Subject review

Forestry Ergonomics and Occupational Safety in High Ranking Scientific Journals from 2005–2016

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Abstract

The occupational safety and health change through time due to technological and social development. It is an obligation of scientific research to impartially and critically examine these changes and propose measures to reduce negative impacts on people. Since the forestry as an industry sector follows general changes, we tried to establish the situation in the field of occupational safety and health in forestry by reviewing the studies in the period 2005–2016. The review included studies, the results of which have been published particularly in scientific journals relating to the field of forestry and ergonomics with an impact factor. The findings show that the number of published articles in the field of occupational safety and health and ergonomics increases. Studies were mostly limited to only three continents, namely Europe and North and South America, and 26 countries in total. The majority of research was conducted in Canada, Brazil and Sweden. The largest number of research relates to traditional technologies of harvesting (chainsaw and skidder), whereas the Nordic states prevail in terms of modern, mechanized technologies. The study shows that international and intercontinental cooperation of researchers must be further stimulated in the field of research and education. It has been identified that there is a lack of studies addressing the issue of biomass production, forest road and skid trail construction, and some new technologies. There is a deficiency of cognitive studies, studies of workers' burnout and comprehensive studies of ergonomics and productivity in the field of ergonomics. The uniform statistics of recording accidents will provide the research to be conducted in all forestry operations and enable the preparation of efficient preventive measures.

Keywords: forestry, ergonomics, safety, review

1. Introduction

The aim of each society and individual must be to preserve work as a basic right and need of every human being, as through work men achieve fulfillment at a personal and social level. However, the work should have no negative impacts on workers' health and it should provide them a dignified life in old age. Within this context, the ergonomics as a science and a profession adjusts work to workers so as to reduce difficulty and harmfulness of work by providing adequate work efficiency, which is reflected in a reduced level of illnesses or injuries at work. Thus, a commitment of the ergonomics society is to provide ergonomic knowledge and tools in a form useful for decision-makers who require assistance (Brewer and Hsiang 2002).

Regardless of introducing modern methods of harvesting and production, the forest work is considered one of the most dangerous industrial activities with a high share of lethal accidents and injuries (EU-OSHA 2008, Adams et al. 2014). Due to natural environment, heavy loads and frequent use of manual tools and machines, workers are exposed to physical, physiological and environmental factors that result in various illnesses, related in particular to muscles, skeleton, nerves and vascular system and impairment of hearing (Gallis 2006, Bovenzi 2008, Fonseca et al. 2015). With the development of mechanical harvesting, the work transferred from outdoors to a cabin thus reducing physical difficulty of work and exposure to most environmental risk factors. An increased human/machine interaction (Burman and Löfgren 2007) and the change of work from »doing to thinking« (Hollnagel and Woods 2005) caused the focal points of accident to change (Axelsson 1998) and new injuries (Repetitive strain injuries – Axelsson and Pontén 1990) as well as new, cognitive risk factors to occur. As a consequence, it appears that, in mechanical harvesting, the traditional ergonomic paradigm »less is better« should be replaced by »more can be better«, since reduced physical activity also has harmful impacts on health (Straker and Mathiassen 2009). To comprehensively improve the situation of occupational safety and health in the field of forestry, the rooted culture of »can do« must be replaced by »can do safely«, which requires changes in the entire chain of wood production (Adams et al. 2014).

Notwithstanding the mechanized wood production expanding to the fields where the work was executed in a traditional way, e.g. using chainsaw and cable skidder, traditional harvesting technologies remain applicable in difficult working conditions (e.g. co-natural, mostly deciduous forests) and private small-scale forests. Work technology used, out-of-date work equipment, non-use of personal protection equipment and lack of knowledge and experience cause poorer occupational safety and health of private forest owners than is the case with professional workers (EU-OSHA 2008).

Constant social and technological changes have also an impact on forest use and importance of its functions, i.e. on forest production and consequently occupational safety and health. For this reason, the aim of this study is to analyze ergonomics and occupational safety in the field of forestry in the past twelve years and in particular identify the focal points of research in terms of technology, risk factors and characteristic fields. On the basis of the results, potential deficiencies/uncovered fields of the previous research were defined and guidelines for further research given.

2. Methods

The study addressed the period from 2005 to December 2016. It included journals in the field of forestry and ergonomics from the Web of Science collection, which had an impact factor (Fig. 1). According to our experience and the purpose and content of the journals, the review additionally included two journals, one in the field of forestry (International Journal of Forest Engineering) and one in the field of occupational safety (Safety Science). To select articles from journals, the key words »ergonomics« and »safety« were used for forestry journals, while in other journals the word »forestry« was applied. It was additionally required that studies be partially or entirely conducted in the field of forestry, forest workers, forest machines or tools. The review thus excluded marginal fields of forestry, e.g. arboriculture and fire protection, and the works not performed in forests (e.g. ornamental nursery). After examining titles and abstracts, the final selection included 136 full-text articles, i.e. 76 in the field of ergonomics and 60 in the field of occupational safety.

The ergonomics articles were then classified according to their contents and risk factors in 16 fields, which are defined in the European ergonomic and safety guidelines for forest machines (ErgoWood 2006) and 8 additional fields. In terms of the latter, the field »Independent data« needs to be highlighted. It included articles that used ergonomic indicators only as basic data for other purposes, e.g. establishing the impact of piece rate wages on health and safety (Johansson et al. 2010) or similarity of processes (Leszczyński 2010).

In addition to articles directly addressing a specific factor, the articles with an indirect impact on the level of workers' exposure were also included in the classification. Thus, for example, coupling forces exerted by fellers during wood harvesting (Malinowska-

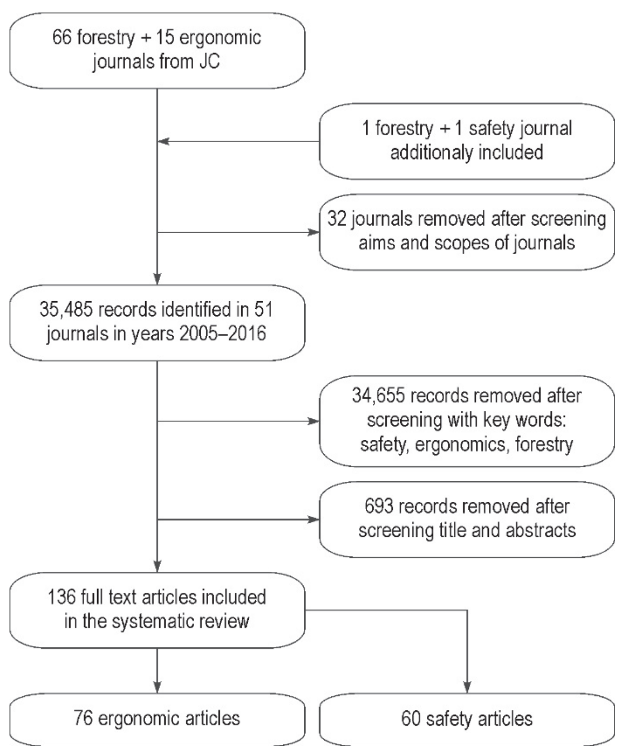

Fig. 1 Flow diagram of articles selection

Borowska et al. 2011) or characteristics of a seat (Ji et al. 2015) were included in »Vibrations«. If a study dealt with several fields, the article was also classified in several fields.

