Retrospective Risk Assessment of Forestry Workers in the United States: Injuries, Fatalities, and Hazards Impacting Occupational Health

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Abstract

Forestry (including logging) is one of the most hazardous occupations due to environmental, ergonomic, chemical, mechanical, mental, and physical components of the job. In the United States (US), workplace injuries account for one-third of all injuries and one-sixth of all fatal injuries among people ages 20-64 years of age. The fatal accident rate of forestry workers in the US is 19-times higher than other physically demanding industries such as construction and manufacturing. Forestry workers must deal with multiple workplace factors that range from moving heavy machinery and other job tasks while adapting to changes in terrain and weather. Forestry workers also may encounter wild animals, arachnids, insects, and snakes. Arboviruses (transmitted primarily by mosquitoes) and bacterial pathogens (transmitted primarily by ticks) are potential health threats to foresters. There are a limited number of studies that have retrospectively assessed work-related injuries/fatalities in forestry/logging industries and current literature is deficient on the additional health hazards associated with foresters. Consequently, the purpose of this study is to compile what is known about potential

health and safety risks in foresters from the standpoint of biological (e.g., insects/arachnids, plants); chemical (e.g., pesticides); ergonomic (e.g., awkward postures, forceful motions); physical (extreme temperature, noise, vibrations, and radiation); psychosocial (e.g., workplace factors that cause stress, strain, or interpersonal problems for the worker); and safety (e.g., beetles and trucking) hazards that impact the overall health and injury status of workers. The aims of this study on forestry workers are to: 1) Analyze causes of injuries/fatalities to inform future intervention studies focused on risk mitigation, 2) Build the foundation for using multiple databases to analyze trends in injuries/fatalities, 3) Determine whether there are any trends/associations between work-related risk factors and workplace injuries/fatalities among foresters/loggers over a 16-year period (2003-2019), 4) Evaluate trends in injuries/fatalities to determine where intervention efforts are most needed, 5) Systematically review current knowledge on health hazards in the forestry industry, and 6) Identify knowledge gaps related to forestry and logging injuries, and fatalities for future studies to address. Our findings determined that, for the period of study (2003-2018 for fatalities; 2005-2019 for injuries), “contact with objects and equipment” was the primary cause of injuries and fatalities. “Transportation”-related incidents ranked second for the cause of fatalities, while “falls, slips, & trips” was the second leading cause of injuries. Our systematic review of recent literature showed that while many studies have focused on machinery related injuries and deaths, some areas of occupational health in the forestry industry have been understudied with in the US in the last ten years. Areas identified as needing additional study include chemical exposures from pesticides and diesel exhaust, cold and heat related illnesses, and exposure to ticks and mosquitoes.

Our findings identified major gaps in knowledge for health and safety of US forestry/logging workers and occupational health outcomes. Future research should focus on these areas with an emphasis on intervention strategies that eliminate or mitigate the deleterious health effects of occupational exposures. By identifying specific needs of the forestry industry, more appropriate interventions and aids can be designed and implemented to benefit worker health and safety. Here, we have identified several areas of research that need to be addressed in the future. The areas identified here should be addressed in a collaborative effort between researchers and the forestry industry to promote worker health and safety.

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Glossary

Term	Definition
Boles	AKA Trunk; The main stem of a tree; usually covered with bark; the bole is usually the part that is commercially useful for lumber.
Bucking	Process of felled trees being cut into logs; Bucking involves cutting off the limbs and tops, then cutting the trunk into specified lengths.
Choker	A length of steel cable with attachments for encircling the end of a log to be yarded.
Cut-to-length	Complete all processing (e.g., delimbing, topping, and bucking) at the stump with a harvester, and fully processed logs are transported to landing or roadside by a forwarder.
Fell	To cut down.
Feller	A worker in a logging crew whose primary role is to use a chain saw to fell trees.
Forwarder	A forestry vehicle that carries the felled logs from the stump to a roadside landing.
Forwarding	In logging operations forwarding is the stage where cut tree trunks or logs are moved from the stump to flat level areas along roads where cut trees are processed into logs and logs are stockpiled before being loaded for transport to mills.
Hand Planters	A worker who carries a large bag of seedlings and plants them one at a time at a desired spacing using a planting tool such as a spade.
Logging	The process of harvesting trees by workers who fell, process, and transport tree logs.
Log Landing	A place where felled trees/logs are gathered and sorted in or near the logging operation for further processing prior to transport to a facility for further processing.
Psychosocial Hazards	Factors in the work environment that can cause stress, strain, or interpersonal problems for the worker.
Rigging Crew	The workers who set up and handle the steel cables at a logging site.
Skidder	Large wheeled, or occasionally tracked, off-road vehicles equipped with a small bulldozer-style blade at the front for pushing away stumps or rocks, and a towing system at the rear for pulling cut trees to flat level areas along roads where cut trees are processed into logs and logs are stockpiled before being loaded for transport to mills.
Sawyer	A person whose work is sawing wood
Tree-length	Remove the limbs and tops at the stump, and transport merchantable boles to the landing or roadside for further processing.

Whole-tree	Trees are severed from the stump and the above -ground portions of the trunks (e.g., bole, limbs, and top) are transported to a landing or roadside for processing.
Yarding	This term refers to using a high-lead or other cable system to lift and pull cut trees or logs to a flat level area for processing.

Retrospective Risk Assessment of Forestry Workers in the United States: Injuries, Fatalities, and Hazards Impacting Occupational Health

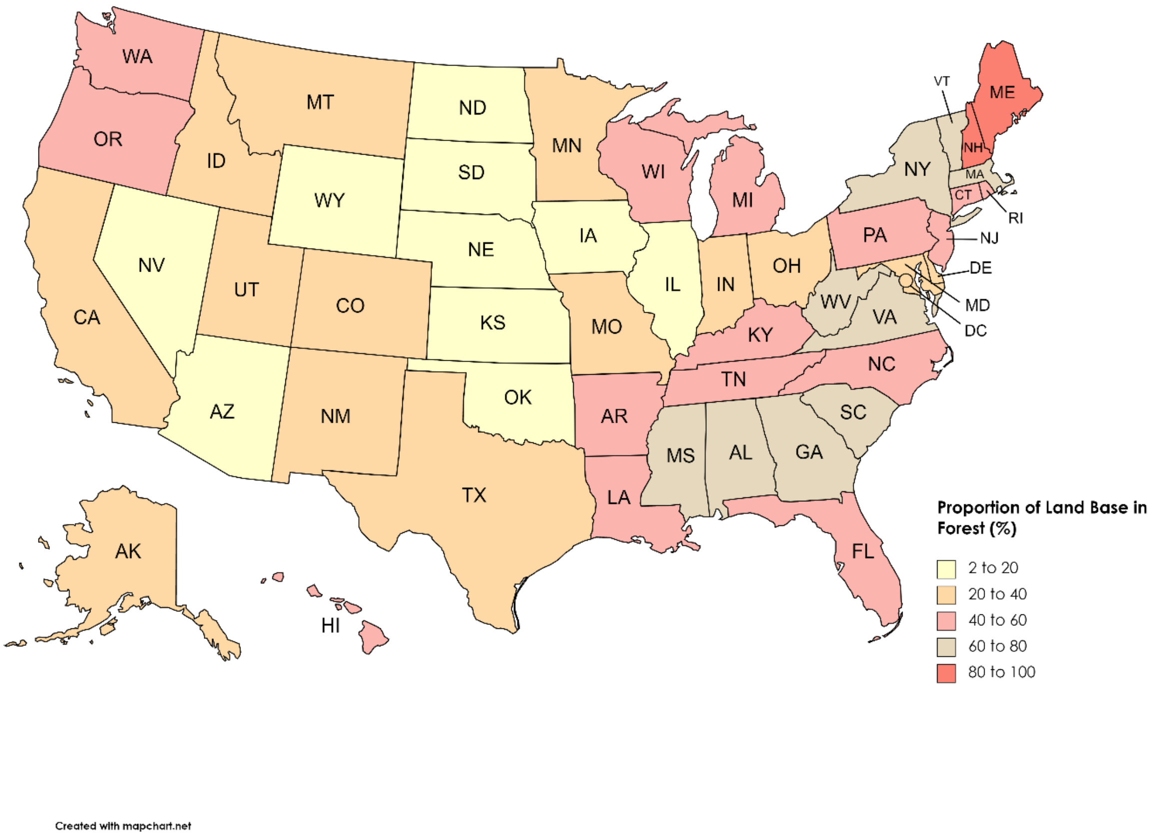
CHAPTER 1: INTRODUCTION

Occupational injury is a major public health problem in the United States (US) and elsewhere (OSHA, 2021a). The Occupational Safety & Health Administration (OSHA) reported that on average, in 2019, more than 100 people per week died on the job (OSHA, 2021b). The US Bureau of Labor Statistics (BLS) reported, that forestry/logging industry employment in 2019 included 99.1% private sector workers plus 0.9% local, state, and federal workers (BLS, 2021). The forestry industry includes logging, e.g., the process of harvesting trees by workers who fell [cut down], process, and transport tree logs. These workers experience some of the highest rates of workplace injuries and fatalities (BLS, 2021). In the late 1990s/early 2000s forestry workers in the US had a fatal accident rate 19-times higher than other industries such as construction and manufacturing (Mirabelli, Loomis, & Richardson, 2003). In 2021, the forestry accident rate was reported to be 30-times the rate of other industries in the US (Mulhollem, 2021). Factors that may explain the high fatality rate of workers in the forestry industry include: the nature of working outdoors; multiple workplace factors such as working with heavy machinery/equipment; job tasks that often require unnatural and uncomfortable working postures; and exposure to noise and vibration from large equipment (Kim et al., 2017). Additionally, disparities in safety training, availability, use of personal protective equipment (PPE), and work processes; as well as differences in worker ages and levels of experience may help explain the high work-related fatalities (Mirabelli et al., 2003).

The forestry industry workforce encompasses many distinct types of workers, including those who harvest forest-related products and/or provide support services for the maintenance and sustainability of forests. This includes owners, managers, and operators of forested acreage, timber harvesters (loggers/fellers), forest managers (fire control), non-timber harvesters (nut, mushroom, and pinecone foragers), recreation managers and guides, and state and federal park rangers (National Research Council, 2008). Most of these jobs occur in locations that are rural, and far removed from important resources like hospitals (Grzywacz et al., 2013).

In the US, most forests are replenished naturally and only 9% of forests are manually planted. However, the percentage planted has been on the rise in recent years (Oswalt et al., 2014). The South accounts for 73% of planted timber in the US, and the North/South make up 61% of the total US timber harvested from 2007-2014 (Oswalt et al., 2014). A separate study that reviewed changes in the logging sector between 1990 and 2016 showed that the South alone was responsible for 63% of the total annual timber harvest volume (Conrad et al., 2018). The South became the top harvesting region, in part, when restrictive federal policies such as the Northwest Forest Plan (NFP) in the Pacific Coast caused timber production to migrate to other regions (Conrad et al., 2018). Regulations for protecting the northern spotted owl, and restrictions on the use of public lands in the Pacific Northwest (PNW) region are some of the other reasons listed by the NFP for the migration of timber production to the South (Das, Alavalapati, Carter, & Tsigas, 2005). Figure 1 illustrates the percent of total land area forested by states annually (Oswalt et al., 2014).

Figure 1. Percent of Total Forested Land Area, By State (Oswalt et al., 2014).



Occupational health and safety studies have typically focused on the physical causes of forester fatalities and/or injuries (e.g., equipment-related, human error) (Frank et al., 2013; Kim et al., 2017; Patterson, 2014). However, workers in the forestry industry also have the potential to encounter wild animals, arachnids, insects, and snakes. Arboviruses (transmitted primarily by mosquitoes) and bacterial pathogens (transmitted primarily by ticks) are potential health threats to foresters (Covert & Langley, 2002). Zoonotic diseases are underdiagnosed and underreported as occupational diseases, making it difficult to accurately assess the prevalence of this issue in the forestry industry (Richard & Oppliger, 2015). Current literature is lacking on many health hazards associated with foresters. Few have retrospectively assessed work-related injuries/fatalities in forestry/logging industries, and current literature is lacking on many additional health and safety hazards associated with foresters.

Hence, the aims of this study on US foresters are to:

1) Analyze causes of injuries/fatalities to inform future intervention studies focused on risk mitigation,
2) Build the foundation for using multiple databases to analyze trends in injuries/fatalities,
3) Determine whether there are any trends/associations between work-related risk factors and workplace injuries/fatalities among foresters/loggers over a 16-year period (2003-2019),
4) Evaluate trends in injuries/fatalities to determine where intervention efforts are most needed, and
5) Systematically review current knowledge on health hazards in the forestry industry.

The objectives of this study on US foresters are to:

1) Identify the top three sources of workplace injuries in the Forestry & Logging sectors.
2) Identify the top three causes of workplace deaths in the Forestry & Logging sectors.
3) Identify knowledge gaps in the literature for health hazards in the forestry industry for future studies to address.

CHAPTER 2: REVIEW OF LITERATURE

Exposures in Forestry and Health/Safety Concerns

The US harvests, on average, 205 million metric tons of timber annually (Oswalt, Smith, Miles, & Pugh, 2014). This is almost double the output by the next top harvesting country (Russia) (Conrad, Greene, & Hiesl, 2018a). Thus, forestry-related occupational health and safety outcomes should be a major focus for research as they can come from a multifaceted set of exposures in the workplace (Quandt et al., 2013). These exposures can be related to: 1) the natural work environment (e.g., terrain, slope, and weather conditions); 2) the work environment generated by the industry (e.g., machinery, tools, and chemicals); 3) conditions created by industry tools (e.g., noise pollution from heavy machinery, chainsaws, or airborne particulates [sawdust created when felling a tree]); 4) industry products (e.g.,timber); and/or 5) a combination of these and other factors that result in negative health outcomes (Quandt et al., 2013). The extent to which workers experience issues, depends on industry- and worksite-related factors (Quandt et al., 2013). Factors can range from external contextual factors (e.g., market prices, policies, and/or laws) to employer-specific factors (e.g., pace of work, provision of safety gear, and training) to task-specific factors (e.g., repetition) (Grzywacz et al., 2013; Quandt et al., 2013). Health outcomes resulting from the wide range of potential environmental exposures can vary in the time of onset (immediate to delayed) and duration (acute to chronic) (Quandt et al., 2013).

Workers within the agriculture and forestry sectors are generally paid by the number of units produced (Department of Industrial Relations, 2017; Grzywacz et al., 2013). This type of compensation system is often referred to as ‘piece-rate’, motivating attention to quick work and high production, with potential negative consequences for safe work practices (Grzywacz et al., 2013). Piece-rate logging has been described in two different categories: 1) Product and grade: Paid per log and the grade quality of the log; 2) Straight rate: Paid per volume (or weight) regardless of grade (MOFA, 2021). Both categories may create a rush incentive for worker performance that could lead to higher accident rates; as workers cut corners on safety measures to increase production (MOFA, 2021). Davis & Hoyt (2020) showed an increased risk of occupational accidents and injuries for piece-rate compared to salaried workers. The same study asserts that poor health outcomes linked to piece-rate pay (Davis & Hoyt, 2020). This could negatively impact a company's bottom line; as worker injuries could result in increased health-related absences(Davis & Hoyt, 2020). This in turn would potentially lower performance due to injury, and increases healthcare costs (e.g., medical expenses) (Davis & Hoyt, 2020). It has been argued that forestry workers are willing to accept higher risk of physical injury rather than risk a reduction in economic return (Patterson, 2007). A separate study also showed piece-rates associated with a higher chance of injury for a variety of occupations, including forestry/logging (Bender, Green, & Heywood, 2012). Bender et al. (2012) found that manual workers operating under piece-rates have an injury rate 7% higher than other workers. In the same study, non-manual workers paid by piece-rate showed a 1.5% higher injury rate.

