parts [20,21]. After the assessment, the necessity of improvement is indicated. According to the literature, unfavorable and bad working postures are closely linked to MSD occurrence [50,51].

Postural load is assessed in manual, motor-manual, and fully mechanized work. Lopes et al. [52] stated that manual planting operations caused greater postural discomfort in the legs of 56% of workers, while the fertilization and herbicide application caused discomfort in the shoulders of 41% and 56% of interviewed workers, respectively. A study by Borz et al. [32] in motor-manual felling reported a postural risk index of 191.11% for the worker handling the brush cutter and 192.02% for the manual assistant, indicating rather reduced risks. Starting a chainsaw is a mostly over-looked operation from an ergonomics standpoint; however, Landekić et al. [17] stated that the safest method of starting the chainsaw from the ground is the riskiest in terms of postural load, which, over time, can contribute to health problems in forest workers. The results of the Brazilian study [53] showed that the feller buncher operators remained seated in a static position for a long period, with fists turning outside the neutral line and without pauses for recovery, although REBA and RULA (Rapid Upper Limb Assessment) methods identified low postural risk. In wood processing operations with a harvester, the spinal column and neck were the most affected body parts, presenting medium postural risk. A Swedish study [54] observed that increasing forwarder speed and size of obstacles increased postural loads expressed as a range of motions.

3.3.4. MSDs (Musculoskeletal Disorders)

Work-related Musculoskeletal Disorders are conditions in which some or all of the following apply:

- The work environment and performance of work contribute significantly to the condition;
- The condition is made worse or persists longer due to work conditions.

A workplace ergonomics program can aim to prevent or control injuries and illnesses by eliminating or reducing worker exposure to work-related MSD risk factors using engineering and administrative controls [55].

For assessing the prevalence of self-reported musculoskeletal symptoms, different types of questionnaires are used. A Polish study [56] showed the dominant MSD symptoms among loggers to be those of the lower back (66.3%) and hands/wrists (left 50.1%, right 51.3%). A significant percentage of respondents also reported symptoms of the upper back (45.6%), shoulders (38.2% for each shoulder), and knees (left 36.0%, right 39.4%). Landekić et al. [57] stated that workers employed by a state-owned company have a higher prevalence of MSD symptoms in almost all anatomical locations compared to chainsaw operators employed by private forest contractors. According to Staněk et al. [58] the most stressed part of the chainsaw operator's body at the end of a shift was the lumbar region. In addition to obvious forest operations, forest measurement work can affect the development of MSD symptoms, as stated in a Brazilian study [59] where the activities of rigorous volume determination and soil collecting have been considered as having great risk of developing MSDs. Forwarder operators in South Africa reported having experienced work-related MSDs during the last 12 months mainly in the lower back, neck, shoulders, and upper back [60].

3.3.5. Thermal Comfort, Gases and Particulates, Repetitive Motion, Fatigue, Human Factors, and Visibility

The residual risk factors with more than one record are compiled in this sub-subsection. Regarding thermal comfort, a Romanian study [61] showed that the Wet Bulb Globe Temperature (WBGT) index values (−4.6 °C and 23 °C) revealed severe thermal stress on the chainsaw operator. The same authors [62] stated that the microclimate and carbon monoxide exposures inside skidder and farm tractor cabins were within their limits in the process of collecting wood. Santos et al. [63], in their study of ergonomic parameters of forwarder operators, characterized the forwarder operation as repetitive, with simple simultaneous movements of hands, wrists, and fingers. The results of the study conducted in New Zealand [64] suggest that it may not be possible to identify correlations between workloads (based on physical and cognitive stresses) and fatigue measures using in situ measurements as results are highly personalized to individual workers. Nakata et al. [65], in their survey of log truck drivers in Japan by questionnaires and interviews, stated that non-occupational drivers felt more fatigue; 66.6% had felt tired or exhausted compared to 31.8% of occupational drivers. A Brazilian study on human factors and work conditions in forest maintenance and planting operations [66] indicated that the workers' average age was 34.9 years, most of them of rural origin, married, with a low level of education, and short time experience in the company and the function—14.9 and 12.5 months, respectively. Oliveira et al. [24] in their ergonomic assessments of forestry machines using the ergonomic Degree of Compliance (V) method assessed the skidder visibility as poor in the lateral plane (V 0.0) in both shifts worked due to shocks and bumps in the machine's movements and visibility difficulty during the operation.