Similar to ergonomics articles, the articles relating to occupational safety were divided according to their content into 5 fields. A special field »Integrated safety« included articles where the results of research directly affected the level of occupational safety and health. Thus, for example, this field included articles where tools and methods of directional felling were developed (Noll and Lyons 2010) or which established the suitability of mobile anchors in cable skidding (Leshchinsky et al. 2016).

All articles were additionally divided according to the year of publication, countries and continents where the research has been conducted. If the location was not clear from the article, it was attributed to the country of the first author of research. In a similar way, all articles were also divided according to the respective technology or phase of work within the technological process of forest exploitation. Under the selected technology or phase of work, articles dealing with tools, accessories or working methods of the selected technology or phase of work were also included. For example, under the section »Chainsaw«, in addition to articles that measured the exposure of work with a chainsaw (e.g. Horvat et al. 2005), the articles that addressed the issue of antivibration gloves (e.g. Goglia et al. 2008b), coupling forces exerted by fellers (Malinowska-Borowska et al. 2011) or the impact of using forestry equipment on hearing loss (Fonseca et al. 2015) were also included. If several technologies were included in a study, the article was also classified in several technologies.

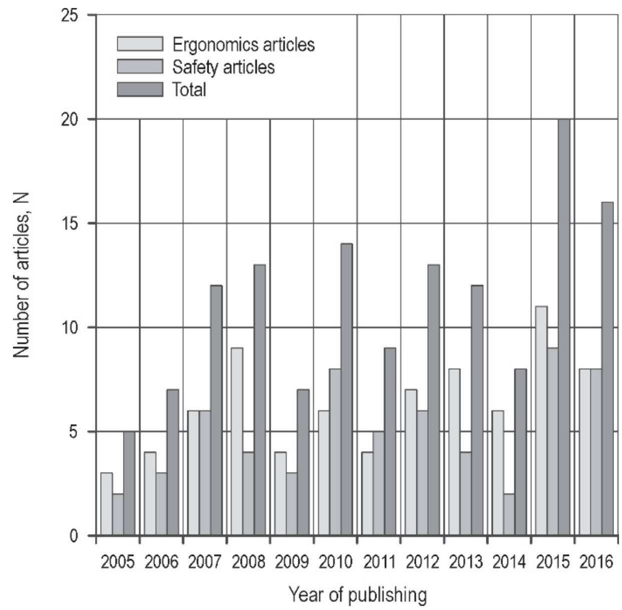

Fig. 2 Number of articles published in the period 2005–2016

3. Results

3.1 Temporal and spatial dynamics of publishing

The number of articles related to safety and ergonomics gradually increased in the analyzed period (Fig. 2). If we include this article, which will be published in March 2017, in 2016, the average number of articles published in the last six years increased by 34% (from 9.6 to 13.0 articles). Two thirds of all articles were published in forestry journals.

Ergonomics researches included 18 countries on five continents (Fig. 3). The vast majority of researches (95%) were conducted on three continents, i.e. Europe (58%), South America (20%) and North America (17%). The largest number of studies according to individual countries was conducted in Brazil (15) and Canada (11). Sweden, Croatia, Italy and Austria, with more than 6 studies, stand out in Europe in terms of the number of studies.

Compared to ergonomics research, the studies related to safety were more widespread, since they were conducted on seven continents and in 20 countries (Fig. 3). In this case as well, approximately 75 % were performed in Europe (50%), and North America (27%), i.e. most of them in the USA, Canada and Sweden.

3.2 Technologies and risk factors

The largest share of ergonomics articles (Fig. 4) addressed harvesting (35%) and skidding (38%) technology, followed by planting, care and protection of forests (pre-harvesting operations, 12%), while the smallest share dealt with biomass production technology (6%) and transport (1%). In terms of individual machines, the articles mostly analyzed the work with chainsaw, skidders and agricultural tractors, and forwarders and harvesters, which in total represents 59% of all forestry machines included in the articles. In terms of technology, the fully mechanized cut-to-length (CTL – harvester + forwarder) and whole-tree (WT – feller buncher + grapple skidder) harvesting technologies were addressed in 24% or 13% of articles, respectively.

The results (Fig. 4) also show differences in technologies considered according to continents. Thus, for example, studies of harvesting with chainsaw and skidding with skidders occur on all five continents, studies of technologies used in pre-harvesting operations only

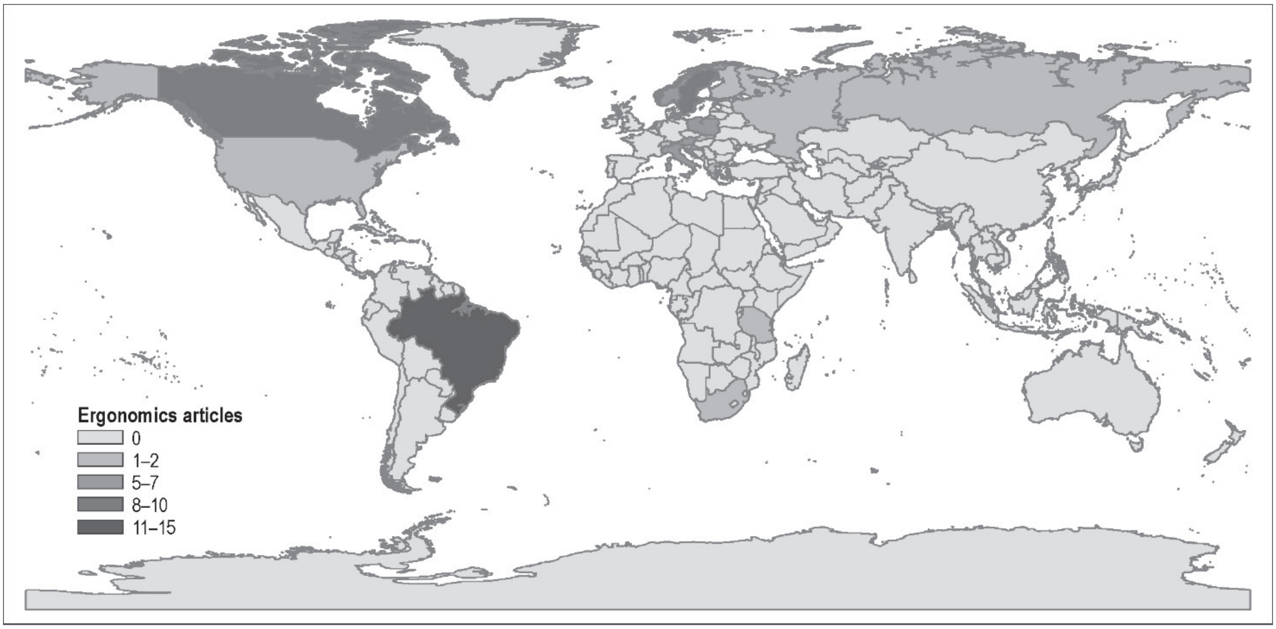

Fig. 3 Number of forestry ergonomics (up) and safety (down) articles published in journals with impact factor per world countries in the period 2005–2016

in North and South America, while the majority of studies of CTL technology (69%) and cable skidding (67%) were conducted in Europe. There are also large differences within European countries. Thus, for example, the studies of CTL technologies (83%) prevail in the Nordic countries, while the studies of work with chainsaw (100%) and skidding with skidders are more prevalent in other nine European countries.