Furthermore, it is widely documented that many agriculture-related jobs (including forestry/logging) are increasingly carried out by immigrants (Frank, Liebman, Ryder, Weir, & Arcury, 2013; Grzywacz et al., 2013; Quandt et al., 2013; Richardson, Loomis, Wolf, & Gregory, 1997). Hence, the agricultural sector is often largely exempt from federal protections offered through the Fair Labor Standards Act and the National Labor Relations Act (Grzywacz et al., 2013). The BLS does not include citizenship status in their required annual surveys. The ‘Survey of Occupational Injuries and Illnesses’ form includes demographic questions like age, gender, and race, along with other questions regarding the employee's status within the company. With the lack of reporting of citizenship status, there could be a gap in reported occupational injury data surrounding immigrants that enter the US to work.

In the US, the logging industry underwent substantial structural changes between 1900-2000 (Stuart, Grace, & Grala, 2010). Logging became a more mechanized process, making the use of manual labor and productivity more efficient. In the South, the logging industry went from labor intensive to capital intensive (Stuart et al., 2010). Fully mechanized, whole tree harvesting systems are the most common and productive systems (Conrad, Greene, & Hiesl, 2018b). When comparing logging injuries between pre- and post-modernization (e.g., the addition of machinery), there has been a reduction in injuries (Patterson, 2014). However, with the advent of specialized machinery, there has been an associated increase in productivity demands and excessive shift lengths compared to traditional logging (Patterson, 2014).

An additional safety concern in forestry is high employee turnover rates, making it difficult to retain safety-trained employees (Nkomo, Niranjan, & Reddy, 2018). New employees are often inexperienced and can be prone to job-related accidents (Nkomo et al., 2018). In a forestry worker demographics report, 43% of forestry workers have less than one year of experience (Zippia, 2022). In a study conducted on loggers in Montana and Idaho, inexperienced workers made up of 36% of the working population

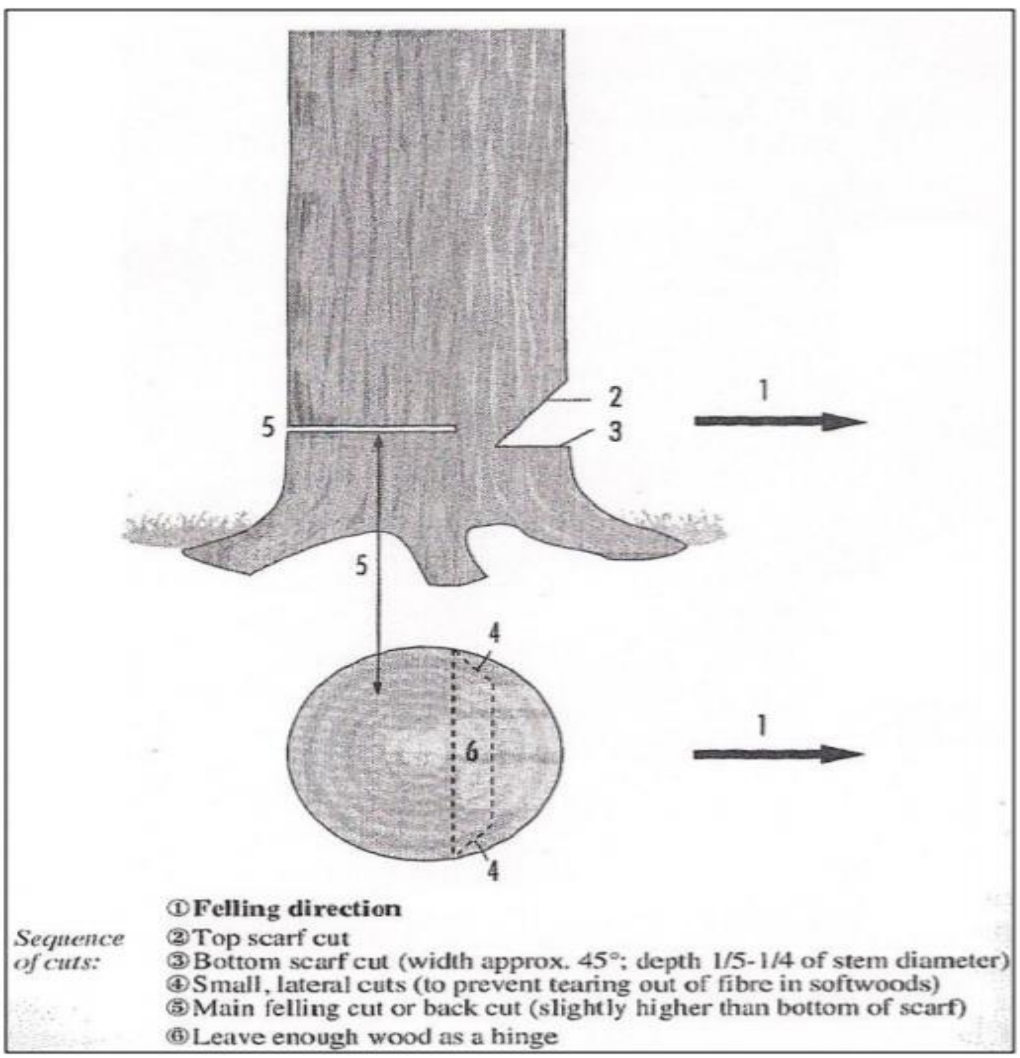
(Lagerstrom et al., 2017). One survey found that loggers reported strongly preferring on-the-job training (Leon & Benjamin, 2012). The same survey also found that logging safety and equipment maintenance were top training priorities (Leon & Benjamin, 2012). This indicates that the logging community could be receptive to future intervention programs focusing on these areas.

Logging/Tree Harvesting

One of forestry's main sub-industries (a smaller industry that falls under the umbrella of a major industry) is logging (Kim et al., 2017). Logging is one of the most dangerous occupations due to physical demands, fluctuating work site locations (typically remote), weather exposure, and other factors (Kim et al., 2017). The US Department of Labor (USDOL) divides loggers into five worker categories: fallers, supervisors, logging equipment operators, saw machine setters, operators, tenders, and truck drivers (USDOL, 2022). The number of workers in each of these categories is based on the type of logging system utilized (e.g., conventional chainsaw logging or mechanical; if mechanical, which machines are operated are considered). There is a wide range of heavy machinery equipment that can be utilized. Selection of the machinery equipment is based on terrain, the region that the harvest is taking place, and the resources of the logging company (Lagerstrom, Magzamen, & Rosecrance, 2017).

There are two main logging systems for felling trees, conventional chainsaw logging and mechanical logging. Moving the felled trees is accomplished in one of four ways: Skidder, horse logging, line skidding, and helicopter logging (Lagerstrom et al., 2017). The felling process occurs during both conventional chainsaw logging and mechanized harvesting methods. A trained feller (specializes in cutting down trees) will first make two converging “scarf cuts,” one each on the top (Item 2, Figure 1) and bottom (Item 3, Figure 2) (Patterson, 2014). The “scarf cut” is made on the side of the tree where the tree will fall (Item 1, Figure 2). Next, the feller must make a deeper cut, known as the “back cut” (Item 5, Figure 2), on the opposite side of the tree. As the wedge is driven into the back cut, it causes the entire tree trunk to tip over until it falls over (Patterson, 2014).

Figure 2. Tree Felling Diagram (Patterson, 2014)



In conventional chainsaw logging, trees are felled, delimbed, and cut to length using chainsaws (Lagerstrom et al., 2017). In mechanical felling there are two basic types of felling machines that are being used in many forestry operations, 1) feller-buncher: cuts trees and places them in bunches and 2) feller-director: cuts trees and directs the fall (Patterson, 2014). There are three types of tree harvesting systems: 1) whole-tree, 2) tree-length, and 3) cut-to-length. In whole-tree systems, trees are severed from the stump, and the above-ground portions of the trunks (e.g., bole, limbs, and top) are transported to a landing or roadside for processing (Conrad et al., 2018). Tree-length systems remove the limbs and tops at the stump, and transport merchantable boles to the landing or roadside for further processing (Conrad et al., 2018). Cut-to-length systems complete all processing (e.g., delimbing, topping, and bucking [felled trees cut into logs]) at the stump with a harvester, and fully processed logs are transported to landing or roadside by a forwarder (Conrad et al., 2018). Figure 3 illustrates differences in harvesting systems (Conrad et al., 2018).

After the felling and processing of the trees, loading and transportation takes place (Patterson, 2014). There are two methods for getting trees ready for loading and transport: “yarding” and “skidding” (Patterson, 2014). Yarding uses a thick cable to lift and pull cut trees to an area where the trees can be made into logs and then be loaded for transport (Patterson, 2014). Forwarding, (which is when cut tree trunks or logs are moved from the stump to a flat level area where the cut trunks are processed into logs), can take different forms. These include: 1) skidding (most common) – skidders (wheeled or tracked off-road vehicles) used to tow logs along the ground and 2) forwarding - primarily used in

Figure 3. Harvesting Methods Used by Loggers in the US (Conrad et al., 2018)

1. https://www.tigercat.com/products/forestry-machinery/
2. https://piercepacific.com/products/forestry/denharco-delimbers/
3. https://incident-prevention.com/ip-articles/chainsaw-safety-planning-and-precision-felling-techniques

areas with soft ground, in which the action of dragging the trees would cause damage to the ground (Patterson, 2014). When using a skidder is not available or cannot be used due to terrain, weather conditions or other environmental factors, horse logging, line skidding, and helicopter logging methods can be used in its place (Lagerstrom et al., 2017). For each of the methods, a worker is responsible for attaching cables to the logs for them to be hauled off site (Lagerstrom et al., 2017). In ground-based (completely mechanical) harvesting systems, the loggers using the skidder and processer are protected by the enclosed cab, which can help reduce injuries (Newman et al., 2018). Cable harvesting systems utilize both ground workers (e.g., fellers) and heavy machinery (e.g., yarder) (Newman et al., 2018). Cable harvesting systems can occur on slopes >40% incline and begin with a feller felling a tree with a chainsaw (Newman et al., 2018). Next the rigging crew workers set chokers (e.g., steel cables) around logs by hand before they are yarded up hill to a log landing (Newman et al., 2018). Ground based harvesting method versus cable harvesting methods are illustrated in Figure 4. The processes of felling, processing, and transportation are dangerous (Patterson, 2014); however, workers generally perceive these activities as moderately dangerous (Kim et al., 2017). The variety of logging operation methods likely plays a major part in the differences in injury and fatality rates among loggers in the US (Lagerstrom et al., 2017). Factors such as job task, logging system type, and degree of mechanization also contribute to the prevalence, type, and severity of logging occupational injuries and fatalities (Lagerstrom et al. 2017). Non-mechanized harvesting methods have been shown to have higher risk than mechanized systems (Lagerstrom et al., 2017). Other important risk factors are that hardwood harvesting is typically conducted by a two- or three-person team using a single tree selection method with chainsaws to fell the tree. Tree characteristics (e.g., shape) are other risk-influencing factors (Myers & Fosbroke, 1994). Moreover, harvesting hardwoods experienced higher worker fatality rates compared to harvesting softwoods (Myers & Fosbroke, 1994). Factors potentially influencing occupational fatalities are shown in Table 1. These factors range from issues such as logging safety being unregulated and harvesting quotas to environmental factors, such as wood type, and terrain. While fully mechanized harvesting systems are now common in the US, there are regional differences (Conrad et al., 2018). Chainsaw systems persist in mountainous terrain (Conrad et al., 2018). Cut-to-length systems which utilize heavy machinery like harvesters and forwarders are common in the Lake States (Conrad et al., 2018).

Figure 4. Ground Based Versus Cable Harvesting Methods (Newman et al., 2018)

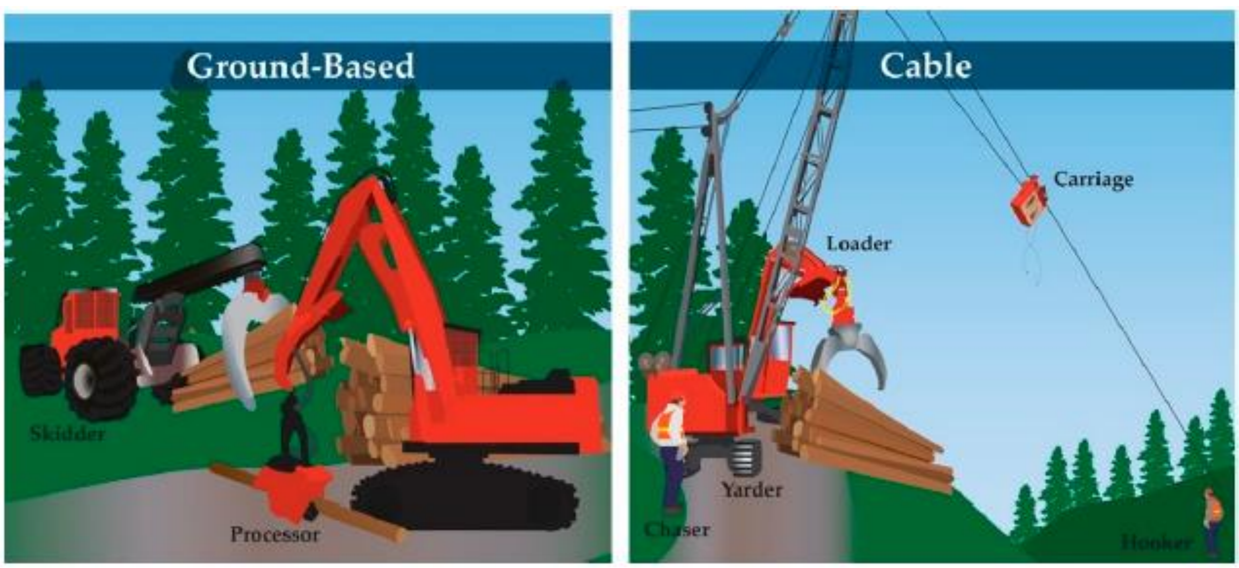


Table 1. Possible Factors Influencing Risk of Fatal Occupational Injuries in the US Logging Industry, (Myers & Fosbroke, 1994)

Lower Fatality Risk	**Higher Fatality Risk**
Softwood harvesting	Hardwood harvesting
Pulpwood harvesting	Sawtimber harvesting
Clear-cut harvesting	Selective harvesting
Plantation stands	Natural stands
Mechanized harvesting	Traditional harvesting
Steady wood markets	Cyclical wood markets
Level terrain	Steep terrain
Corporate operation	Small business operation
Managed forest stands	Unmanaged forest stands
Logging safety regulated	Logging safety unregulated

Injuries & Fatalities in Forestry

Tiesman et al. (2011) reported that agriculture, forestry, fishing, and hunting industries had the highest traumatic brain injury (TBI) -related fatality rate among all major industries (5.7 per 100,000 workers/year), and the logging subindustry had the highest occupational TBI fatality rate of all industries (29.7 per 100,000 workers/year). In comparison, the next highest subcategory for TBI fatality rate was crop/animal farming and forestry (4.4 per 100,000 workers/year) (Tiesman, Konda, & Bell, 2011). In 2015, the US logging industry total fatality rate (all causes) was 132.7 per 100,000 workers, the highest in any private industry (Kim et al., 2017). In 2015, the annual rate of lost workdays due to injuries in loggers was 144.1 days per 100,000 workers (Kim et al., 2017). Occupational health and safety risks for forestry and logging has been ranked in the top five most hazardous jobs in the US (Shishlov, Schoenfisch, Myers, & Lipscomb, 2011). Occupation-related injuries and fatalities can cause production delays, increase project costs, and increase medical burdens/disabilities for workers (Antwi-Afari et al., 2019). While previous research has conducted epidemiological and psychological studies on these industries and their employees, few have evaluated long-term trends.