3.3.6. Illumination, Cab, Controls, and Seat

This sub-subsection compiles risk factors with only one record. Included risk factors, along with visibility, and gases and particulates, are a part of the European Ergonomic and Safety Guidelines for Forest Machines [25] that propose a methodology for evaluating and obtaining an ergonomic profile of typical forest machines (skidder, forwarder, and harvester). The stated risk factors are mentioned in two articles about the comprehensive ergonomic assessment of wood harvesting machines. Illumination was mentioned in a Brazilian article [24], which stated that skidder night illumination is non-compliant, scoring only 0.6 degrees of compliance. The remaining four risk factors were studied in a Russian article by Gerasimov and Sokolov [23] who stated that despite the extensive development of cabs, problems still exist.

4. Discussion

Similar to the previous study [26], the number of publications increased over the observed time period with the last 4 years having an above-average (10 publications) number of publications. This could imply the increase in interest of the scientific community in forestry ergonomics topics due to reoccurring problems, with the forestry workforce shortage [67] consequently leading to higher funding of this kind of research. Furthermore, there is an ever-growing number of JIF journals to be published, and the necessity of publishing due to career development is a big driving factor in some countries [68].

Regarding the spatial distribution of published articles, an evident drawback of this review is that, due to the WOS database, only articles written in Latin were considered, which partially excludes articles from countries like Russia and China. An evident change from a previous study by Potočnik and Poje [26] is the lack of articles from North America, where only seven articles originated from. Brazil is by far the country with the most published articles. The sheer magnitude of forest operations in the Amazonian rainforest has understandably raised many questions and problems to be investigated regarding forestry ergonomics. Cumulatively, European countries published the most articles in the observed time period. The reason for this could be found in Europe's multicultural setting with a significant number of universities and institutes. Also, as a contributing factor, modern forestry was developed in French- and German-speaking European countries [69].

Journals with the most publications recorded are mostly high-ranking journals within the top 50% (Q1 and Q2) according to their JIF, making them attractive for publication due to reasons mentioned by de Rijcke et al. [68]. On the other hand, the majority of Brazilian articles, 19 out of 27, were published in their domestic journals.

Harvesting and wood extraction operations are the most represented in this review, which is understandable as those operations form the core of forest work and involve multiple risk factors. Furthermore, regarding the machine or tool used, chainsaws and skidders have the most records noted. This is in line with a previous study by Potočnik and Poje [26]. According to Lundbäck et al. [70], at least one-third of industrial roundwood worldwide is harvested and extracted by partially mechanized systems, including chainsaw + skidder. A comprehensive ergonomic evaluation of harvesting systems by Gerasimov and Sokolov [23] concluded that motor-manual tree-length harvesting performed with cable skidders showed the worst results in terms of ergonomics. Likewise, de Oliveira et al. [24] assessed the skidder visibility and illumination as poor and non-compliant, respectively.

Pre-harvesting operations and tools are next in order of appearance regarding a number of records. These operations still require motor-manual or even manual tools involving a high proportion of manual labor [71]. Logically, these operations are subjected to substantial risk factors such as postural load [52], workload [72], noise [3], and vibration [10] and the forestry research community took an interest in them, especially in Brazil, Canada, and Indonesia (Figures A1 and A2).

Forwarders, harvesters, and farm tractors make up a bulk of the machines used in partially or fully mechanized harvesting systems. While forwarders and harvesters are considered the pinnacle of fully mechanized harvesting systems [73,74], mechanized harvesting of wood carried out by cut-to-length processing can present ergonomic risks, causing the emergence of occupational diseases [4]. It is considered an unhealthy environment that exposes operators to physical and psychological disorders [19,75]. Farm tractors are still used in forestry as a platform for core forest operations such as winching, forwarding, loading, or even harvesting [76,77]. Their application is mostly tied to agroforestry and small-scale forestry [78]. Nevertheless, risk factors such as workload during winching [79], noise [80], MSD occurrence [81], and postural load [82] are present.

The ergonomic assessment of feller bunchers, according to this review, is geographically mostly tied to North and South America (Figure A2), where they are used the most [83,84] but not exclusively [85,86]. Risk factors that occurred in their application consist of noise [5,6,87], vibration [88], postural load [53,82], and MSD occurrence [89].

Manual work and tools are generally tied to measuring and managing operations in forestry [13,16,59,90] where workload and postural load were assessed. They are also involved in pre-harvesting and harvesting [15], e.g., postural load during manual cultivation and assistance with a wooden stick to help direct the felling; and wood extraction [15,48], e.g., MSD occurrence and workload while sorting small logs and manual loading, respectively.

Ergonomic assessment of biomass production is mostly present in chipping [91–93] where noise and vibration are the main concerns. Articles regarding wood transport include only timber trucks as a means of transportation and assess vibration [94], MSD occurrence [19], postural load [95], and noise [87]. Research of risk factors in controlled tests include vibration [96,97] and workload [98].