In the analyzed period, more than a half (51%) of safety-related studies addressed the general situation of occupational health in the field of forestry, in forestry as an industrial activity, in individual companies or in the work of forest workers (Fig. 5). In terms of the number, felling with the chain saw (25%) stands out among individual forestry operations. Two most frequently represented fields of research are present on seven and five continents, respectively. Except for wood transport, studies of all other operations took place in Europe.

From the analysis of articles according to risk factors, it is established (Fig. 6) that more studies ad-

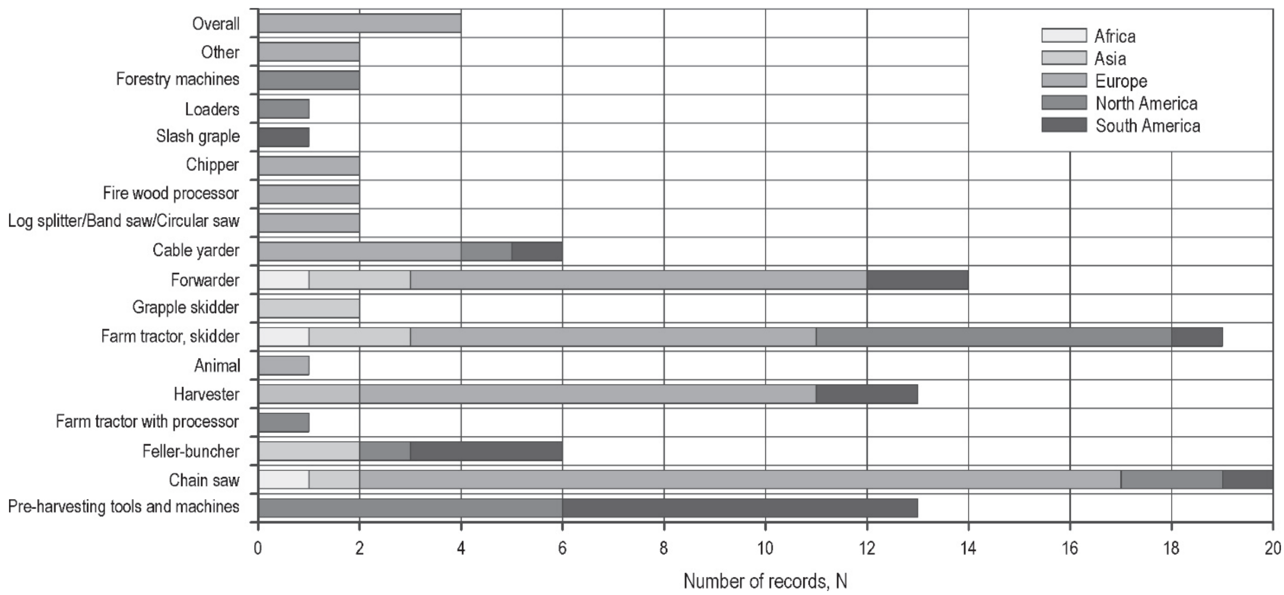

Fig. 4 Representation of forestry machines in ergonomics articles published in journals with impact factor per continents in the period 2005–2016

dressed physical and physiological risk factors, which limit the use of technologies due to unsuitable dimensions and physiological fitness of workers, than environmental risk factors (29%), such as noise, vibrations, etc. In terms of individual risk factors included in the studies, three stand out most prominently: vibrations, cardiovascular load and working positions, which together represent more than a half (51%) of all studied factors. However, no study included four risk factors referring to manuals and instructions, maintenance, maintenance index and biological agents.

Differences in individual risk factors are also evident in the classification according to continents. Thus, for example, most studies of physical risk factors were conducted in South America, where physical characteristics of workers were compared with dimensions of machines, establishing spine load through body positions and psychophysical workload of workers.

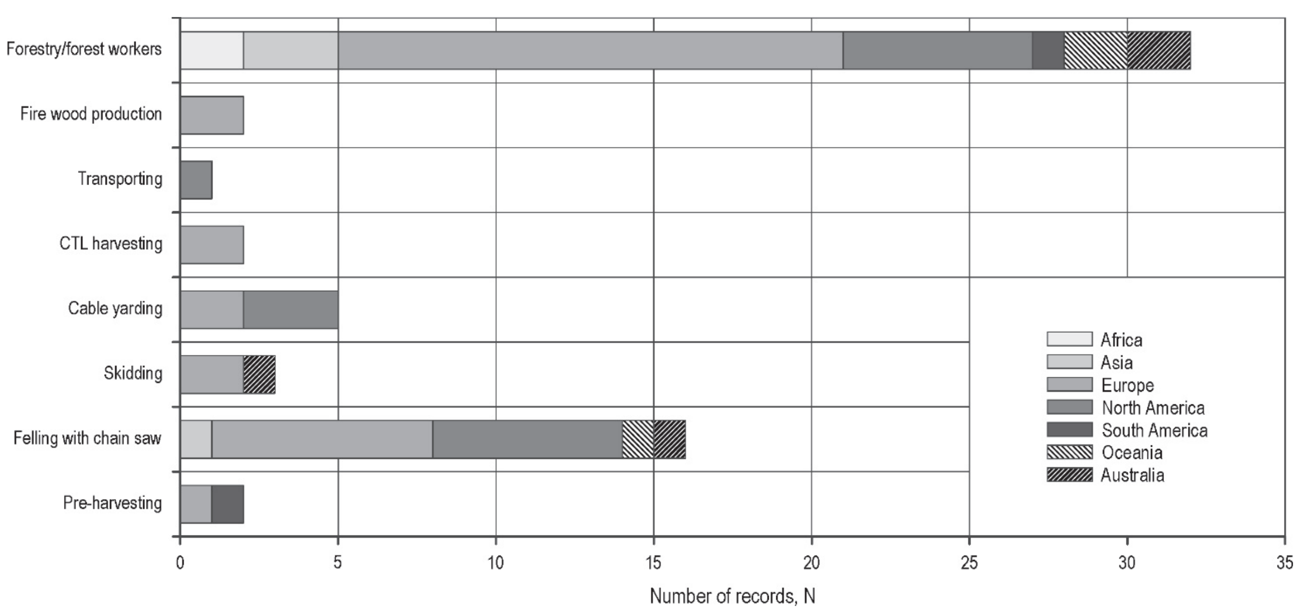

Fig. 5 Representation of forestry operations in safety articles published in journals with impact factor per continents in the period 2005–2016