Forestry worker trauma can be divided into seven categories: 1) acute (immediate injury), 2) musculoskeletal, 3) chemicals, 4) dust/particulates, 5) weather, 6) infections/envenomation due to animals/arthropods, and 7) noise (Quandt et al., 2013). Many hazards in the forestry occupation are 'built into' how the job is performed and who is performing the job. An example of a built-in job hazard is the terrain and other site factors such as slope, and soil type which can influence worker safety. When the job site has a steep slope there is an increased risk of machinery accidents and rock falls (FAO, 2020). Soil texture can also impact worker safety e.g., clay soil becomes slippery when wet which can lead to machinery accidents (FAO, 2020).

Hardwoods make up most of the harvest in the North and South regions, and softwoods comprise most harvests in the Rocky Mountain and Pacific Coast regions (Oswalt et al., 2014). One study showed that regions predominantly harvesting hardwoods experienced the highest worker fatality rates compared to regions primarily harvesting softwoods (Myers & Fosbroke, 1994). This is partly because the average hardwood tree being cut weighs more than half a ton, and the trees grow in sloped rough terrain (Myers & Fosbroke, 1994). Another contributing factor is that hardwood tree species store a higher amount of potential kinetic energy than softwoods, and may be more likely to exhibit unpredictable behavior during the felling process (Lundstrom et al., 2021).

Accidents that occur at agricultural work sites can range from burns and minor cuts to traumatic injuries such as fractures and amputation. Forestry workers can suffer injuries from falls, handling chainsaws or other machinery, and/or being struck by trees/logs resulting in contusions, strains, lacerations, fractures, and traumatic brain injury (Frank et al., 2013). These types of injuries are also consistent with the use of logging machinery (Kim et al., 2017). Machine operators can be injured while performing machine maintenance/repair, and from falls while mounting/dismounting machinery (Kim et al., 2017). Machine operators, along with logging workers, can be exposed to contact risks related to moving machinery and/or machine rollover (Kim et al., 2017).

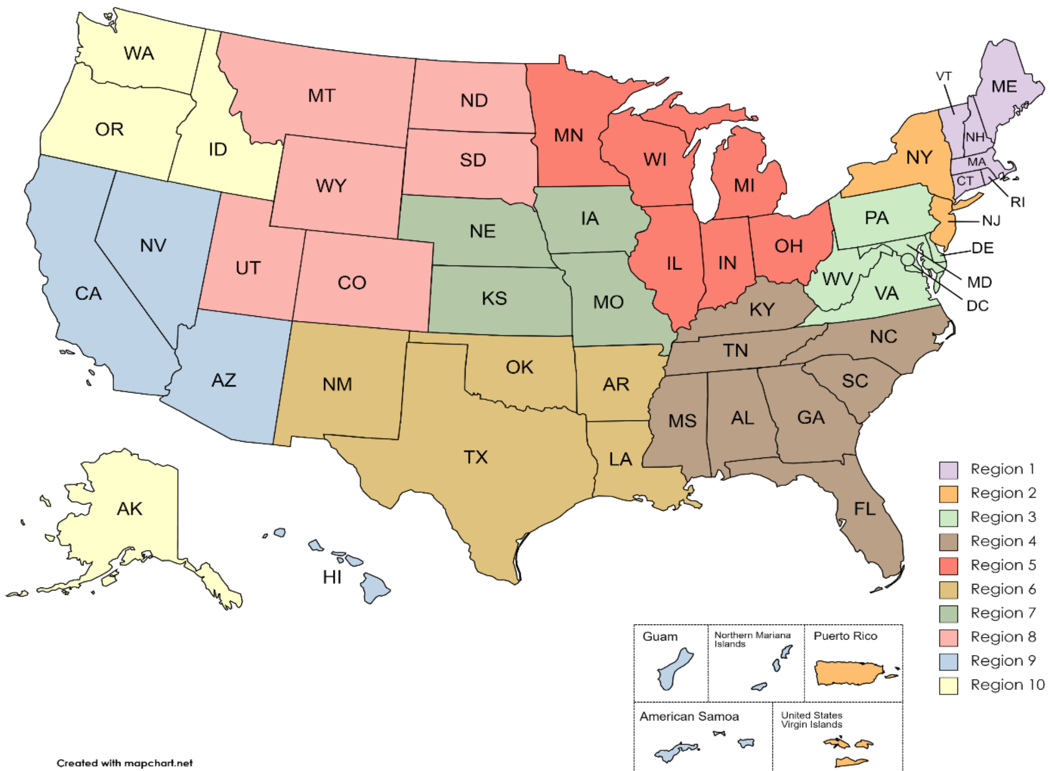
Leigh et al. (2006) examined the financial cost of occupational injury and fatalities for multiple occupations in the US in 1993. The same study combined the fatal and non-fatal injury cost per worker for each occupation, and ranked farming, forestry, and fishing with the highest cost at $5,163 per worker in 1993 (Leigh, Waehrer, Miller, & McCurdy, 2006). This equates to >18 times the lowest combined cost per worker rate in 1993 ($279 per worker for executives and managers) (Leigh et al., 2006). The price per worker was determined by examining workers' compensation records, estimates of lost wages, and jury awards for 1993 (Leigh et al., 2006). For fatality cost per worker, the percentage of total costs attributed to combined fatalities for farming, forestry, and fishing (62.7% of costs spent on fatal injuries) was higher than other work industries (range: 7.9-32.9% of costs spent on fatal injuries) (Leigh et al., 2006). Percentages were calculated by compiling: 1) medical cost information from worker compensation records in the Detailed Claims Information dataset, 2) the National Health Interview

Survey, and 3) prior work on medical costs for fatalities (Leigh et al., 2006). The average cost of fatal injuries for each occupation was determined (Leigh et al., 2006). In the aforementioned study, cost of occupational injuries/illnesses was divided into three broad categories: direct, indirect, and quality of life. Direct costs included expenses such as hospital payments, rehabilitation, burial costs, emergency services, etc. An example of an indirect cost is productivity loss (e.g., both from the worker and administration due to filling out worker compensation forms and interviewing witnesses) (Leigh et al., 2006). Indirect costs also include the cost of training the replacement worker. Quality of life costs include '*the value attributed to the pain and suffering experienced by injured workers and their families*' (Leigh et al., 2006). The costs presented by Leigh et al. (2006) were incidence-based and included all costs of injury/illness over the injured workers' lifespans.

Regional Differences

The US Forestry Service and US Department of Agriculture (USDA) divides the US into four main regions: North, South, Rocky Mountain, and Pacific Coast (Figure 6) (Oswalt et al., 2014). Alaska is occasionally treated as its own region (Oswalt et al., 2014). The US forests are predominately concentrated in the South and Northeast, the Lake States, the Rocky Mountains, and Alaska (Oswalt et al., 2014). Approximately 68% of US forest land is classified (by the USDA) as available for timber production. This means that those forests can produce 0.56 m^3/acre of industrial wood annually (Oswalt et al., 2014). In the eastern part of the US, oak/hickory forests are the largest forest type. The second largest are the pine forests of the South and third are the mixed maple/beech/birch (*Acer/Fagus/Betula*) forests of the North (Oswalt et al., 2014). In the Rocky Mountain and Pacific Coast regions, most forests are Douglas Fir (*Pseudotsuga*) (18%), with a mix of hardwoods and pinyon/juniper (*Pinus/Juniperus*) forests which make up 17% and 15%, respectively (Oswalt et al., 2014). Alaska's forests differ from the Pacific Coast as this state has extensive boreal forests dominated by mixed western softwoods and fir/spruce (*Abies/Picea)* 45% and 34%, respectively (Oswalt et al., 2014). Lagerstrom (2017) cited that the logging activities performed in the intermountain west region (Montana & Idaho) is 'especially hazardous' due to the steep terrain, extreme weather, and remote work locations (Lagerstrom et al., 2017). Table 2 illustrates differences in harvesting systems between the regions (Conrad et al., 2018).

Figure 5. OSHA Regions for Local Emphasis Programs (OSHA, 2019)



OSHA Regional Identifier	States
Region 1	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
Region 2	New Jersey, New York, Puerto Rico, Virgin Islands
Region 3	Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia
Region 4	Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee
Region 5	Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin
Region 6	Arkansas, Louisiana, New Mexico, Oklahoma, Texas
Region 7	Iowa, Kansas, Missouri, Nebraska
Region 8	Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming
Region 9	Arizona, California, Hawaii, Nevada, and American Samoa, Guam and Northern Mariana Islands
Region 10	Alaska, Idaho, Oregon Washington

Figure 6. Major Forestry Assessment Regions of the US Defined by US Forestry Service & US Department of Agriculture

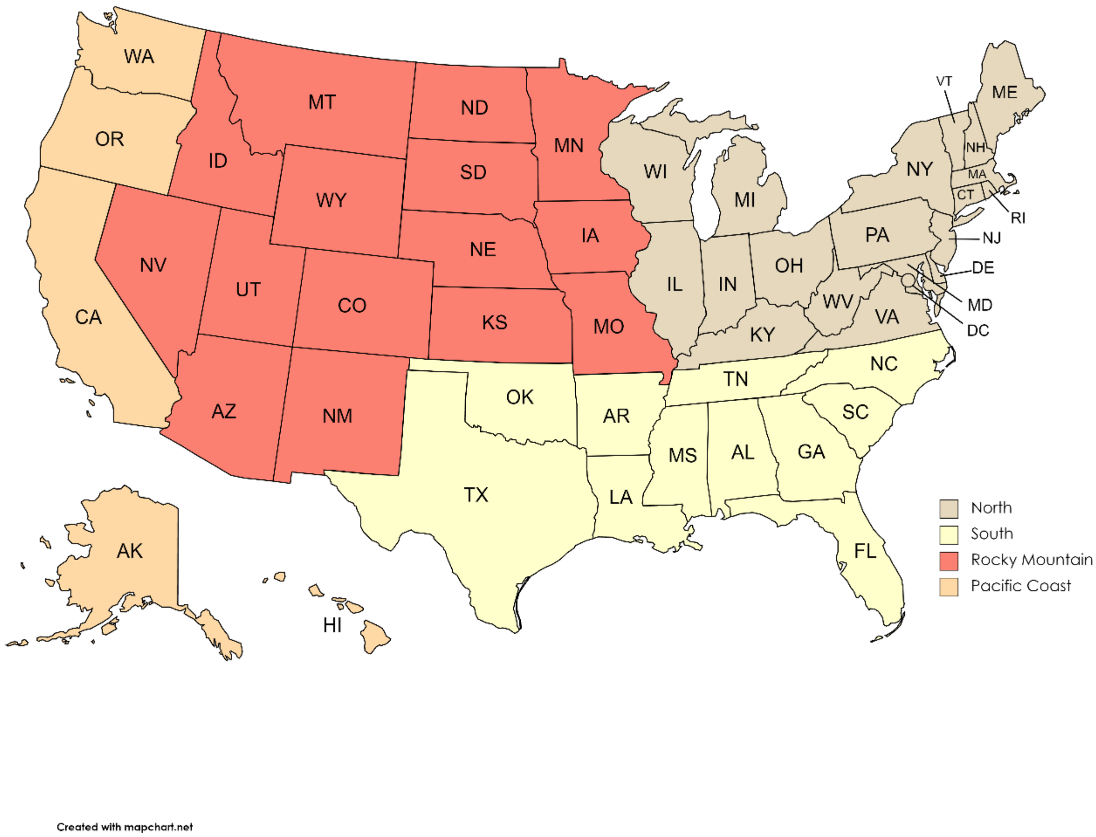


Table 2. Harvesting Systems & Equipment Configurations by Region (Conrad et al., 2018)

State	Harvesting system	Most common equipment configuration		
		Felling	*Transport*	*Processing*
North				
Maine	*Whole tree*	Swing-to-tree feller-buncher	Grapple skidder	Stroke delimber, pull-through delimber, slasher saw
Michigan	*Cut-to-length*	Harvester	Forwarder	Harvester
New Hampshire	*Whole tree*	Swing-to-tree feller-buncher	Grapple skidder	Stroke delimber, pull-through delimber, slasher saw
New York	*Whole tree*	Swing-to-tree feller-buncher	Grapple skidder	Stroke delimber, pull-through delimber, slasher saw
Southern New England (Connecticut, Massachusetts, Rhode Island)	*Tree-length*	Chainsaw	Cable skidder	Not reported
Vermont	*Whole tree*	Swing-to-tree feller-buncher	Grapple skidder	Stroke delimber, pull-through delimber, slasher saw
Virginia Mountains	*Tree length*	Chainsaw	Cable skidder	Chainsaw, slasher saw
Virginia Piedmont/Coastal Plain	*Whole tree*	Drive-to-tree feller-buncher	Grapple skidder	Pull-through delimber, slasher saw
West Virginia	*Tree length*	Chainsaw	Cable skidder	Chainsaw, slasher saw
Wisconsin	*Cut to length*	Harvester	Forwarder	Harvester
South				
Georgia	*Whole tree*	Drive-to-tree feller-buncher	Grapple skidder	Pull-through delimber, slasher saw
South Carolina	*Whole tree*	Drive-to-tree feller-buncher	Grapple skidder	Pull-through delimber, slasher saw
Rocky Mountain				
Minnesota	*Whole tree*	Swing-to-tree feller-buncher	Grapple skidder	Pull-through delimber, slasher saw
Pacific Coast				
Inland Northwest	*Whole tree*	Swing-to-tree feller-buncher	Grapple skidder	Processor & stroke delimber

**Conrad et al., 2018 did not specify why some states were not included in the table*

"*Tree length*" chainsaw harvesting systems have persisted outside the South and areas such as Minnesota, even though the terrain could support mechanized processes (Conrad et al., 2018). The reasoning behind the persistent use of chainsaws was not discussed in this study, but one possible reason is the costs of equipment (e.g., chainsaw costs hundreds to thousands of dollars whereas a feller-buncher machine costs >$200,000) (NEF Equipment, 2021; SLE Equipment, 2021). In Vermont and New York, loggers used chainsaw felling 71% and 68% of the time, respectively (Conrad et al., 2018). Yet, in these states, chainsaw felling only accounted for 23% (Vermont) and 34% (New York) of annual harvest volume (Conrad et al., 2018). Reasons for usage differences between chainsaws and machines like feller-bunchers could be attributed to machine-based felling having higher productivity rates than a manual feller using a chainsaw (Wang, Long, & McNeel, 2004). Because of steep terrain in the Pacific Coast region, nearly half of the annual timber harvest is conducted with chainsaws (Conrad et al., 2018). In the South, "whole tree" systems predominate the logging industry. Technological change via advances in forest biotechnology and increasing investments in intensive forest management are improving productivity in the forestry industry (Das et al., 2005). However, the impacts of environmental regulations and improvements in forestry productivity are not uniform across the US due to regional variations in forest land ownership and investment potential for productivity enhancements (Das et al., 2005). For example, private forestland is more concentrated in the South, while public forestland is more common in the Pacific West (Das et al., 2005). The South holds great promise for intensively managed forest plantations via forest biotechnology, and most of the highly productive forestlands in the US (approx. 91 million acres) are in this region

(Das et al., 2005). The South accounts for more than 50% of total US softwood production and approximately 50% of total US hardwood production (Das et al., 2005).