Somewhat in line with a previous study [26], records of five risk factors stand out: workload, noise, vibration, postural load, and MSD occurrence. Forest work is, and will remain, labor intensive. Technological development allowed a transition from manual work systems to motor-manual and fully mechanized systems. This was beneficial for improving safety and health at work [99–101]. However, with the shift of technologies, some risk factors only changed their point of influence and remained relevant, some were completely minimized, and new ones emerged. Substitution of a motor-manual system with a fully mechanized one shifts the workload from physical to mental and vibration from hand–arm to whole body. Postural load and MSD occurrence, although present in fully mechanized systems, pose a greater threat during motor-manual pre-harvesting and harvesting. Even though noise exposure is easily controllable [26], according to this review, noise is still a present risk factor in forest operations.

5. Conclusions

The main conclusions can be reduced to several points:

- The number of articles is ever-increasing with the last four years having an above average number of articles (12). An increase is also observed cumulatively compared to a previous study [26], from 76 to 102 articles.
- Countries from Europe and South America (Brazil) have the most publications at 57 and 27, respectively.
- Most of the journals are ranked in the top 50%, while Brazil—a country with the highest number of articles—was mostly (19 out of 27) publishing in domestic journals.
- Harvesting (44%), wood extraction (27%), and pre-harvesting (13%) operations have the highest percentage of records.

- Chainsaw, skidder, and pre-harvesting tools are the most observed means of work with 24%, 11%, and 11% of records, respectively.
- The risk factors with the highest percentage of records are workload (23%), noise (20%), vibration (20%), postural load (16%), and MSD occurrence (7%).

Furthermore, this review can give insight into the current state of forestry-ergonomics-related articles in JIF journals. Forestry ergonomics, being somewhat of a marginal topic, ironically, is most certainly a field with a high potential for new scientific discoveries.

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Data Availability Statement: Data supporting this study can be found in Appendices A and B.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Operation	Austria	Brazil	Canada	Croatia	Czech Republic	Finland	Germany	Greece	Indonesia	Iran	Italy	Japan	New Zealand	Poland	Portugal	Romania	Russia	Serbia	Slovakia	Slovenia	South Africa	South Korea	Sweden	Türkiye	USA
Pre-harvesting		6	3	1			1		2					1		1						1			1
Harvesting	1	16		4	3		1	1	2	3	5		1	5	1	5	1		2	2			1	1	1
Wood extraction		13			1		1	1	1	1	4		1	1	1	1	1	1		1	1		2	1	1
Wood transport							1		1			1												1	1
Biomass production						1		1			3									1				1	
Measuring/managing		1										1		1		1									
Controlled tests			3																	1					

Figure A1. Number of records in operation category per country (warmer colors indicate higher number).

Machine/tool	Austria	Brazil	Canada	Croatia	Czech Republic	Finland	Germany	Greece	Indonesia	Iran	Italy	Japan	New Zealand	Poland	Portugal	Romania	Russia	Serbia	Slovakia	Slovenia	South Africa	South Korea	Sweden	Türkiye	USA
Pre-harvesting tools		6	3	1			1		2					1								1			1
Manual work/tools		1								1		1		2		2				1				1	
Chainsaw	1	5		5	2		1	1	2	3	3		1	4	1	4	1		1	1				1	
Harvester		6			1						2			1			1		1	1			1		
Feller buncher		7															1								1
Processor		2											1			1	1								1
Farm tractor		3						1	1		3			1		1		1						1	
Crawler tractor		1																							1
Slash grapple		1																							
Skidder		8	2				1		1	1					1	1	1								1
Forwarder		5			1												1			1	1		3		
Tower yarder											1														
Loader		2											1		1									1	
Animal								1																	
Timber truck							1		1			1												1	1
Chipper						1					1									1					
Debarker											1														
Fire wood processor											1														

Figure A2. Number of records in machine/tool category per country (warmer colors indicate higher number).

Risk factor	Austria	Brazil	Canada	Croatia	Czech Republic	Finland	Germany	Greece	Indonesia	Iran	Italy	Japan	New Zealand	Poland	Portugal	Romania	Russia	Serbia	Slovakia	Slovenia	South Africa	South Korea	Sweden	Türkiye	USA
Vibration		9	2	3	2	1	2			1	4					2	1			2			2		
Noise		11				1	1		1		4			1	1	5	1	1		3					1
Workload	1	6	3		1		2			2	6	1		5		3	1		1	1		1	1	1	
Postural load		11		1			1		2		2			1		3	1						1	1	1
MSD		2		1	1			1	1	1				2		1					1				
Thermal comfort		3														1									
Fatigue										1		1	1												
Human factors		1																	1						
Gases and particulates		1							1							2									
Repetitive motion		4																							
Ilumunation		1																							
Visibility		1															1								
Cab																	1								
Controls																	1								
Seat																	1								

Figure A3. Number of records in risk factor category per country (warmer colors indicate higher number).