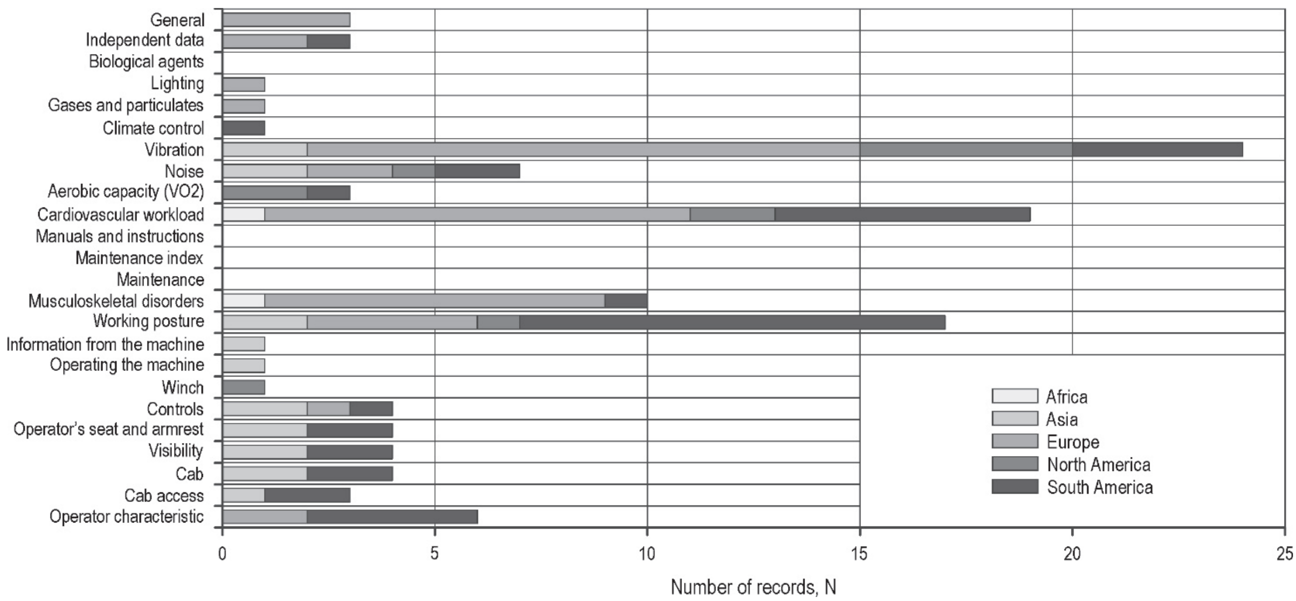

Fig. 6 Representation of risk factors in ergonomics articles published in journals with impact factor per continents in the period 2005–2016

On the contrary, the majority of studies in Europe addressed environmental factors, while in terms of individual factors, the studies of vibrations, cardiovascular load and musculoskeletal disorders prevailed.

The studies of most frequently addressed risk factors are distributed differently according to technologies. Thus, the studies relating to musculoskeletal disorders were most frequently established in connection with the CTL harvesting technology, while the studies of loads due to vibrations and mental and physical load were most frequently established in relation to traditional wood production (chainsaw + skidders).

In terms of occupational safety, the largest number of studies dealt with the prevention of accidents at work, since the studies of preventive measures and integrated safety present almost a half (48%) of all studies. In terms of their scope, only the studies in Europe and North America cover all five fields considered (Fig. 7). Except for the CTL harvesting technology,

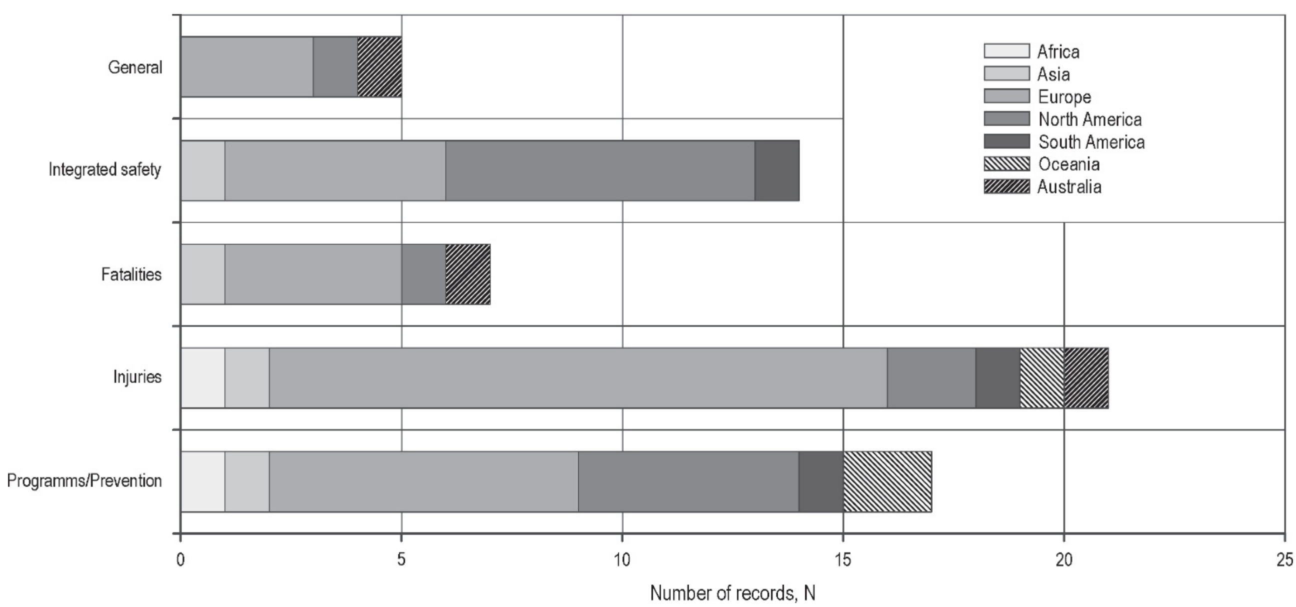

Fig. 7 Representation of risk factors in safety articles published in journals with impact factor per continents in the period 2005–2016

accidents at work were analyzed in all operations, while the studies of lethal accidents were only included in general forestry studies.

3.3 Overview of main study results by forest operations

3.3.1 General

3.3.1.1 Ergonomics

Previous studies have established that the number of ergonomics studies in certain fields, such as skidding with cable cranes, is increasing (Cavalli 2012). This can result from an increasingly wider scope of studies dealing with wood production that reflects the sensitivity of the modern society to the sustainability of human and environmental resources (Košir et al. 2015). In this context, the establishment of ergonomic suitability of work may be the main or side product of broader research. According to previous research, the forestry ergonomics will have to face the challenges, e.g. dissemination of the existing knowledge of classic ergonomics, adjustments of standards to specific local conditions and workers, development of cognitive ergonomics, adjustments of organization of work and people to (exceedingly) fast developing technologies and production processes (Heinimann 2007).

Ergonomics risk factors may also occur in research as impact factors. Thus, by using environmental risk factors and unfavorable body postures, the needed reduction of norms in harvesting was established (de Souza et al. 2015). Similarly, in addition to productivity factors, ergonomics factors in harvesting were used to estimate the benefits of four working operations (Leszczyñski 2010). The work ability index is negatively related to some physical characteristics of a worker, i.e. age and weight, and work experience (Landekić et al. 2013).

3.3.1.2 Safety

In the world of high technological development and internationalization of forestry companies, it is a common concern to provide a healthy, safe and physically acceptable work for all (Rickards 2008).

The frequency of all lethal accidents and lethal accidents of young workers in the industrial sector of agriculture, forestry and fishing is often higher than in other sectors (Cohen et al. 2006, Ehsani et al. 2013). With the rate of 63 accidents/100,000 employees, it may represent 10% of all accidents (Suchomel et al. 2013). The same applies to non-lethal accidents, where the frequency of accidents in individual countries may reach the rate of 98.5 accidents/1000 employees (Suchomel et al. 2013).