Reducing Risk & Enhancing Safety

Safety is defined as the absence of risk (Collard, 1989; Patterson, 2014; Stein, 1975). To a general audience, the concepts of risk and danger are the same, which has resulted in the thinking that safety is the absence of danger (Patterson, 2014). Thus, danger avoidance is a commonsense strategy to achieve safety in the workplace (Patterson, 2014). This assumption leads individuals to avoid dangerous activities and, when accidents occur, they often assume the cause was human error (Patterson, 2014). However, achieving safety in the workplace is rarely a matter of risk avoidance because situations are likely to involve more than one source of danger, and the most obvious source may not pose the greatest threat (Patterson, 2014)

Each year, the Occupational Safety and Health Administration (OSHA) issues directives known as Local Emphasis Programs (LEPs). These LEPs are enforcement procedures designed and implemented at the regional office and/or area office levels, and address industries that pose a risk to workers in the region (OSHA, 2019). The LEPs provide for programmed inspections of establishments in industries with potentially high injury or illness rates, which are not covered by current OSHA inspection scheduling systems or have hazards that are not being addressed adequately under existing targeting programs. The LEPs can be implemented to encompass an entire region (e.g., Region 3 includes Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia) or in specific state(s) in the region. A complete breakdown of LEP regions is shown in Figure 5 (OSHA, 2019). The LEPs are based on knowledge of local industry hazards and/or injury/illness experience. The length of a LEP varies and they may be extended past the original expiration date. In 2015, logging was identified as an area of interest for an LEP (OSHA, 2019). The LEPs are accompanied by outreach to increase awareness of the program as well as the hazards that programs are designed to reduce/eliminate. Outreach may be in the form of informational mailings, training at local tradeshows, and/or presentations at meetings of industry groups and/or labor organizations (OSHA, 2019). All LEPs advance the US DOL strategic goal of promoting safe jobs and fair workplaces, and align with OSHA goals of ensuring safe and healthful working conditions for workers (OSHA, 2018). An LEP for logging operations in Oregon and Washington (Region 10) was issued for 2017-2018, and the LEP was extended through 2021. A separate LEP for logging was issued in Idaho (Region 10) for 2018-2021. A third LEP was issued for logging in West Virginia (Region 3) (OSHA, 2019). According to archival data for OSHA LEPs, there have been no forestry/logging LEPs issued for Region 4 (includes NC). Active LEPs in Region 4 are primarily focused on construction, maritime activities (e.g., inspection, ship building/repair), and the motor vehicle industry. A list of active LEP programs for each region can be found here: https://www.osha.gov/enforcement/directives/lep (OSHA, 2019).

CHAPTER 3: METHODS

Information on worker's compensation reports was requested from the primary agency that handles these types of claims in NC (e.g., NC Forestry Association [NCFA]). Investigators were referred to the insurance agency that handles the claims (e.g., Forestry Mutual Insurance Company); however, the company declined to share data as they generally conduct their own in-house analysis. Thus, focus was shifted from a state-based study to a national-level evaluation based on data obtained from the US BLS. Fatalities, injuries, and illnesses of employees in the forestry industry were identified by analyzing annual data recorded by the BLS. These data were collected by three surveys: 1) "Survey of Occupational Injuries and Illnesses" using the BLS "R1 Number of nonfatal occupational injuries and illnesses involving days away from work by industry and selected natures of injury or illness, private industry" reports for 2005-2019; 2) BLS "R4. Detailed industry by selected events or exposures (Number)" reports for each year (2003-2018 for fatalities; 2005-2019 for injuries); 3) "Census of Fatal Occupational Injuries" (BLS, 2020). Injuries have a different time range than fatalities because the BLS did not report forestry and forestry/logging combined in their occupational injury report for 2003-2004. The year 2019 for injury analysis was added here to keep both injury and fatality analyses within a similar time span (e.g., 16 years of fatalities for 2003-2018 and 15 years of injuries for 2005-2019).

These surveys collected data by industry and classified injuries and/or fatalities into six categories of event/exposure leading to fatality/injury: 1) violence and other injuries by persons or animals, 2) transportation incidents, 3) fires and explosions, 4) falls, slips, and trips, 5) exposure to harmful substances or environments, and 6) contact with objects and equipment. For the purposes of this study, annual injury and fatality totals for each of these six categories for the forestry industry were obtained for 2003-2018 (BLS, 2019; BLS, 2020). Injuries and fatalities were evaluated for forestry/logging combined and with logging analyzed separately. Data regarding the nature of fatalities which came in the six categories: 1) Asphyxiations, strangulations, and suffocations, 2) Internal injuries, 3) Intracranial injuries, 4) Intracranial injuries and injuries to internal organs, 5) Traumatic injuries, and 6) Other traumatic injuries were also obtained from the BLS (BLS, 2018). Data regarding the nature of injuries were categorized in 16 different injury types described in Table 3.

Table 3. BLS Categories for Nature of Non-Fatal Injuries

	Category	**Sub-Category (if applicable)**
1	Sprains, strains, tears	
2	Fractures	
3	Cuts, lacerations, punctures	Total
4		Cuts, lacerations
5		Punctures (except gunshot wounds)
6	Bruises, contusions	
7	Heat (thermal) burns	
8	Chemical burns and corrosions	
9	Amputations	
10	Carpal tunnel syndrome	
11	Tendonitis	
12	Multiple traumatic injuries	Total
13		With fractures
14		With sprains
15	Soreness, pain	
16	All other natures (includes non-classifiable injuries)	

The AgInjuryNews.org database was used to create a map of forestry/logging-related fatalities and injuries by US city for 2015-2020; the short time span (five years) for this analysis is due to limited data available on this platform. The AgInjuryNews.org database is a repository of injury reports, and a source of information for agricultural injuries, fatalities, and agricultural injury prevention methods. The database is populated using several data sources including news outlets, Google alerts, and submission from peer reviewers. In 2019, the US BLS began using AgInjuryNews.org as part of its Census of Fatal Occupational Injuries case discovery of quality assurance (https://aginjurynews.org/LearnMore/Index). The AgInjuryNews.org database only provides data since 2015. The AgInjuryNews.org database's map generator was used to create maps of logger and forester injuries and fatalities (Figures 10-12) with the following filters applied: a) Date Range (2015-2020), b) Country/Region (US), c) Incident Location (Ag-Woods/Forest; Forestry-Logging Site; Manual Operation; Mechanized Operation; Forestry – Other; Forestry - Other – Unspecified; Forestry - Woods / Forest), d) Fatal/Non-Fatal (combined and separated).

Statistical Analysis

A correlation analysis was carried out to assess the relationship between different causes of logger/forester fatalities by cause of fatality for the entire US using SPSS 26 (SPSS, Armonk, New York). Significance was evaluated using $p<0.05$. Injury and fatality rates were calculated for each year of the study (fatalities: 2003-2018; injuries: 2005-2019). Annual injury and fatality rates were calculated by dividing the number of injuries or fatalities (pre-categorized by cause), by the number of forestry and logging workers reported for each corresponding year by the BLS, then multiplied by 10,000 (Tables 5-6 and 11-12, Figures 7-8). The "per 10,000 workers" calculation is a standard measure used by the BLS. Time span-specific incidence rates were calculated by dividing the total number of injuries and/or fatalities (pre-categorized by cause) reported between 2003-2018 (fatalities) and 2005-2019 (injuries), by the average number of foresters/loggers employed between the same years for each industry, multiplied by 100 to obtain a percentage (Tables 7-9 and 14-15). For 2003-2004, injury data for forestry/logging was not available from the BLS and so are not analyzed here. For those years, the BLS only provided a summary analysis (not raw data as in other years); reasons for this were not stated in the BLS reports.

The US Census Bureau (USCB) reported the number of employees for forestry separate from loggers, therefore the two sets of employee counts were added together for each year to get the combined number of logging and forestry workers for each year (USCB, 2021). The mean number of workers was calculated for each year (2003-2018, 2005-2019); (mean **±** standard error) 96,976 **±** 10.2 workers (2003-2018, logging); 92,805 **±** 10.5 workers (2005-2019, logging); 118,796 **±** 3.2 workers (2003-2018, forestry & logging); 115,041 **±** 10.5 workers (2005-2019, forestry & logging) (USCB, 2021). The USCB did not report logging and forestry worker counts for 2003, so the same total of employees reported in 2004 was used for 2003 (USCB, 2021).

Systematic Review of Occupational Health Risks in Foresters

In the public health sector, systematic reviews – *a review that uses explicit, systematic methods to collate and synthesize findings of studies that address a formulated question* – are essential to inform decision makers, who would otherwise be confronted by the mass volume of research on the topic at hand (Page et al., 2021). The foundational principles behind a systematic review can be useful in other areas of research including occupational health and safety. In recent years, both researchers and international institutions in the field of environmental health have increasingly applied the systematic review procedures to evaluate questions related to environmental health. For this study, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines were applied (Figure 7) (Page et al., 2021).

Research question

A Population, Exposure, Comparator, and Outcome (PECO) statement was developed and used to define the research question, determine the search terms, and outline the inclusion and exclusion criteria for the systematic review (Table 4).

Search methods for identifying studies

We conducted a systematic search to identify peer-reviewed, primary research papers. Multiple databases were utilized to identify related articles, including PubMed, Cochrane Central Register of Controlled Trials, and Scopus. A defined search strategy was developed. Peer-reviewed literature published in the databases were refined by being written in English and published between January 2011 and September 2021. A 10-year search cap was chosen to focus on the more recent knowledge that has been published on the subject. Multiple databases were used during the search including East Carolina University One-Search, PubMed, and NIOSHTIC-2 Publications Search. Additional references were obtained from the reference lists of relevant records to capture articles that could have been missing in the original database search. In our database search, the following search terms were use: “foresters AND occupational safety”; “foresters AND occupational outcomes”; “foresters AND occupational health”;

“foresters AND occupational disorders”; “foresters AND weather”; “foresters AND heat stress”; “foresters AND rabies”; “foresters AND poison ivy”; “foresters AND skin diseases”; “foresters AND zoonotic diseases”; “foresters AND vector-borne diseases”; “foresters AND health hazards”; “foresters AND pesticide exposure”; “foresters AND chemical exposure”; “foresters AND ticks”; foresters AND permethrin treated clothing”; “foresters AND insect stings”; “forestry and noise”; “US forestry workers”; “ foresters AND vibration”; “ foresters AND cold stress”; “foresters AND sun exposure”; “foresters AND UV radiation”. In each of the search terms described above the term “Loggers” was put in place of “Foresters”, and the search was redone. To be included in the study, articles had to comply with the Population, Exposure, Comparator, and Outcome (PECO) statement (Table 4). Articles that did not meet the criteria were excluded from the study. Additional exclusion criteria included: studies that were not peer reviewed (e.g., abstracts, theses and dissertations, and white pages), and articles that were summaries (Figure 7).

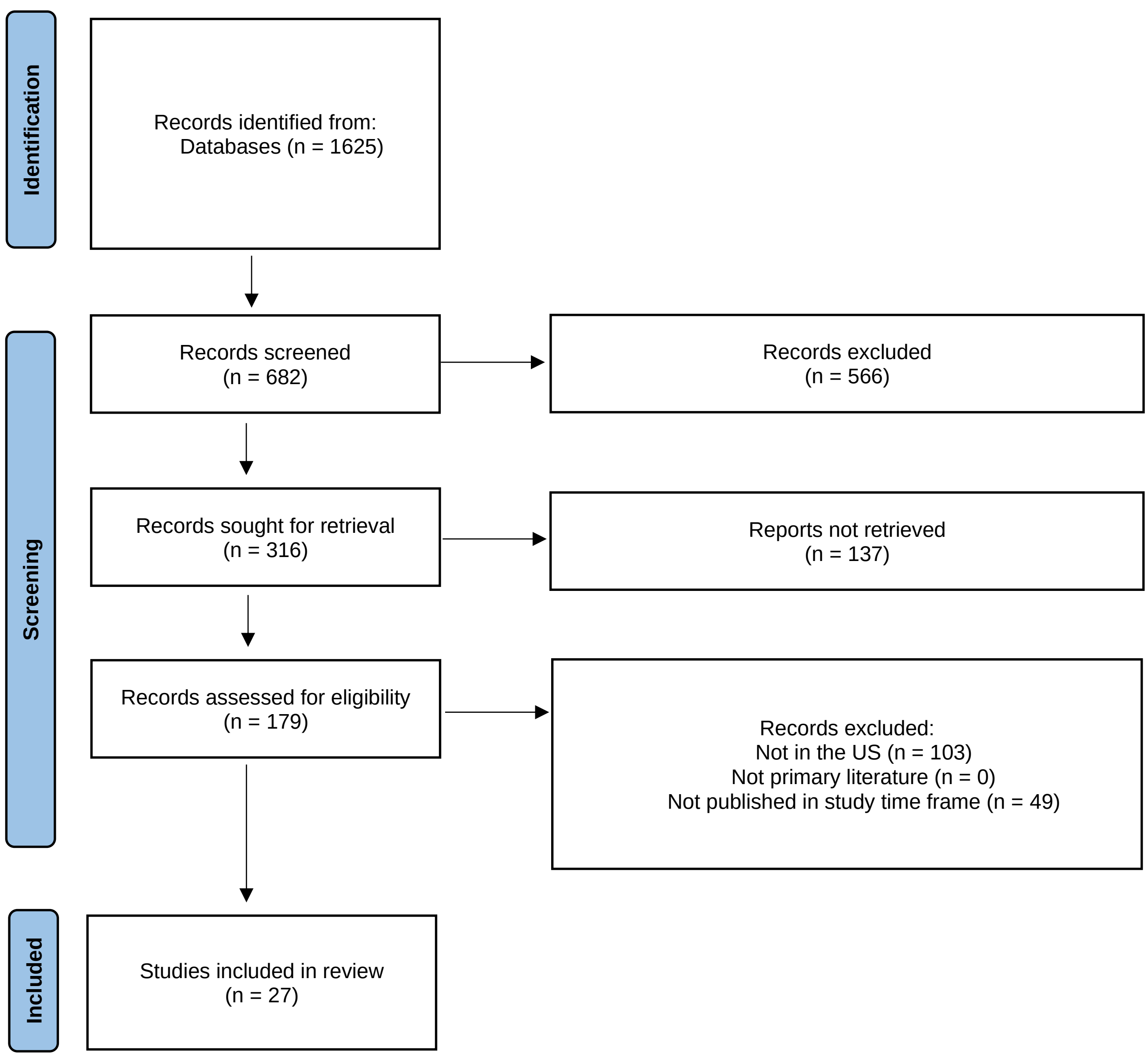
Data extraction

Titles and abstracts of the studies resulting from database searches were screened. Each study that qualified for inclusion was obtained in full text and assessed using the PECO method. The data extracted from each study included: authors, journal, publication year, country, study design, health outcomes addressed, and population of focus (e.g., foresters).