Appendix B

Table A1. List of authors whose articles were used in the analysis.

Authors and Reference Numbers in Chronological Order (Left to Right)			
Nuutinen et al., 2014 [91]	Leszczyński and Stańczykiewicz 2014 [102]	Gerasimov and Sokolov 2014 [23]	Sasaki et al., 2014 [103]
Britto et al., 2014 [104]	Oliveira et al., 2014 [71]	Barbosa et al., 2014 [105]	Silva et al., 2014 [89]
Leszczyński and Stańczykiewicz 2015 [106]	Spinelli et al., 2015 [79]	Almeida et al., 2015 [88]	Yovi and Prajawati 2015 [107]
Dubé et al., 2015 [98]	Ji et al., 2015 [96]	Fonseca et al., 2015 [108]	Poje et al., 2015 [92]
Souza et al., 2015 [109]	Minette et al., 2015 [110]	Huber and Stampfer 2015 [111]	Grzywiński 2015 [112]
Britto et al., 2015 [66]	Poje et al., 2016 [80]	Magagnotti et al., 2016 [113]	Grzywinski et al., 2016 [56]
Dubé et al., 2016 [114]	Ottaviani Aalmo et al., 2016 [76]	Häggström et al., 2016 [29]	Phairah et al., 2016 [60]
Schettino et al., 2016 [59]	Marzano et al., 2017 [115]	Spinelli et al., 2017 [116]	Ji et al., 2017 [97]
Schettino et al., 2017 [82]	Brokmeier 2017 [94]	Poje et al., 2018 [93]	Spinelli et al., 2018 [117]
Granzow et al., 2018 [118]	Cheţa et al., 2018 [119]	Tomczak et al., 2018 [18]	Neri et al., 2018 [120]
Poje et al., 2018 [121]	Billo et al., 2019 [31]	Yovi and Yamada 2019 [19]	Enez and Nalbantoğlu 2019 [95]

Table A1. *Cont.*

Authors and Reference Numbers in Chronological Order (Left to Right)			
Bowen et al., 2019 [64]	Borz et al., 2019 [32]	Poje et al., 2019 [34]	Lopes et al., 2019 [52]
Bligård and Häggström 2019 [122]	Paini et al., 2019 [53]	Grzywinski et al., 2019 [90]	Oliveira et al., 2020 [24]
Santos et al., 2020 [63]	Stenlund et al., 2020 [54]	Spinelli et al., 2020 [46]	Martins et al., 2020 [8]
Szewczyk et al., 2020 [47]	Arab et al., 2020 [72]	Dimou et al., 2020 [81]	Iftime et al., 2020 [62]
Berendt et al., 2020 [123]	Naskrent et al., 2020 [3]	Landekić et al., 2020 [37]	Paini et al., 2020 [124]
Martins et al., 2020 [125]	McLain et al., 2021 [87]	Oliveira-Nascimento et al., 2021 [42]	Schönauer et al., 2021 [44]
Veiga et al., 2021 [33]	Arman et al., 2021 [43]	Zurita Vintimilla et al., 2021 [126]	Szewczyk et al., 2021 [127]
Camargo et al., 2021 [4]	Yovi et al., 2021 [128]	Çağlar 2021 [129]	Borz et al., 2021 [15]
Huber et al., 2021 [35]	Iftime et al., 2022 [61]	Pajek et al., 2022 [49]	Camargo et al., 2022 [5]
Arman et al., 2022 [48]	Lee et al., 2022 [45]	Staněk and Mergl 2022 [130]	Gejdoš et al., 2022 [131]
Camargo et al., 2022 [6]	Hnilica et al., 2022 [132]	Camargo et al., 2022 [7]	Papandrea et al., 2022 [38]
Borz et al., 2022 [16]	Landekić et al., 2023 [17]	Landekić et al., 2023 [57]	Staněk et al., 2023 [9]
Bačić et al., 2023 [10]	Feyzi et al., 2023 [11]	Ottaviani Aalmo et al., 2023 [12]	Neri et al., 2023 [36]
Bačić et al., 2023 [133]	Okuda et al., 2023 [13]	Sláma et al., 2023 [14]	Lima et al., 2023 [134]
Staněk et al., 2023 [58]	Nakata et al., 2023 [65]		

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