The frequency of accidents in forestry companies, with rates between 14.8 and 97.0 accidents/1000 employees or 54.2 accidents/million cubic meters of wood, is often higher than in other sectors (Landekić 2010, Grzywiński et al. 2013, Tsioras et al. 2014, Laschi et al. 2016). The severity of accidents ranged between 18.2 and 48.6 days/accident (Grzywiński et al. 2013, Tsioras et al. 2014, Laschi et al. 2016) and was higher in simultaneous injuries of several body parts (Tsioras et al. 2014) and in older workers (Laschi et al. 2016). The number of lethal accidents of professional forest workers is decreasing and it is even five-times lower than that of non-professionals. The frequency of lethal accidents is the lowest in the Nordic countries, while the highest rate may even reach up to 9.5 accidents/million cubic meters of timber (Klun and Medved 2007).

The largest number of accidents of forest workers occurs at the beginning of a working week, supposedly due to lower attention of workers (Tsioras et al. 2011, Laschi et al. 2016). Regarding the parts of the body, the injuries of arms and legs are the most frequent, falls prevail in terms of causes, while contusions represent the most frequent type of injuries (Potočnik et al. 2009, Tsioras et al. 2011, Grzywiński et al. 2013, Enez et al. 2014, Tsioras et al. 2014, Laschi et al. 2016). The probability of accidents is increasing with the use of chainsaw, hookaroon, number of breaks during work, workday duration (Enez et al. 2014), while the risk also increases due to weather conditions, e.g. rain (Suchomel and Belanová 2009).

In addition to insufficient education and training of workers, the causes, such as disturbances of biological rhythm, increased difficulty of work due to changes in patterns of working time, quick shifting of workplaces, language barriers, job insecurity, occupational stress, works with sub-contractors, deterioration of general welfare of workers, have negative impacts on workers' health and may result in accidents (Papadopoulos et al. 2010, Mylek and Schirmer 2015). Personal and organizational factors are most important causes of lethal accidents in harvesting, while the following causes are the most important individual factors: positioning in danger zones, carelessness, inappropriate behavior and unsuitable selection of workers (Melemez 2015).

The frequency of accidents can be reduced by implementing programs, such as Forest Protection program (e.g. Sustainable Forestry Initiative, Chapman and Husberg 2008), indirectly with the system for environmental management – ISO 14001 (Ackerknecht et al. 2005), proper corporate risk management (Albizu-Urionabarrenetxea et al. 2013) and certification of contractors (Martinić et al. 2011). The frequency of accidents may be reduced with an unconditional commitment to the safety culture at all organizational levels. The safety culture may be enforced through proper education, vocational training, selection of workers and sufficient motivation (Martinić et al. 2007, Albizu Urionabarrenetxea et al. 2010, Tsioras 2010, Melemez 2015). Education and training must be designed to be sufficiently extensive (Tsioras 2012), adjusted to the characteristics of individual groups of workers (Poje et al. 2016) and must primarily reduce the risk of accidents – and then prevent the occurrence of chronic diseases (Montorselli et al. 2010). A special attention must be paid to workers who suffered several injuries, since the cause may lay in recidivism or repeated violations of safe work procedures (Laschi et al. 2016). Since the work in forests is often performed in groups, special focus must be placed on the selection of group members and methods of introducing new members (Burt et al. 2008, Burt et al. 2009).

The data on accidents collected through general forms are usually not useful to design preventive measures (Bentley et al. 2005, Robert et al. 2015), and should therefore be adjusted to individual fields and workplaces (Cohen et al. 2006, Poje et al. 2016). Underreporting (Papadopoulos et al. 2010) and presenteeism (Wilmsen et al. 2015) also affect the statistics of accidents.

3.3.2 Pre-harvesting operations

3.3.2.1 Ergonomics

The majority of ergonomics studies relating to planting, care and protection of forests addressed physical and physiological risk factors. Thus, the loads on lumbar spine due to unfavorable body postures exceed permissible values in transporting saplings (Alves et al. 2006), fertilization and planting (Da Silva et al. 2007, Silva et al. 2008, Vosniak et al. 2010, De Britto et al. 2014), and manual mowing (de Oliveira et al. 2014). The loads on wrists in planting also pose a potential risk of musculoskeletal disorders and repetitive strain injuries (Da Silva et al. 2007, Denbeigh et al. 2013). Cardiovascular loads exceed permissible values (40%) in manual mowing (de Oliveira et al. 2014), brush cutting (Toupin et al. 2007), planting (Da Silva et al. 2007, Silva et al. 2008), weeding with knapsack sprayers (Sasaki et al. 2014) and manual pruning (Nutto et al. 2013). Contrary to the expected, more demanding working conditions in brush cutting reduce cardiovascular loads. This means that workers with piece rate wages compensate their loss of income in more favorable working conditions (Toupin et al. 2007). Since, according to the majority of the previous research, the piece rate payment has a negative impact on occupational safety and health (Johansson et al. 2010), a changed, variable method of payment for work (Toupin et al. 2007) is proposed to reduce the impact of more difficult working conditions on psychophysical workload. The second, general measure reducing the exposure of workers to other risk factors is balancing the difficulty of work with active breaks (Gallis 2013).

Two studies addressing the issue of oxygen consumption, maximum aerobic capacity and heart rate of workers in planting and brush cutting are also very significant for further research. The studies established that oxygen consumption and maximum aerobic capacity can be established precisely enough by measuring heart rate and relations between oxygen consumption and heart rate established in laboratory. This means that there is no need to measure oxygen consumption on-site (Dubé et al. 2015). However, to obtain the right estimation of oxygen consumption, the thermal component must be eliminated from the heart rate (Dubé et al. 2016).

Environmental factors were studied only in using various knapsack sprayers for weeding, pest management or combating diseases (Sasaki et al. 2014). The study thus established that some types of knapsack sprayers exceed permitted thresholds of exposure to noise and whole body vibrations (WBV), and that their operation is very demanding in terms of energy consumption.

3.3.2.2 Safety

The study addressing the machine stability (tractor-subsoiler) for soil preparation established that the maximum transverse slope of terrain must not exceed 23.7^0 (Pereira et al. 2011). During pre-harvesting operations, the frequency and severity of accidents is significantly lower than during harvesting and skidding (Potočnik et al. 2009).

3.3.3 Harvesting

3.3.3.1 Ergonomics

Contrary to pre-harvesting operations, the share of the studies of harvesting with chainsaw addressing physical and physiological risk factors was lower than the share of environmental risk factors. Thus, unfavorable body postures detrimental to health during harvesting with chainsaw (Barbosa et al. 2014) result in musculoskeletal disorders that mostly affect lower back, arms and wrists. The share of fellers with disorders increases with their age and working experience (Grzywiński et al. 2016).

Cardiovascular loads in working with manual saw or chainsaw heavily exceed the permitted values (40%)

and increase with the work productivity (Silayo et al. 2010). The loads on fellers are higher during work in younger than in older stands, and higher when working with a processor than with a skidder (Leszczyński and Stańczykiewicz 2015).

The firmness of grip of the chainsaw handle, affecting the transfer of HA vibrations, depends on worker's experience, work operations and wood hardness. Thus, coupling forces exerted by fellers are higher with less experienced workers, they are higher in felling and cross-cutting than in limbing, and higher with tree species of higher wood hardness (Malinowska-Borowska et al. 2011, Malinowska-Borowska et al. 2012, Malinowska-Borowska and Zieliński 2013).