Table 4. PECO Statement for Eligibility

PECO	***Eligibility Criteria***
Population	Forestry Workers & Loggers in the United States
Exposure	Biological, Chemical, Ergonomic, Physical, Psychosocial & Safety Hazards
Compactor	No studies on workers outside of the United States
Outcome	Any health effects

Figure 7. PRISMA Flow Diagram for Systematic Review



CHAPTER 4: RESULTS

Fatal and Nonfatal Injury Rates for Forestry & Logging Combined

Fatality rates for forestry and logging combined are depicted in Figure 8 and Table 5. Table 5 shows fatality data for the different causes of forestry and logging fatalities in the US. For the category of ‘contact with objects and equipment’, the fatality rate ranges from 2.45 (lowest rate in 2009) to 6.95 (highest rate in 2016) fatalities per 10,000 workers (Table 4). The next highest category is ‘transportation incidents’ with the fatality rate ranging from 1.28 (lowest rate in 2008) to 2.99 (highest rate in 2018) fatalities per 10,000 workers (Table 5). The next four categories ‘falls, slips, trips’ (fatality rate range 0 – 0.27; mean = 0.15); ‘exposure to harmful substances or environments’ (fatality rate range 0 – 0.30; mean = 0.05); ‘violence and other injuries by persons or animals’ (fatality rate range 0 – 0.20; mean = 0.04and); ‘fires and explosions’ (fatality rate range 0 – 0.24; mean = 0.03) indicating that fatal-injuries in these categories do not commonly occur. The BLS-reported fatality rate for all industries in the US (2017) was 3.5 fatalities per 100,000 workers (e.g., 0.35 fatalities per 10,000 workers). Foresters/loggers had a fatality rate (for total/combined causes for all years) of 7.14 per 10,000 workers in 2017 (Table 5), making forestry and logging fatalities > 20.4 times higher than the national average work-related fatality rate.

Table 6 shows the nonfatal injury rates for forestry and logging combined by different causes. Contact with objects and equipment had the highest number of injuries ranging from 15.52 (lowest rate in 2009) to 87.18 (highest rate in 2016) injuries per 10,000, with an overall rate of 44.56 injuries per 10,000 (all years combined for ‘contact’ injuries). For nonfatal injuries the BLS reported that the injury rate for all industries in

2020 was 37.7 per 10,000. Figure 8 shows ‘contact with objects and equipment’ as the primary cause of fatalities in forestry/logging for every year studied. Similarly, ‘contact with objects and equipment’ caused the most nonfatal injuries in forestry/logging (with exception of 2011 in which ‘falls, slips, trips’ was the leading cause of injuries) (Figure 9, Table 6). Additional figures of this data can be found in (Appendix I).

In most years, ‘transportation incidents’ were ranked second for causing fatalities in forestry/logging while ‘falls, slips, trips’ were ranked second for causing nonfatal injuries for most years (except 2011). The third most frequent cause of fatalities in forestry/logging was ‘falls, slips, trips’ (ranked third during six of the 16 years studied). ‘Fires and explosions’ caused fatalities during four out of the 16 years of the study. ‘Exposure to harmful substances or environments’ and ‘violence and other injuries by persons or animals’ caused the least fatalities (e.g., fatalities during three of the 15 years studied).

Table 5. Fatality Numbers and Rates* for Forestry/Logging Combined by Cause, United States, 2003-2018

Year	**Contact with objects and equipment**		**Falls, slips, trips**		**Exposure to harmful substances or environments**		**Transportation incidents**		**Fires and explosions**		**Violence and other injuries by persons or animals**		**Total**	
	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers
2003	82	6.08	3	0.22	0	0.00	30	2.22	0	0.00	0	0.00	115	8.53
2004	70	5.19	3	0.22	0	0.00	28	2.08	0	0.00	0	0.00	101	7.49
2005	68	4.96	0	0.00	3	0.22	23	1.68	0	0.00	0	0.00	94	6.85
2006	59	4.42	3	0.22	0	0.00	37	2.77	0	0.00	0	0.00	99	7.41
2007	66	4.89	4	0.30	0	0.00	22	1.63	0	0.00	0	0.00	92	6.82
2008	77	6.14	0	0.00	0	0.00	16	1.28	3	0.24	4	0.32	100	7.98
2009	30	2.45	0	0.00	0	0.00	18	1.47	0	0.00	0	0.00	48	3.92
2010	43	3.39	0	0.00	0	0.00	25	1.97	0	0.00	0	0.00	68	5.37
2011	54	4.71	0	0.00	0	0.00	17	1.48	1	0.09	0	0.00	72	6.27
2012	48	4.31	3	0.27	0	0.00	10	0.90	0	0.00	0	0.00	61	5.47
2013	52	4.45	0	0.00	0	0.00	24	2.05	1	0.09	0	0.00	77	6.59
2014	65	5.75	4	0.35	0	0.00	23	2.03	0	0.00	0	0.00	92	8.14
2015	54	5.34	1	0.10	3	0.30	21	2.08	0	0.00	0	0.00	79	7.81
2016	71	6.95	0	0.00	3	0.29	28	2.74	1	0.10	0	0.00	103	10.09
2017	41	4.20	4	0.41	0	0.00	29	2.97	0	0.00	2	0.20	76	7.78
2018	49	5.24	3	0.32	0	0.00	28	2.99	0	0.00	1	0.11	81	8.65
Total	929	4.89	28	0.15	9	0.05	379	1.99	6	0.03	7	0.04	1358	7.14

* Number of fatalities (by cause) divided by the total number of forestry and logging workers for years, multiplied by 10,000

Table 6. Nonfatal Injury Numbers and Rates* for Forestry/Logging Combined by Cause, United States, 2005-2019

Year	Contact with objects and equipment		Falls, slips, trips		Exposure to harmful substances or environments		Transportation incidents		Fires and explosions		Violence and other injuries by persons or animals		Total	
	No. of injuries	Rate per 10,000 workers	No. of injuries	Rate per 10,000 workers	No. of injuries	Rate per 10,000 workers	No. of injuries	Rate per 10,000 workers	No. of injuries.	Rate per 10,000 workers	No. of injuries	Rate per 10,000 workers	No. of injuries	Rate per 10,000 workers
2005	870	63.42	610	44.47	0	0.00	100	7.29	0	0.00	50	3.64	1630	118.82
2006	650	48.65	240	17.96	30	2.25	170	12.72	0	0.00	0	0.00	1090	81.58
2007	610	45.23	390	28.92	0	0.00	110	8.16	0	0.00	20	1.48	1130	83.78
2008	430	34.31	200	15.96	0	0.00	160	12.77	0	0.00	0	0.00	790	63.04
2009	190	15.52	130	10.62	0	0.00	110	8.98	0	0.00	0	0.00	430	35.11
2010	310	24.46	220	17.36	0	0.00	70	5.52	0	0.00	0	0.00	600	47.34
2011	450	39.21	540	47.06	0	0.00	170	14.81	0	0.00	0	0.00	1160	101.08
2012	440	39.46	170	15.25	190	17.04	300	26.91	0	0.00	0	0.00	1100	98.66
2013	540	46.19	200	17.11	0	0.00	90	7.70	0	0.00	0	0.00	830	70.99
2014	370	32.74	210	18.58	0	0.00	310	27.43	0	0.00	0	0.00	890	78.74
2015	410	40.53	250	24.71	0	0.00	0	0.00	0	0.00	0	0.00	660	65.24
2016	890	87.18	200	19.59	0	0.00	90	8.82	0	0.00	0	0.00	1180	115.58
2017	240	24.56	250	25.58	0	0.00	20	2.05	0	0.00	0	0.00	510	52.19
2018	730	77.99	230	24.57	100	10.68	250	26.71	0	0.00	0	0.00	1310	139.96
2019	560	59.15	230	24.30	0	0.00	160	16.90	0	0.00	0	0.00	950	100.35
Total	7690	44.56	4070	23.59	320	1.85	2110	12.23	0	0.00	70	0.41	14260	82.64

* Number of injuries (by cause) divided by the total number of forestry and logging workers for years 2005-2019, multiplied by 10,000

Figure 8. Number of Fatalities for Forestry & Logging by Cause, United States, 2003-2018

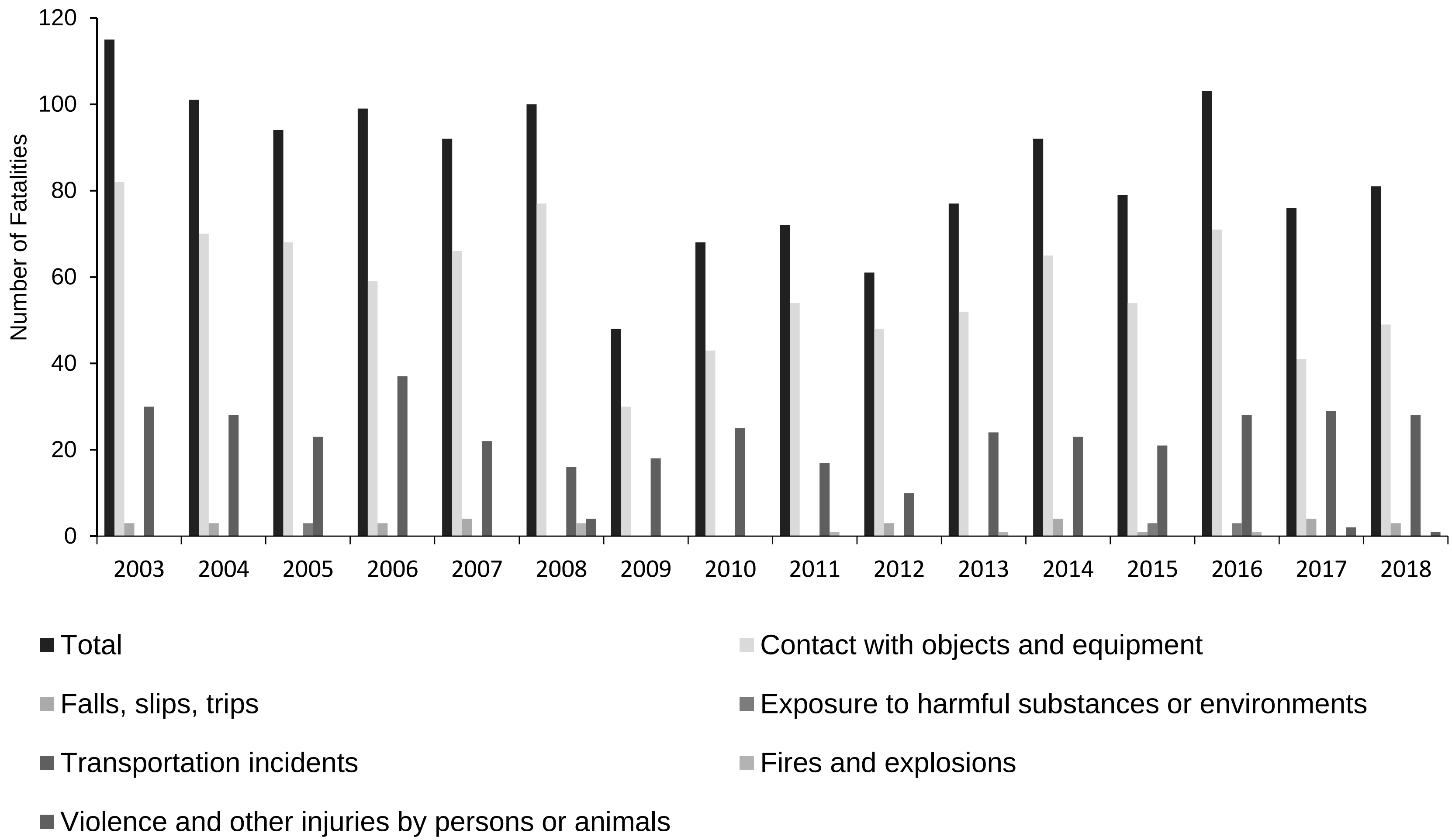
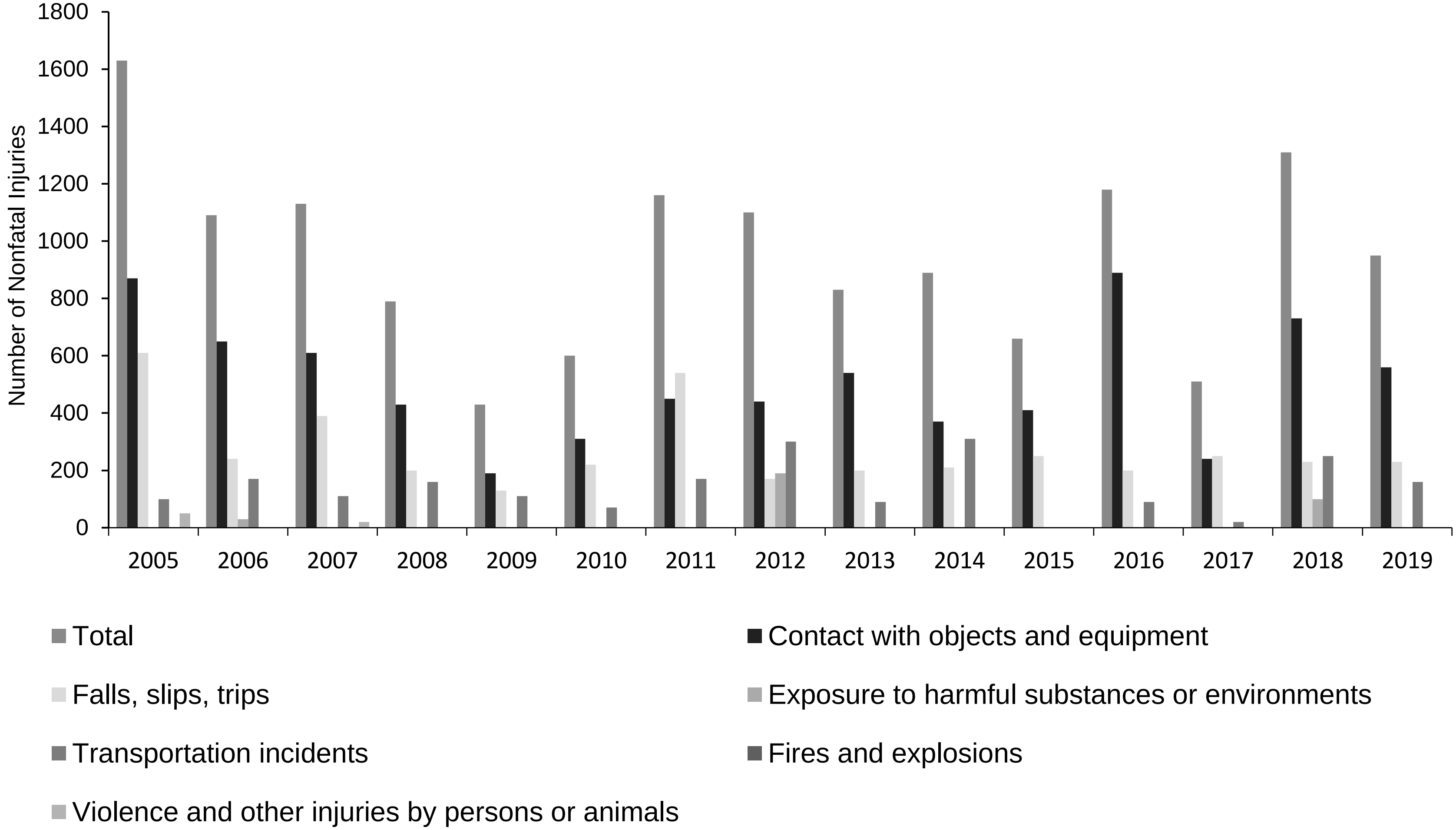


Figure 9. Number of Nonfatal Injuries in Forestry & Logging by Cause, United States, 2005-2019



The third most frequent cause of nonfatal injuries was ‘transportation incidents, followed by ‘exposure to harmful substances or environments’, ‘violence and other injuries by persons or animals’, and ‘fires and explosion’. Time span incidence rate calculations (Tables 7 and 8) show ‘contact with objects and equipment’ as the primary cause of fatalities and injuries for their respective time periods. ‘Contact with objects and equipment’ caused 2.5 times more fatalities than the second leading cause (transportation incidents), and 32.6 times more fatalities than the third leading cause (falls, slips, and trips) (Table 7). Table 8 shows that ‘transportation incidents’ were the third leading cause of injuries with ‘falls, slips, and trips’ ranking as the second most leading cause of injury. ‘Contact with objects and equipment’ caused 1.9 times more injuries than ‘falls, slips, and trips’ and 3.6 times more injuries than ‘transportation incidents’ (Table 8). For both Tables 7 and 8 (as well as Tables 13 and 14) the exact average of logging and forestry and logging employees was used to keep the incidence rate as accurate as possible. Table 9 shows the nonfatal injury time span incidence rate for forestry/logging by nature (2005-2019). Sprains, strains, tears were the number one nature of injury (2.695%) followed by all other natures (non-classifiable injuries) (2.351%) and fractures (1.878%).

Table 7. Fatality Time Span Incidence Rate for Forestry/Logging by Cause, United States, 2003-2018

Causes	Total Fatalities 2003-2018 (a)	Mean Number of Foresters/Loggers 2003-2018 (b)	Incidence Rate [(a/b)*100] (%)
Transportation incidents	379	118,796	0.201
Violence and other injuries by persons or animals	7	118,796	0.004
Contact with objects and equipment	929	118,796	0.492
Falls, slips, trips	28	118,796	0.015
Exposure to harmful substances or environments	9	118,796	0.005
Fires and explosions	6	118,796	0.003

Table 8. Nonfatal Injury Time Span Incidence Rate for Forestry/Logging by Cause, United States, 2005-2019

Causes	Total Injuries 2005-2019 (a)	Mean Number of Foresters/Loggers 2005-2019 (b)	Incidence Rate [(a/b)*100] (%)
Transportation incidents	2,110	115,041	1.834
Violence and other injuries by persons or animals	70	115,041	0.061
Contact with objects and equipment	7,690	115,041	6.685
Falls, slips, trips	4,070	115,041	3.538
Exposure to harmful substances or environments	320	115,041	0.278
Fires and explosions	0	115,041	0.000

Table 9. Nonfatal Injury Time Span Incidence Rate for Forestry/Logging by Nature, United States, 2005-2019

Natures	Total Injuries 2005-2019 (a)	Mean Number of Foresters/Loggers 2005-2019 (b)	Incidence Rate [(a/b)*100] (%)
Sprains, strains, tears	3100	115,041	2.695
Fractures	2160	115,041	1.878
Cuts, lacerations, punctures	1580	115,041	1.373
Bruises, contusions	530	115,041	0.461
Amputations	110	115,041	0.096
Multiple traumatic injuries	680	115,041	0.591
Soreness, pain	1930	115,041	1.678
All other natures(1)	2705	115,041	2.351

1. Nature of injury columns: chemical burns, heat (thermal) burns, carpal tunnel, and tendonitis were excluded due to no injuries reported for these natures for all. 2. Data for years 2011 and 2016 were not available. 3. Includes non-classifiable responses

Table 10 depicts the correlation results for forestry and logging fatalities showing the relationship between six causes of fatalities/ injuries (transportation incidents; violence and other injuries by persons or animals; contact with objects and equipment; falls, slips, trips; exposure to harmful substances or environments; fires and explosions) by nature of fatal injury (asphyxiations, strangulations, suffocations; internal injuries; intracranial injuries; intracranial injuries and injuries to internal organs; traumatic injuries; other traumatic injuries). A significant correlation was observed between 'Internal injuries' and 'Contact with objects and equipment' ($r = 0.653$, $p = 0.029$) (Table 10). There was also a significant correlation between 'Traumatic injuries' and 'Falls, slips, trips' ($r = 0.633$, $p = 0.037$) (Table 10). Intracranial injuries had a significant correlation with 'Contact with objects and equipment' ($r = 0.599$, $p = 0.052$).

Table 10. Forestry & Logging Fatality Correlation Analysis (2003-2018). Significant *p*-values indicated by bold text.

Variables		**Asphyxiations, strangulations, suffocations**	**Internal injuries**	**Intracranial injuries**	**Intracranial injuries and injuries to internal organs**	**Traumatic injuries**	**Other traumatic injuries**
Transportation incidents	*Correlation*	-0.576	-0.263	0.385	0.130	0.350	-0.401
	P-value (2-tailed)	0.064	0.435	0.243	0.703	0.291	0.222
Violence and other injuries by persons or animals	*Correlation*	0.422	0.422	0.309	-0.229	-0.302	0.411
	P-value (2-tailed)	0.196	0.196	0.355	0.499	0.367	0.210
Contact with objects and equipment	*Correlation*	0.003	0.653	0.914	0.599	0.577	0.565
	P-value (2-tailed)	0.994	**0.029**	0.000	**0.052**	0.063	0.070
Falls, slips, trips	*Correlation*	-0.415	0.241	0.126	0.465	0.633	0.142
	P-value (2-tailed)	0.205	0.476	0.711	0.149	**0.037**	0.677
Exposure to harmful substances or environments	*Correlation*	0.285	0.197	0.386	0.044	-0.047	0.143
	P-value (2-tailed)	0.395	0.562	0.241	0.897	0.890	0.674
Fires and explosions	*Correlation*	0.443	0.327	0.240	-0.258	-0.334	0.371
	P-value (2-tailed)	0.172	0.326	0.478	0.444	0.316	0.261

Fatal and nonfatal injury maps for foresters/loggers in the US are shown (Figures 10-12) (AgInjuryNews.org). Fatal and non-fatal incidents occurred primarily on the west or east coasts, with a total of 135 incidents (Figure 10). Figure 11 shows that three of the 42 total injuries occurred in the Midwest from 2015-2020. Figure 12 also shows a clustering of fatalities in the Pacific Northwest (PNW) region associated with the area.

Figure 10. Incidents of Fatalities & Injuries Combined Map for Forestry & Logging by City, United States, 2015-2020 (AgInjuryNews.org)

Figure 11. Incidents of Injuries Map for Forestry & Logging by City, United States, 2015-2020) (AgInjuryNews.org)

Figure 12. Incidents of Fatalities Map for Forestry & Logging by City, United States, 2015-2020, (AgInjuryNews.org)

Fatality/injury for Logging

Fatality rates (2003-2018) for loggers are shown (Figure 13, Table 11) and indicate that 'contact with objects and equipment' was the most frequent cause of fatality in loggers (4.92 fatalities per 10,000 workers for all years combined), followed by 'transportation incidents' (2.31 fatalities per 10,000 workers for all years combined). As previously stated, the BLS-reported fatality rate for all industries in the US (2017) was 3.5 fatalities per 100,000 workers (0.35 fatalities per 10,000 workers). Fatalities for all cause types were (8.38 fatalities per 10,000) 23-times higher than the national average. The next most frequent cause of fatalities in loggers was 'falls, slips, trips' (0.14 fatalities per 10,000 workers); however, no fatalities were recorded due to 'falls, slips, and trips' during 2005-2011. Figure 14 and Table 12 depicts the nonfatal injury rates for logging by cause in the United States. As was the case for fatalities, 'contact with objects and equipment' was the most frequent cause of injury in loggers (52.87 injuries per 10,000 workers). The category of 'falls, slips, trips' was also the second leading cause for injuries during the same time frame (27.23 injuries per 10,000 workers) (Table 12). Additional figures of this data can be found in (Appendix I).

Figure 13. Number of Fatalities for Logging by Cause, United States, 2003-2018

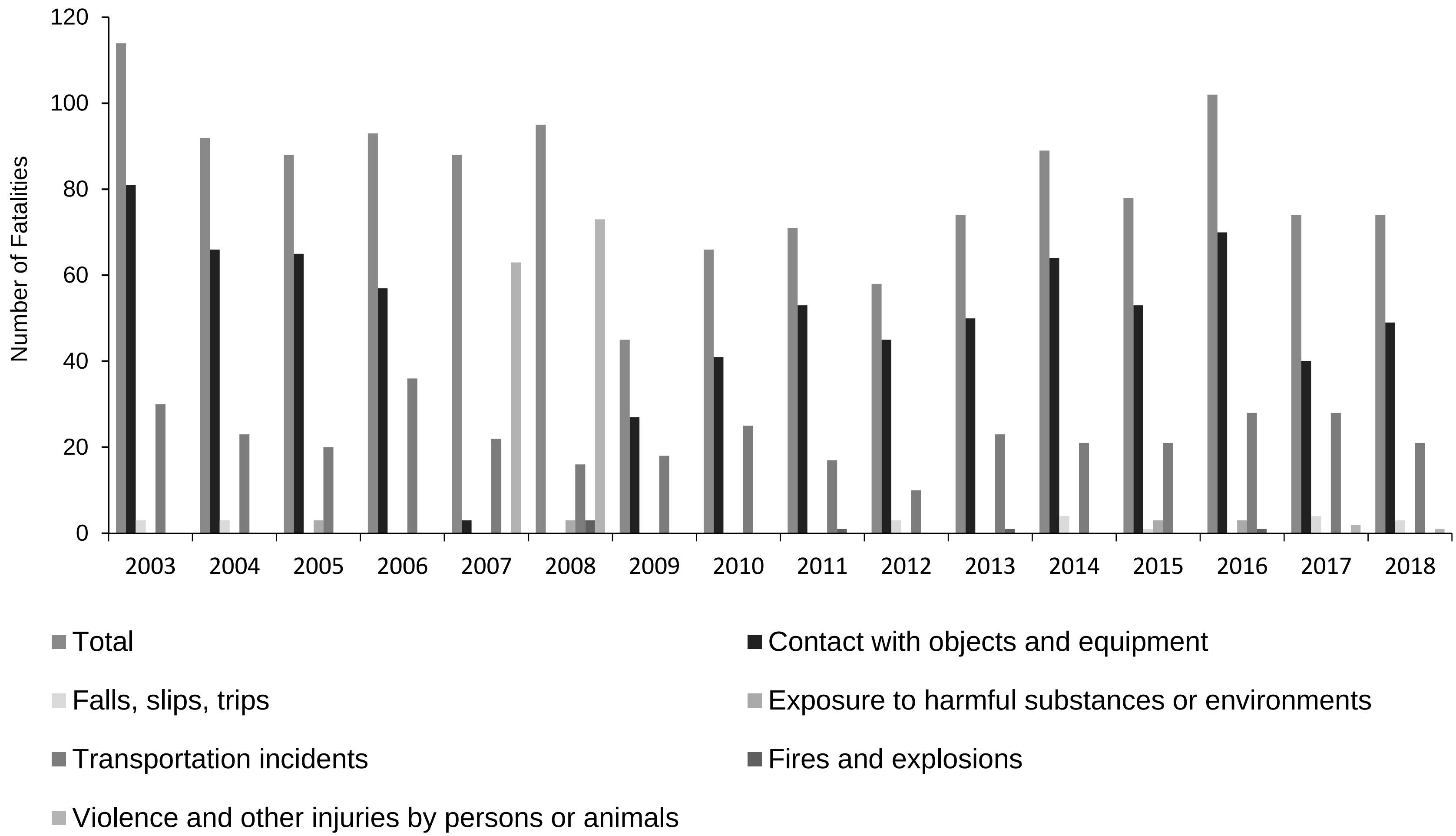


Table 11. Fatality Rates* for Logging by Cause, United States, 2003-2018

Year	**Contact with objects and equipment**		**Falls, slips, trips**		**Exposure to harmful substances or environments**		**Transportation incidents**		**Fires and explosions**		**Violence and other injuries by persons or animals**		**Total**	
	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers	No. of fatalities	Rate per 10,000 workers
2003	81	7.02	3	0.26	0	0.00	30	2.60	0	0.00	0	0.00	114	9.88
2004	66	5.72	3	0.26	0	0.00	23	1.99	0	0.00	0	0.00	92	7.97
2005	65	5.52	0	0.00	3	0.25	20	1.70	0	0.00	0	0.00	88	7.48
2006	57	4.88	0	0.00	0	0.00	36	3.08	0	0.00	0	0.00	93	7.97
2007	3	0.27	0	0.00	0	0.00	22	1.95	0	0.00	63	5.59	88	7.81
2008	0	0.00	0	0.00	3	0.28	16	1.50	3	0.28	73	6.86	95	8.93
2009	27	2.71	0	0.00	0	0.00	18	1.81	0	0.00	0	0.00	45	4.52
2010	41	4.18	0	0.00	0	0.00	25	2.55	0	0.00	0	0.00	66	6.72
2011	53	5.80	0	0.00	0	0.00	17	1.86	1	0.11	0	0.00	71	7.78
2012	45	5.00	3	0.33	0	0.00	10	1.11	0	0.00	0	0.00	58	6.45
2013	50	5.40	0	0.00	0	0.00	23	2.48	1	0.11	0	0.00	74	7.99
2014	64	7.26	4	0.45	0	0.00	21	2.38	0	0.00	0	0.00	89	10.09
2015	53	6.40	1	0.12	3	0.36	21	2.54	0	0.00	0	0.00	78	9.42
2016	70	8.53	0	0.00	3	0.37	28	3.41	1	0.12	0	0.00	102	12.43
2017	40	5.39	4	0.54	0	0.00	28	3.78	0	0.00	2	0.27	74	9.98
2018	49	7.15	3	0.44	0	0.00	21	3.06	0	0.00	1	0.15	74	10.80
Total	764	4.92	21	0.14	12	0.08	359	2.31	6	0.04	139	0.90	1301	8.38

* Number of fatalities (by cause) divided by the total number of logging workers for years 2003-2018, multiplied by 10,000

Figure 14. Number of Nonfatal Injuries for Logging by Cause, United States, 2005-2019