When working with chainsaw in regeneration stands, loads on hands and arms caused by vibrations (HAV) exceeded the action value of daily exposures (Goglia et al. 2012a) defined in the European and, due to harmonization, also national legislations of the European countries (Goglia et al. 2012b). The HAV exposures, when using Kasper safety bar, are not different compared to the use of conventional bar (Rottensteiner and Stampfer 2013). However, HAV differs between tree species and is higher with tree species of higher wood density (Rottensteiner et al. 2012). One of the possible measures to reduce the harmful effect of HAV on workers is the use of anti-vibration gloves, which must comply with international standards (Goglia et al. 2008a). The studies show that there are significant differences between the types of anti-vibration gloves in terms of their insulation effectiveness (Goglia et al. 2008b).

High exposures of fellers to noise cause hearing impairments, in particular if the personal protection equipment is not used (Fonseca et al. 2015). On the contrary, the exposure of fellers to fir wood dust (1.29 mg/m^3) does not exceed limit values of daily exposure (Horvat et al. 2005).

Dimensions of machines must be adjusted to physical characteristics of an operator to provide a safe and healthy work. Thus, the largest deficiency in mechanized harvesting with feller-bunchers is its limited possibility of adjusting the seat, cab access, controls and working postures (Fernandes et al. 2009, Fernandes et al. 2011). In addition to physical risk factors in mechanized harvesting with feller-bunchers, the WBV loads also significantly exceed the action value of daily exposure (Almeida et al. 2015).

A long-term exposure of operators of mobile forestry machines to WBV increases the risk of musculoskeletal disorders and reduces work productivity (Jack and Oliver 2008, Village et al. 2012). Thus, the consequences of a relatively safe work with harvesters are manifested in musculoskeletal and nerve disorders. Pains most often occur in the area of the neck, lower back and shoulders (Hanse and Winkel 2008, Rehn et al. 2009, Silva et al. 2014). Neck pains may thus occur due to long periods of static muscle operation at low intensity and short time of muscle rest (Østensvik et al. 2008a, Østensvik et al. 2009). The occurrence of musculoskeletal disorders depends on the organization of work (Østensvik et al. 2008b). It decreases with the level of work control and job rotation (Hanse and Winkel 2008), while it increases with the duration of employment in the forestry sector (Silva et al. 2014). The negative impact of exposure to WBV on the occurrence of musculoskeletal disorders in mechanized CTL harvesting and skidding was not proved (Rehn et al. 2009).

High incidence of musculoskeletal disorders of harvester operators and other operators intensely engaged in operating machines and cranes requires an ergonomic optimization of the levers. Thus, the results show that by using levers with short handles and when working at a higher gain, the efficiency of work increases, while the physical load decreases or remains the same as when using levers with long handles (Huysmans et al. 2006).

The study of cognitive abilities of harvester operators, which is also the only study in this field included in the research, showed that the following characteristics of an operator are needed for a skilful and productive work: comprehensive perception, wide use of memory functions, non-verbal deduction, spatial perception, coordination, concentration and motivation. In terms of work efficiency, none of the aforementioned abilities is superior; it is only important to have these abilities (Ovaskainen and Heikkilä 2007). Information collected in the eye-tracking study (Häggström et al. 2015) is among the most important data to provide an efficient machine management, possibility to automate procedures and develop decision support systems.

Since the work with harvesters and forwarders is often done also at night and under artificial light, it is recommended to use xenon lights which, compared to halogen lights, have a higher colour temperature and thus improve peripheral vision. Xenon lights are also more energy efficient, since one 35W xenon light provides the same illumination as do three 70W halogen lights (Poom et al. 2007).

Exposure of harvester operators to noise is lower than in wood extracting with forwarders and does not exceed low action values of daily exposure (Messingerová et al. 2005).

3.3.3.2 Safety

During harvesting, accidents most often occur when felling trees (Laschi et al. 2016), the main reason being an interaction with parts of trees (Potočnik et al. 2009). The risk of accident is also different for different methods of felling. Thus, for example, the felling of individual trees poses a higher risk than clear-felling (Neyland et al. 2012). The risk of accident of professional workers is due to their underestimating the danger and a higher tempo of work during regular felling than during salvage felling (Poje et al. 2016). Fatigue and dehydration cause a higher frequency of accidents in summer months and in late morning hours (Bentley et al. 2005).

Unforeseen interactions with a falling tree or branches and equipment are usually the main causes of accidents during felling performed by private forest owners (Neely and Wilhelmson 2006). Additionally, poor or wrong working technique, insufficient training, deficient or no personal protection equipment result in an increased risk of lethal and non-lethal accidents (Neely and Wilhelmson 2006, Häggqvist et al. 2010, Lindroos and Burström 2010, Brzózko 2016).

To reduce the risk of accidents during harvesting, fellers must be properly trained, and the contents and emphasis of trainings must be different for professional and non-professional fellers (Poje et al. 2016), beginners and experienced workers (Bentley et al. 2005), and adapted to their linguistic comprehension (O'Neal et al. 2007). The level of harvesting mechanization and control must be increased and employee turnover reduced (Bell and Grushecky 2006). Fellers must be physically and mentally fit to adapt to changing working conditions, because even experienced workers cannot anticipate all dangers (Bentley et al. 2005, DeMille and Lyons 2016). Immediately before the harvesting starts, a felling plan must be prepared in compliance with working conditions hazards (Lyons and Demille 2015). Efforts to improve the safety during felling are also made by developing new methods and auxiliary tools for directional tree felling (Lindroos et al. 2007, Noll and Lyons 2010, Lyons and Noll 2011, Lyons and Ewart 2012, Lyons 2015), since the studies show that the positioning of workers in the danger zone is one of the major factors causing lethal accidents (Melemez 2015). It is possible to reduce the risk of a kickback during cross-cutting with chainsaw by applying caution according to types and state of wood, right selection of chainsaw power and the length of the bar, the selection and maintenance of chain and its tension, and efficient chain brake (Dąbrowski 2012, Dąbrowski 2015). An innovative method to improve the ability of feller foremen is a computer game Felling Safety Game (Yovi and Yamada 2015).

When introducing mechanized felling, which reduces the risk of accidents (Bell and Grushecky 2006), physical capacities and demographic characteristics of operators must be taken into account (e.g. age, Ferrari et al. 2012). However, not only proper skills, abilities, work techniques and training, but also all interactions between workers, technology, organization and environment must be comprehensively taken into account to provide an efficient and safe work (Häggström and Lindroos 2016).

3.3.4 Wood extraction

3.3.4.1 Ergonomics

Operations with a high share of manual work, e.g. chainsaw felling and skidding with mules and agricultural tractors, cause musculoskeletal disorders and, mainly due to pains in the arms and wrists, lower back and neck, prevent the works to be executed (Gallis 2006). Since WBV is one of the possible causes for musculoskeletal disorders, the studies established that WBV in wood skidding still exceeds the permitted thresholds and that there have been no significant changes in the respective field in the last two decades (Cation et al. 2008, Jack et al. 2010, Pandur et al. 2013, Almeida et al. 2015). Exposure to VBW, in addition to working conditions (Cation et al. 2008, Jack et al. 2010), also depends on physical characteristics of an operator, e.g. his weight and characteristics of the seat (Ji et al. 2015, Ji et al. 2017). To provide a safe and healthy work with skidders, the areas, such as technical safety devices, accessing devices, cabin design, lighting devices, handling and safety requirements for designing and operating winches (Beuk et al. 2007), are important in particular.