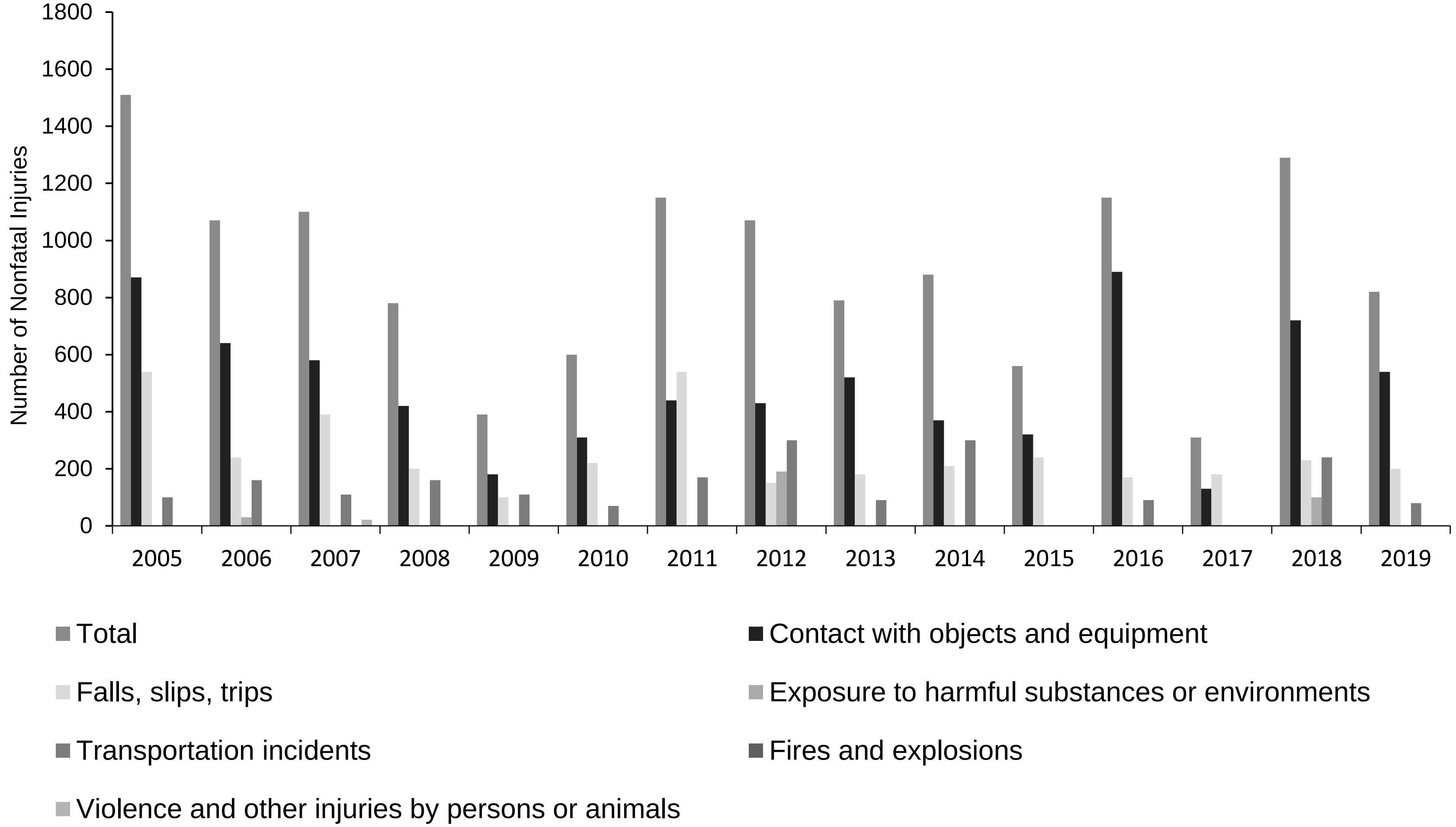


Table 12. Number of Nonfatal Injuries in Logging by Cause[1], (2005-2018)[2]

Year	Contact with objects and equipment		Falls, slips, trips		Exposure to harmful substances or environments		Transportation incidents		Fires and explosions		Violence and other injuries by persons or animals		Total	
	No. of injuries	Rate per 10,000 workers	No. of injuries	Rate per 10,000 workers	No. of injuries	Rate per 10,000 workers	No. of injuries	Rate per 10,000 workers	No. of injuries	Rate per 10,000 workers	No. of injuries	Rate per 10,000 workers	No. of injuries	Rate per 10,000 workers
2005	870	73.93	540	45.88	0	0.00	100	8.50	0	0.00	0	0.00	1510	128.31
2006	640	54.84	240	20.57	30	2.57	160	13.71	0	0.00	0	0.00	1070	91.69
2007	580	51.49	390	34.62	0	0.00	110	9.76	0	0.00	20	1.78	1100	97.65
2008	420	39.50	200	18.81	0	0.00	160	15.05	0	0.00	0	0.00	780	73.35
2009	180	18.07	100	10.04	0	0.00	110	11.04	0	0.00	0	0.00	390	39.15
2010	310	31.57	220	22.40	0	0.00	70	7.13	0	0.00	0	0.00	600	61.10
2011	440	48.19	540	59.14	0	0.00	170	18.62	0	0.00	0	0.00	1150	125.95
2012	430	47.80	150	16.67	190	21.12	300	33.35	0	0.00	0	0.00	1070	118.94
2013	520	56.16	180	19.44	0	0.00	90	9.72	0	0.00	0	0.00	790	85.33
2014	370	41.97	210	23.82	0	0.00	300	34.03	0	0.00	0	0.00	880	99.81
2015	320	38.63	240	28.98	0	0.00	0	0.00	0	0.00	0	0.00	560	67.61
2016	890	108.48	170	20.72	0	0.00	90	10.97	0	0.00	0	0.00	1150	140.18
2017	130	17.53	180	24.27	0	0.00	0	0.00	0	0.00	0	0.00	310	41.80
2018	720	105.07	230	33.56	100	14.59	240	35.02	0	0.00	0	0.00	1290	188.25
2019	540	75.71	200	28.04	0	0.00	80	11.22	0	0.00	0	0.00	820	114.96
Total	7360	52.87	3790	27.23	320	2.30	1980	14.22	0	0.00	20	0.14	13470	96.76

* Number of injuries (by cause) divided by the total number of logging workers for years 2005-2019, multiplied by 10,000

Table 13 shows that ‘Transportation incidents” caused the highest (0.37%) incidence of fatalities for loggers. ‘Violence and other injuries by persons or animals’ were ranked second for cause of fatalities (0.14%) in loggers. ‘Contact with objects and equipment’ ranked third overall for cause of fatalities (0.08%) in loggers.

Table 13. Fatality Time Span Incidence Rate for Logging by Cause, United States, 2003-2018

Causes	Total Fatalities 2003-2018 (a)	Mean Population of Loggers 2003-2018 (b)	Incidence Rate [(a/b)*100] (%)
Transportation incidents	359	96,976	0.37
Violence and other injuries by persons or animals	139	96,976	0.14
Contact with objects and equipment	76	96,976	0.08
Falls, slips, trips	21	96,976	0.02
Exposure to harmful substances or environments	12	96,976	0.01
Fires and explosions	6	96,976	0.01

Injury time span incidence rate calculations showed that ‘contact with objects and equipment’ was the leading cause of injuries in loggers (7.93%), followed by ‘falls, slips, trips (4.08%) and ‘transportation incidents’ (2.13%) (Table 14).

Table 14. Nonfatal Injury Time Span Incidence Rate for Logging by Cause, United States, 2005-2019

Causes	Total Injuries 2005-2019 (a)	Mean Population of Loggers 2005-2019 (b)	Incidence Rate [(a/b)*100] (%)
Transportation incidents	1980	92,805	2.13
Violence and other injuries by persons or animals	20	92,805	0.02
Contact with objects and equipment	7360	92,805	7.93
Falls, slips, trips	3790	92,805	4.08
Exposure to harmful substances or environments	320	92,805	0.35
Fires and explosions	0	92,805	0

Table 15. Nonfatal Injury Time Span Incidence Rate for Logging by Nature of Injury [(1)], United States, 2005-2019[(2)]

Nature of Injury	Total Injuries 2005-2019 (a)	Mean Number of Foresters/Loggers 2005-2019 (b)	Incidence Rate [(a/b)*100] (%)
Sprains, strains, tears	3100	115,041	2.695
Fractures	2160	115,041	1.878
Cuts, lacerations, punctures	1580	115,041	1.373
Bruises, contusions	530	115,041	0.461
Amputations	110	115,041	0.096
Multiple traumatic injuries	680	115,041	0.591
Soreness, pain	1930	115,041	1.678
All other natures of injury[(3)]	2705	115,041	2.351

1. Nature of injury columns: chemical burns, heat (thermal) burns, carpal tunnel, and tendonitis were excluded due to no injuries reported for these natures for all. 2. Data for years 2011 and 2016 were not available. 3. Includes non-classifiable responses

A correlation analysis showed the relationship between the six causes of logging fatalities (e.g., transportation incidents, violence and other injuries by persons or animals, contact with objects and equipment, falls/slips/trips, exposure to harmful substances or environments, fires and explosions) by nature of fatal injury (e.g., asphyxiations/strangulations/suffocations, internal/intracranial injuries, intracranial injuries and injuries to internal organs, traumatic injuries, and other traumatic injuries) (Table 16). Significant correlations were observed between; ‘asphyxiations and strangulations. Suffocations’ was significantly negatively correlated to ‘transportation incidents’ (r = -0.604, p = 0.049) and ‘violence and other injuries by persons or animals’ was positively correlated to ‘other traumatic injuries (r = 0.471, p = 0.037) (Table 16).

Table 16. Logging fatality correlation analysis (2003-2018). Significant *p*-value indicated in bold text.

Variables		Asphyxiations, strangulations, suffocations	Internal injuries	Intracranial injuries	Intracranial injuries and injuries to internal organs	Traumatic injuries	Other traumatic injuries
Transportation incidents	*Correlation*	-0.604	0.370	0.319	-0.434	0.486	-0.402
	P-value (2-tailed)	**0.049**	0.262	0.338	0.182	0.130	0.220
Violence and other injuries by persons or animals	*Correlation*	0.089	0.576	0.232	-0.374	0.243	0.632
	P-value (2-tailed)	0.794	0.064	0.492	0.257	0.471	**0.037**
Contact with objects and equipment	*Correlation*	-0.151	-0.269	0.314	0.472	0.032	-0.353
	P-value (2-tailed)	0.658	0.424	0.347	0.142	0.927	0.286
Falls, slips, trips	*Correlation*	0.003	-0.247	0.235	0.559	-0.056	0.017
	P-value (2-tailed)	0.994	0.464	0.487	0.074	0.869	0.960
Exposure to harmful substances or environments	*Correlation*	0.541	0.456	0.513	-0.199	0.201	0.496
	P-value (2-tailed)	0.086	0.159	0.106	0.557	0.554	0.121
Fires and explosions	*Correlation*	0.429	0.163	0.295	-0.044	-0.190	0.480
	P-value (2-tailed)	0.188	0.632	0.378	0.897	0.576	0.135

Development of Educational Materials on Injury Prevention for Distribution to Foresters

After identifying the most frequent causes of forester injuries/fatalities, the information was used to develop an educational pamphlet that will help increase knowledge among foresters/loggers and their employers (Appendix II). The goal is to have workers and employers be more informed regarding the common causes of injuries/fatalities, which may improve worker safety. In this pamphlet, key findings are summarized (e.g., for the period of study [2003-2019]), ‘contact with objects and equipment’ was the primary cause of injuries and fatalities. ‘Transportation’-related incidents ranked second for the cause of fatalities (2003-2018), while ‘falls, slips, & trips’ was ranked second for the cause of injuries (2005-2019). The pamphlet also includes tips on how to help prevent injuries/fatalities for these three causes. This pamphlet will be made available both online and in print form.

Systematic Review of Occupational Health Risks in Foresters

Studies focusing on the biological, chemical, ergonomic, physical, psychosocial, and safety hazards of forestry and logging workers over the last 11 years (2011-2022) were pooled here in this study. These studies focused solely on forestry and logging workers in the US and showed the significant need for additional research in this area. We excluded studies that combined foresters and loggers with other agro-occupations for reasons discussed further in this paper. The studies that were included were divided into five categories: Biological, Chemical, Ergonomic, Physical, Psychosocial, & Safety – Hazards and Table 17 provides a snapshot of the studies included in this review.

Biological Hazards

Workers in the forestry industry have the potential to encounter wild animals, arachnids, insects, snakes, and other potential threats. Arthropod bites and arthropod-borne infections are among the most frequent occupational hazards among foresters, but few articles could be found that focus on this issue in US foresters (Haeberle, 2020). A 2018 report found that Hymenoptera-related deaths accounted for ~30% of the total animal-related fatalities between 2008-2015, and the number of deaths has remained steady over the last 20 years (Forrester et al., 2018). Despite these statistics, only one study in the last 10 years evaluated Hymenoptera. Hymenoptera is an order of insects that includes ants, bee, wasps, yellow jackets (Brock, 2021; Dillane et al., 2019), and other related organisms. Venom from Hymenoptera stings can result in mild symptoms ranging from localized itching or swelling to systemic reactions (e.g., anaphylaxis) which can be life threatening; thus, Hymenoptera pose a potential health threat to foresters (Dillane et al., 2019). Access to medical attention is limited as foresters often work in remote locations (Dillane et al., 2019). Dillane et al. (2019) evaluated Hymenoptera stings/bites in foresters using a 29-question survey (Dillane, Richards, Balanay, & Langley, 2019). Of the total number of participants (n = 474), >90% reported experiencing hymenopteran stings while on the job (Dillane et al., 2019). Only two participants reported the need for medical intervention (Dillane et al., 2019). The survey also found that participants' attitude towards hymenopteran was relatively apathetic with 70% reporting as "not concerned" about being stung (Dillane et al., 2019).

Arboviruses (transmitted primarily by mosquitoes) and bacterial pathogens (transmitted primarily by ticks) are additional health threats to foresters due to the nature of their outdoor work (Covert & Langley, 2002). Forestry workers are at risk of tick-borne diseases such as Lyme borreliosis, tick-borne encephalitis, anaplasmosis, relapsing fever, tularemia, babesiosis, and rickettsiosis (Haeberle, 2020). Examples of arboviruses include St. Louis encephalitis virus (SLEV), Eastern equine encephalitis virus (EEEV), Western equine encephalitis virus (WEEV), West Nile virus, Powassan virus, and Colorado tick fever virus (Covert & Langley, 2002). A 2012 study evaluated the seroprevalence of: 1) tick-borne zoonotic disease agents (*Anaplasma phagocytophilum, Borrelia hermsii, Borrelia burgdorferi,* Colorado tick fever virus, *Ehrlichia chaffeensis, Francisella tularensis*, and spotted fever group rickettsiae); 2) mosquito-borne zoonotic disease agents (*Bunyaviridae* and *Flaviviridae*); and 3) other routes of transmission (e.g., flea-borne, soil-borne, direct contact, and food-borne; *Bartonella henselae*, Brucella spp*., Coxiella burnetii, Leptospira spp., Toxoplasma gondii*, typhus group rickettsiae, and *Yersinia pestis*) (Adjemian et al., 2012). The serum analysis found that 12 participants showed evidence of incident infection with one of six different agents: *B. anthracis, B. henselae*, California serogroup viruses, Leptospira spp., spotted fever group rickettsiae, and *T. gondii* (Adjemian et al., 2012). Five participants showed evidence of incident infection with *B. henselae* or spotted fever group rickettsiae; one was infected with both. Only one participant during the study period had incident infection with a mosquito-borne pathogen serologically identified as La Crosse virus (Adjemian et al., 2012). In the same study, a questionnaire was also administered to the National Park Service staff on potential risk factors and clinical features (Adjemian et al., 2012). The questionnaire results found that 81% of the participants reported insect bites during the study period, 32% found ticks on their skin or clothes (Adjemian et al., 2012). Nearly half (56%) reported contact with animals at work, including rodents (37%), canids (18%) (Adjemian et al., 2012). A minority of participants reported higher-risk zoonotic exposures, including contact with dead rodents (20%) and canid bites (Adjemian et al., 2012). One of the methods utilized by study participants to reduce exposure to tick and mosquito bites was using specifically treating clothing with insecticide/repellent (Adjemian et al., 2012). Vaughn et al. (2014) and Wallace et al. (2016) both used the same study population: State Divisions of Forestry, Parks and Recreation, and Wildlife Workers. Foresters (n = 34) from the Appalachian Region of the US was the population utilized by Richards et al. (2015). The Appalachian Region consists of Kentucky, NC, Ohio, Tennessee, Virginia, and West Virginia (Richards et al., 2015). Vaughn et al. (2014) and Wallace et al. (2016) carried out a two-year double-blind randomized intervention with 159 participants, 80 of which were assigned to the control group (non-treated clothing) and 79 were assigned to the experimental group (treated clothing). Vaughn et al. (2014) focused on the incidence of tick bites compared between control and treatment groups over a two-month period. Wallace et al. (2016) assessed study participants for tick-borne infections and examined seroconversion (e.g., a fourfold rise in antibody IgG titer) risk factors (Wallace et al., 2016). Despite similarities in their study design, these studies showed differing results (Vaughn et al., 2014; Wallace et al., 2016). Vaughn et al. (2014) found that the effectiveness of permethrin treated clothing at reducing tick bites in the first year of wear was 82%. However, the effectiveness dropped to 34% for the second year in the study (Vaughn et al., 2014), likely due to washing and other factors. In a separate study, the authors found that control participants received a lower rate of tick exposure (13 bites/person) than those in the group (21 bites/person) wearing permethrin treated clothing (Richards et al., 2015). One possible explanation for this finding is that the two groups were in different locations, and these locations are likely to have differing levels of tick abundance (Richards et al., 2015). Wallace et al. (2016) found that wearing permethrin treated clothing lowered the risk of infection of tick-borne disease, but it was not a statistically significant decrease. A study by Richards et al. 2021, looked at the effectiveness of permethrin clothing over the period of one year, and the amount of permethrin absorbed into the foresters' body after repeated wearing. This study, which was conducted on a small subset of foresters in central NC found that only 33% of the long lasting permethrin-impregnated (LLPI) clothing evaluated after one year of use contained no measurable amount of permethrin (Richards et al., 2021). The study also looked at permethrin metabolites in the workers' urine at four intervals: baseline (prior to study), one month, three-four-months, and one-year. Results of the urine analysis for permethrin metabolites showed an increase at the one month and three-four-month marks, but at the one-year mark metabolites had decreased. Similar findings were observed in a three-month pilot study, where it was observed that permethrin metabolites in the urine decreased after initial usage of the LLPI (Sullivan et al. 2019). This result aligns with the findings of the LLPI having a significant decrease in permethrin concentration at the one-year mark (lower concentration of permethrin in clothing means lower permethrin to be absorbed into the body) (Richards et al., 2021). A 2019 pilot study found that, in the same study population, the absorbed dosage of permethrin averaged < 4 μg/kg/d of body weight (Sullivan et al., 2019)