The first phase of skidding, transporting of wood from tree-stumps to the skid trail (machine) is done with a winch. Due to high forces caused by friction between log and surface, all integral parts, such as wire rope and stop-end connections, must be properly designed to provide minimum safety requirements for their operation (Hartter and Garland 2006). The replacement of metal wire ropes with synthetic ones has reduced the force needed to extend a rope, but failed to reduce the expected cardiovascular workload (Ottaviani et al. 2011, Magagnotti and Spinelli 2012). The same also applies to the slack-pulling device, where its application only increased the work efficiency (Spinelli et al. 2015). According to authors, the main reason for the unchanged cardiovascular workload is that the movement of workers, in particular the older ones, is physically the most demanding task in the forest (Aalmo et al. 2016). Secondary causes, such as lighter means of work and tools, only temper the issue of excessive workload. To reduce the workload, several measures must be implemented simultaneously (Magagnotti and Spinelli 2012). On the contrary, the application of an auxiliary winch in collecting the wood increased the efficiency and reduced the cardiovascular workload as a lower number of workers was required (Magagnotti et al. 2016).

Although muscoloskeletal disorders are also experienced by forwarder operators, in particular pains in the lower back, neck, shoulders and the upper back (Phairah et al. 2016), these disorders are experienced more frequently by harvester operators (Silva et al. 2014). This can be the result of a less intense operation of the control lever and consequently shorter static loads of muscles (Østensvik et al. 2008a, Østensvik et al. 2009). Positions of parts of the body determined by the cabin design are not necessarily the most suitable, since they are not adjusted to physical characteristics of operators (Fontana and Seixas 2007).

When operating forwarders, the variability and exposure to WBV are the highest during movements (Rehn et al. 2005, Häggström et al. 2016). Factors that affect the variability are the operator, machine model and terrain type (Rehn et al. 2005). Different types of grabs have no impact on the exposure to WBV, but have nevertheless an impact on the damage to other trees in the stand (Häggström et al. 2016). Although the exposure of forwarder operators to noise does not exceed permissible loads, it is higher than in felling with harvesters due to faster and more frequent movements (Messingerová et al. 2005).

The study, which was based on the interviews with operators, showed that some types of cable cranes do not meet ergonomic requirements. This applies in particular to cable cranes without a cabin (Penna et al. 2011). By using radio controlled but heavier chokers, compared to the standard ones, the productivity increases, and consequently also the workload (Stampfer et al. 2010).

The most complex ergonomics studies of forestry machines and systems were conducted in North-West Russia (Gerasimov and Sokolov 2009, Gerasimov and Sokolov 2014). By using more than a hundred measured parameters and parameters obtained from the interviews with operators, the studies evaluate their suitability in terms of ergonomics. The findings show that the fully mechanized harvesting is the most suitable in terms of ergonomics and that harvester and forwarder are the most suitable combination of machines in CTL harvesting, while in terms of tree methods this applies to feller-buncher and grapple skidder. The least suitable technologies are those that include feller, skidder operator and choker setter. Visibility and working postures stand out as the worst fields of ergonomics.

3.3.4.2 Safety

The largest number of accidents during cable yarding occurs due to breaking of spar and anchor trees. On average, the accident severity is lower than during harvesting (Potočnik et al. 2009) and manual skidding or skidding with skidders, while the established frequency of accidents is 36 accidents/million cubic meters of extracted wood (Tsioras et al. 2011). Instead of trees, mobile machines can be used as end supports in cable yarding, whereby their mass and state of the ground are important for a safe operation of the entire system (Leshchinsky et al. 2015). The planning of cable yarding system by using theoretical models and software provides its rational and safe implementation (Bont and Heinimann 2012, Dupire et al. 2016).

3.3.5 Biomass production

3.3.5.1 Ergonomics

The production of firewood with a firewood processor is at least 25% more efficient and physically less demanding when using a combination of circular saw and hydraulic log splitter. The cardiovascular workload does not exceed the limit in either case (Lindroos 2008). In addition to a lower workload, the health hazard due to unfavorable body positions during firewood production with semi-mechanized or fully-mechanized systems is lower (Spinelli et al. 2017).

Measured WBV loads during the production of wood chips are higher in truck-mounted chippers, while the noise load is higher in tractor-trailer chippers. WBV exposure is higher in the production of chips from hardwood than from softwood (Rottensteiner et al. 2013). A daily exposure to noise exceeds the lower action value of daily exposure in case of higher utilization of machines (Poje et al. 2015), while some types of truck-mounted chippers can exceed the action value of daily exposure to WBV (Rottensteiner et al. 2013). WBV loads on operators of slash grapple during the collection of harvesting residues exceed the action value of daily exposure (Almeida et al. 2015).

3.3.5.2 Safety

During the production of firewood, most accidents occur when using splitters, with finger injuries being the most frequent (Lindroos et al. 2008). The causes of accidents are not in compliance with the safe work procedures, improper level of machine safety, use of gloves and operation of a machine with more than one worker (Lindqvist and Nilsson 2011).

3.3.6 Wood transport

3.3.6.1 Safety

The review of previous studies provided only one article addressing wood transport. Authors established that the safety of wood transport with trucks was lower, although the number of accidents due to mechanical faults and alcohol decreased. From 1991 to 2003, the frequency of accidents increased from 11 to 19 accidents per 1 million of transported wood (Greene et al. 2007).

4. Discussion

The greatest drawback of this research is that its scope is limited only to journals with impact factor. This means that, in addition to journals not included in the Web of Science collection, all grey literature was also left out, although it definitively includes important ergonomics project reports, such as Vibrisks, Ergowood and Comfor (EC 2016). Not observing this part of literature may definitely have an impact on our result, in particular if considering its purpose. Thus, for example, the projects are mostly focused on establishing guidelines and may cover very narrow, specific fields or areas. On the contrary, the publishing in journals with impact factor (IF journals) often depends on the popularity, originality and generality of their content.

Despite the aforementioned drawbacks, the research is believed to have succeeded in showing the focal points of studies in the field of occupational safety and health in forestry in the period 2005–2016. The complexity of results of these studies published in IF journals ensures to some extent their quality and current relevance in a broader research community. In addition to assessing the current state and potentially uncovering fields of interests, the research results represent a referential point for all similar future research and also the identification of trends in the development of occupational safety and ergonomics in forestry.

The research established that studies are mostly limited only to three continents. If the above mentioned issue of the scope of research is taken into account, the result of the spatial distribution of studies depends on actual capacities, such as research funding, tradition, education and staff potential, and also on the needs of researchers to be published in IF journals. The needs to be published are greater in countries where publications are crucial for an academic or research career, and directly or indirectly related to the funding of program groups and research (Rijcke et al. 2016).

Similar to Cavalli (2012) in its review paper on cable yarding, this research established that the number of publications increased in the period concerned. In addition to the necessity of publishing and increasing the number of IF journals, the cause may also be in an accelerated technological development of machines (eg. harwarders and autonomous forest machines, Hellström et al. 2006, Ovaskainen and Heikkilä 2007, Ringdahl et al. 2012) or their individual parts (eg. chocker, winch, grapple, seat, Stampfer et al. 2010, Häggström et al. 2016, Magagnotti et al. 2016, Ji et al. 2017) and in changes of work processes (eg. tree-topping, Huber and Stampfer 2015). The major driving force of occupational safety and health development may be linked with the development of human values, where health and environmental protection are considered as basic values; general (exceedingly) fast development of technology which, inter alia, calls for a change of standardized methods of work (Brewer and Hsiang 2002); and economic differences and crises that promote changes in work technologies (Archibugi et al. 2013).

By classifying the studies according to technologies, it was established that the majority of studies were still conducted on »traditional« technologies (chainsaw + skidder). The result makes sense considering that the majority of wood is still produced by using these technologies on a global scale, and that the work in this case is more dangerous (Potočnik et al. 2009, Tsioras et al. 2011). On the other hand, it seems that there has been no transfer of knowledge, for example, on traditional ergonomics, as one of the challenges in 2007 (Heinimann 2007). The reason for this failure may be in linguistic barriers, inaccessibility of older literature, and still insufficient international, and in particular, as the results indicate, intercontinental cooperation.

In terms of participation in studies, three fields of ergonomics stand out, namely: vibrations, cardiovascular workloads and working postures. It is obvious that the exposure to HA and WB vibrations still remains the central problem of forestry, since both in harvesting and extraction, regardless of the technology used, the vibrations exceed action values of permissible daily exposure. Similar also applies to unfavorable body positions during work, which together with other factors result in musculoskeletal disorders. If the studies of exposure to vibrations and noise are compared in terms of their number, obviously the number of the latter is significantly lower. The reason may be ascribed to a lower number of machines that cause overloads and to the fact that protection measures are more efficient and relatively simpler. Thus, for example, a regular use of personal protection equipment and noise insulated machine cabins may significantly reduce the exposure, without affecting the work productivity. On the contrary, the measures for reducing the exposures to vibrations, psychophysical workload and unfavorable body positions often decrease the work productivity (Gallis 2013). To efficiently reduce exposure to vibrations without significantly affecting the productivity, it is necessary to replace technologies, e.g. chainsaw with harvester or skidder with forwarder, which however is not always possible because of working conditions (Mihelič and Krč 2009). The second option is to change the operators behavior (Tiemessen et al. 2007), which must be correlated with the method of payment (Johansson et al. 2010).

A great share of manual work in forestry occurring in all phases of wood production, and prevailing in pre-harvesting tasks, traditional harvesting and firewood production, causes a high frequency of studies addressing cardiovascular workloads. Cardiovascular loads frequently exceed permitted limits. Due to relative simplicity, the measurement of cardiovascular loads is frequently included in broader, complex work studies (Košir et al. 2015).

On the other hand, there are no or very few studies in some fields. Thus, no studies referring to manuals and instructions or maintenance were detected, although the studies indicate that the maintenance of machine, for example in mechanized harvesting, is one of the main reasons for the dissatisfaction of operators (Walker et al. 2005) and poses the highest risk of accident (Väyrynen 1982). Similar applies to the exposure to biological substances, although working in natural environment poses a constant health hazard as a consequence of operating with flora and fauna. One of the reasons for the aforementioned fields not being included in the research is the above mentioned scope of research. Other reasons for not including these field may be an a priori underestimation of the risk factor significance (e.g. maintenance), inaccessibility of data (e.g. maintenance index) and blind trust (e.g. to producers).

Similar to ergonomics studies, also the studies addressing the occupational safety differentiate in their representation of individual forestry operations and content of research. The main reason may lie in the nature of work, risks of accident and accessibility of data. Thus, most studies have been conducted in forestry in general, which may be ascribed to the nature of work of forest workers, who take part in several work phases of wood production (e.g. harvesting and extracting) simultaneously, which is in particular true for working in groups (Poje and Potočnik 2007). In terms of individual operations, most studies deal with chainsaw felling, i.e. the working operation with the highest accident risk (Potočnik et al. 2009). Since non-lethal accidents are over 100-times more frequent than the lethal ones, the accidents at work were addressed almost in all technologies concerned, while the lethal accidents were dealt with only in general.

5. Conclusions and recommendations

According to our knowledge, this research is the first attempt to review the articles published in journals with impact factor in the field of occupational safety and ergonomics in forestry. Notwithstanding the drawbacks of the respective research, we are convinced that it succeeded in showing the research situation in terms of time dynamics, spatial scope and classification according to technologies and risk factors.

On the basis of the results, we thus assume that the number of publications in journals with the impact factor will also increase in the future, namely due to an increasing number of forestry and ergonomics journals with the impact factor, uniformity of the evaluation of research performance and also development of technologies and measurement techniques. By increasing the number of publications, the studies will also increase their spatial scope, but only under the condition that the number of researchers be increased and international cooperation and education improved.

The up-coming technological development of the existing technologies and automation and robotization of the forest work will require more emphasis on ergonomics research of cognitive risk factors. The robotization of work will even enhance the issue of mental overloads, which is already acute during current CTL harvesting (Berger 2003), and through the extension of a work day increase the possibility of ergonomic traps (Synwoldt and Gellerstedt 2003). At the same time, a new paradigm »more can be better« will have to be considered, since the studies establish that too low physical activity can have a negative impact on the health of workers (Straker and Mathiassen 2009). Development of new technologies, adjustment of work organization to technological progress (Heinimann 2007) and escalation of competition between manual and mechanized wood production will still require a continuous control of occupational safety and physical, physiological and environmental risk factors. It is expected that new requirements, primarily intended to protect the environment (e.g. reduction of emissions, use of alkylate fuels), will also have a positive impact on the health hazard (Neri et al. 2016). Due to the technological development of measurement techniques and international projects, it is expected that measurements of ergonomics factors will be more often included in broader, more complex studies of the impact of wood production technologies on the efficiency, environment and people.

Further studies need to be directed in supplementing this research and improving the knowledge on individual technologies and fields that have been identified as insufficiently explored. To complete the overall picture, the research must also include the articles in the field of medicine and grey literature, as well as a study for the period before 2005. No analyses of lethal accidents according to individual phases of wood production have been found in the studies of occupational safety. There are also no risk analyses that would be based on a comparison between injured and non-injured workers (or workers with one or multiple injuries) or hazardous or non-hazardous working conditions. This would provide the answers to the question: »Which of the factors, such as environmental, organizational or personal, increase the accident probability?«.

In terms of technologies and fields, additional studies are needed in particular in the fields of wood transport, biomass production, construction and maintenance of roads and skid trails, and new technologies, such as battery powered tools. According to individual fields of ergonomics, there is an insufficient number of: cognitive studies in all work phases of wood production (Häggström 2010); studies of burnout workers due to overload that additionally increases the risk of accident (Ahola et al. 2013); comprehensive ergonomics studies similar to Gerasimov and Sokolov (2014) and studies of productivity that would take into account all ergonomics requirements for safe and healthy work in setting the standards. To successfully reduce accident risks, it is first necessary to prepare and harmonize the statistics of forestry data collections. Only this will provide the collection of suitable information and in-depth analyses to prepare preventive measures for individual fields. In terms of the objective of this research, the impact and loads of forest production and wood industry (e.g. noise, dust) on wildlife and urban centers still remains completely uncovered. Due to high environmental awareness, the care for healthy natural habitats is one of the fields of future studies.

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