Kosoy et al., 2016 performed a serological analysis for mosquito-borne bunyaviruses. The study evaluated the sera for neutralizing antibodies using plaque reduction neutralization test (PRNT) against six orthobunyaviruses: La Crosse virus (LACV), Jamestown Canyon virus (JCV), snowshoe hare virus (SSHV), California encephalitis virus, and Trivittatus virus (TVTV) belonging to the California serogroup and Cache Valley virus (CVV) belonging to the Bunyamwera serogroup (Kosoy et al., 2016). Serum samples were also tested for immunoglobulin G (IgG) antibodies against LACV and JCV by enzyme-linked immunosorbent assay (ELISA) (Kosoy et al., 2016). The study period was one year; two sera samples were gathered during the testing period, one at the start of the study and one at the end (Kosoy et al., 2016). Participants of the study consisted of 295 US National Park Service and US Forest Service (USFS) employees of Great Smoky Mountains National Park (GRSM), Rocky Mountain National Park (ROMO), and Grand Teton National Park with adjacent Bridger-Teton National Forest (GRTE-BTNF) (Kosoy et al., 2016). The national parks were separated into two groups, eastern (GRSM) and western (ROMO, GRTE-BTNF) (Kosoy et al., 2016). The analysis found the presence of neutralizing antibodies to LACV and JCV in all sera, which were positive for IgG antibodies against those viruses (Kosoy et al., 2016). The PRNT analysis found that one third of participants had neutralizing antibodies, indicative of previous infection with mosquito-borne bunyaviruses (Kosoy et al., 2016). Participants in the eastern region had a higher seroprevalence to LACV and western participants had higher seroprevalence to snowshoe hare virus (Kosoy et al., 2016). Seroprevalence to JCV was found in all participants (Kosoy et al., 2016).

Chemical Hazards

Only one published article was found included evaluating chemical exposure in US forestry workers. Kim et al. (2017) conducted a cross-sectional study in which Virginian loggers (n = 122) completed a self-reporting survey related to safety and health related to logging equipment. One aspect of this questionnaire related to diesel exhaust exposure symptoms. More than half (57.4%) of study participants reported common diesel exhaust exposure (Kim et al., 2017). These symptoms included having work-related eye/mouth irritation and/or unpleasant smells while operating a machine or when working near a machine (Kim et al., 2017).

In one niche study on USFS worker exposure to asbestiform amphibole (Libby Amphibole [LA]; an ore within the mineral vermiculite) was assessed for risk of cancer (https://iris.epa.gov/ChemicalLanding/&substance_nmbr=1026). The vermiculite mine was the world’s leading source of vermiculite for 70 years until its closure in 1990 (Gavett et al., 2016). Vermiculite is used for insulation, as an absorbent material, and as a soil conditioner, with applications in the construction, agricultural, horticultural, and industrial markets (Gavett et al., 2016). The Libby vermiculite ore coexists with a complex array of amphibole mineral types referred to as Libby amphibole (LA) asbestos (Gavett et al., 2016). Raw vermiculite ore from the Libby mine has been estimated to contain up to 26% LA, and was dispersed throughout the site (including the Kootenai National Forest) because of mining and milling operations and the use of vermiculite for insulation and soil amendments. Studies have demonstrated the presence of amphibole fibers in tree-bark, forest floor litter ("duff"), and soil (Ward et al., 2006; Hart et al., 2009; Harper et al., 2015). Thousands of acres of the Kootenai National Forest are included under the Superfund site designation. The USFS is responsible for managing federal lands in the Kootenai National Forest, and these workers are required to enter and work in the area. Current USFS workers perform tasks such as trail maintenance and fuels management, which are performed with strict supervisor review and approval based on need, duration, and time of year. Thus, the USFS workers stationed in Libby, Montana may be at risk for LA exposure through inhalation as they perform their job duties. Harper et al.'s 2015, cancer risk assessment found that workers are likely to be at low risk for developing cancer based on having a Hazard Index of <1 (Harper, Butler, Berry, & Wroble, 2015). This study highlights that workers in the forestry industry are at risk for occupational hazards from a wide range of sources not just the common ones, like equipment and human error.

Ergonomic Hazards

The Agriculture, Forestry, and Fishing sector has some of the highest work-related musculoskeletal disorder (MSD) rates across all industry sectors (Granzow et al., 2018). The use of mechanized equipment in the forestry industry has been found to not eliminate the risk of occupational health disorders (Granzow et al., 2018). A 2019 study conducted a self-reported survey related to musculoskeletal symptoms with a focus on the cause related to logging machine usage (Rodriguez, Casanova, Levin, Gimeno Ruiz de Porras, David, & Douphrate, 2019). The study included 88 logging machine operators from three states (Arkansas, Louisiana, and Texas) who participated in their survey (e.g., respondents were asked to report yes or no to experiencing the pre-defined questions about musculoskeletal symptoms in the last 12 months) (Rodriguez et al., 2019). Study participants in Kim et al. (2017) consisted of 122 Virginian loggers. Nearly all participants surveyed (98%) (Kim et al., 2017) reported experiencing musculoskeletal symptoms in at least one body part in the year that preceded the survey. Whereas only 55.7% of respondents reported in Rodriguez et al. (2019) having at least one musculoskeletal symptom in the last 12 months (Rodriguez et al., 2019). The most reported area of the body experiencing musculoskeletal symptoms was the lower back (49.2%), followed by the knee (37.7%) and shoulder (35.3%) (Kim et al., 2017). Rodriguez et al. (2019) reported the most common body regions for musculoskeletal symptoms as upper back (31.8%), lower back (30.7%), and lower extremities (30.7%) (Rodriguez et al., 2019).

In the aforementioned study, the authors also reported on ergonomic related factors that could lead to musculoskeletal symptoms (Rodriguez et al., 2019). The study found that most musculoskeletal symptoms were reported in the lower extremities when working in awkward or cramped conditions (55.6%) and for the lower back when bending and/or twisting in an awkward way (50.0%) (Rodriguez et al., 2019). In a study of Montana loggers, the authors found that the anatomical areas with the highest prevalence of musculoskeletal symptoms for all loggers over the 12-month time-period evaluated were the ‘low back’ (38.1%), shoulders (27.6%), neck (24.8%), and knees (24.7%) (Lagerstrom, Magzamen, Brazile, & Rosecrance, 2019). In a separate study of logging machine operators in the southern US, 10.5% of survey respondents self-reported a MSDs diagnosis, 74.3% reported current mild back pain at the time of the survey, and 71.7% reported mild back pain in the last year (Lynch et al., 2014). The survey also evaluated if pain was associated with which machine they preferred to operate. There was no significant difference between the preference of machine types (feller buncher, wheeled skidder, dozer, loader, and semi-tractor) in relation to pain but the loader (which is a stationary machine) had the highest preferred percentage amongst the groups (Lynch et al., 2014). Working in the same position for long periods and working in hot, cold, humid, or wet conditions were at the top of the list for MSDs causative factors according to the Rodriguez et al. study. A separate study identified that increased musculoskeletal issues were associated with traditional harvesting systems, increased years of experience (e.g., older workers), and increased body mass index (BMI) (Lagerstrom et al., 2019). The development of MSD in traditional harvesting system workers is correlated with the use of chainsaws, which is a primary component of this harvesting system (Patterson, 2014). Age and BMI has also been previously linked to the development of MSDs (Tantawy et al., 2017; Viester et al., 2013). Lagerstrom et al., 2019 reported that, of the 743 professional loggers in Montana who participated in the study, loggers using traditional felling practices with chainsaws were more than twice as likely to report musculoskeletal symptoms than those using mechanized logging equipment.

A 2018 study looked at MSDs in Alabama reforestation workers, specifically those who hand planted seedlings into the ground (Figure 15) and are members of the Alabama Forestry Commission (Granzow et al., 2018). Participants were observed for one workday (dawn to dusk) during the prime planting month of January (Granzow et al., 2018). Workers were individually shadowed during the day, and the specific tasks they performed were noted (Granzow et al., 2018). Forceful muscular exertions were measured using continuous surface electromyography (EMG) recordings were acquired from the bilateral upper trapezius and anterior deltoid muscles (Granzow et al., 2018). Direct measurements of posture, movement velocity, and rest / recovery were taken using Actigraph GT9X Link inertial measurement units (IMUs) (Granzow et al., 2018). The study found that hand planters spent >50% of their time performing moderate, vigorous, or very vigorous levels of physical activity (Granzow et al., 2018). Results from the study indicated that hand planters are exposed to higher levels of extreme posture and movement velocities for the upper arms and trunk in comparison to other occupational groups that report a high prevalence occupational MSDs, such as construction workers (Granzow et al., 2018).

Figure 15. Hand Planter in Oregon 2020, (Oregon Forests, 2020)

Physical Hazards

Activities in the forestry industry such as using chainsaws and unlatching cables used to hold and move logs are high on the list of noise exposure sources in the industry (Lawson, 2018). Neitzel et al. 2002, reported noise levels of logging activities and found that tree fellers (who use chainsaws) and hooktenders (who unlatch the cables) had the highest average of noise exposure at 98 and 97 decibels (dBA), respectively. The National Institute on Deafness and Other Communication Disorders states that long or repeated exposure to sounds at or above 85 dBA can cause hearing loss and the louder the sound, the shorter the amount of time it takes to develop noise-induced hearing loss (US DHHS, 2022). For comparison, a normal conversation measures between 60-70 dBA (US DHHS, 2022). Three of the articles in this review reported on the effect of noise exposure on forestry and logging workers (Fonseca et al., 2014; Masterson et al., 2018; McLain et al., 2021). One study design consisted of conducting hearing tests using an audiometer, while the other chose to use personal noise monitoring. Fonseca et al. (2014) compared the hearing threshold for logger against that of normal population at the frequencies of 1000, 2000, and 4000 Hz. Of these three frequencies, loggers were found to be most susceptible to hearing loss at 4000 Hz (Fonseca et al., 2014). Greater hearing loss was reported in correlation with the amount of experience a logger had in the industry, however this correlation could be confounded by age (Fonseca et al., 2014). McLain et al. (2021) showed that, of the 31-cable loggers that wore the noise dosimeters, 92% of them were over exposed to noise based on the NIOSH recommended criteria (McLain et al., 2021). The study also discovered that less than half (46%) of the loggers wore PPE (e.g., hearing protection)

(McLain et al., 2021). When working 12-hour shifts, 33% of mechanized operation loggers were overexposed to noise (McLain et al., 2021). In the Fonseca et al. (2014) study, only 30.8% of participants wore hearing protection (Fonseca et al., 2014). Masterson et al. (2018) compared noise exposure to US Agriculture, Forestry, Fishing, and Hunting (AFFH) sectors between 2003-2012. They found that workers in the Forestry and Logging category had a higher prevalence of hearing loss (~21%) compared to the prevalence of all AFFH combined (19%) (Masterson et al., 2018). The sub-category of "Forest nurseries and gathering of forest products" had the highest prevalence of hearing loss across all categories and sub-categories with a prevalence of 36% (Masterson et al., 2018).

An evaluation of occupational heat induced illness was conducted in Washington State; it included 84 worker compensation claims and 60 heat rule citations (Spector, Krenz, Rauser, & Bonauto, 2014). For context, the State of Washington set and adopted workplace safety standards for heat exposure: Washington Administrative Code 296-307-097. Spector et al. (2014) showed that the majority (73%) of agriculture and forestry heat-related illness claims had a clinical diagnosis of heat syncope, heat cramps, heat exhaustion, heat edema, or heat fatigue (Spector et al., 2014). A small percentage of cases (15%) were attributed to heat stroke and renal failure; with 6% requiring intensive care and one death reported during the time-period of the study (Spector et al., 2014). The same study noted that extenuating factors could have impacted the risk of HRI (e.g., 15% of claims reported medication, supplement, and/or alcohol/drug related factors and 19% of claims reported a concurrent medical condition) (Spector et al., 2014).

Psychosocial Hazards

The NIOSH defines psychosocial hazards as factors in the work environment that could cause stress, strain, or interpersonal problems for the worker (CDC-NIOSH, 2022). The working conditions in the forestry industry that fall under the umbrella of psychosocial hazards include: 1) long working hours / irregular working hours; 2) income; 3) employment insecurity; 4) a workers' autonomy (e.g., a worker's ability to control and direct their own work) (Mylek & Schirmer, 2015). In a recent study of Maine loggers, it was found that, on average, mechanized loggers had longer workdays (11.8 vs. 9.7 hours) and had longer commutes from home to work site (72.6 vs. 40.7 minutes) than conventional loggers (Scott et al., 2020). This difference does not equate to an easier workday for conventional loggers. For conventional loggers, the later start time is due to the need for daylight to see in the woods, and the shorter day is due to the strenuous activity of using a chainsaw (Scott et al., 2020). Mechanized operations use of heavy equipment provides the worker the protection of a cab. For a mechanized logger, their workday begins well before dawn, with help from the bright flood lights (Scott et al., 2020). While most of the mechanized loggers' work takes place inside the cab, they still must maintain situational awareness when getting in and out of the cab multiple times a day to conduct equipment checks to ensure proper operation (Scott et al., 2020). Regardless of logging style, the mental acuity needed to properly and safely fell trees is high and requires a great deal of skill (Scott et al., 2020). This longitudinal cohort study delved further into the health factors impacting Maine loggers and found that the rate of health insurance among mechanized and conventional loggers was

79.8% and 74.3%, respectively (Scott et al., 2020). This difference was not statistically significant (*p*-value = .9760) (Scott et al., 2020). Additionally, Rates of employer-provided workers' compensation coverage differed significantly between mechanized and conventional loggers with mechanized loggers more likely to have workers' compensation coverage (Scott et al., 2020). Moreover, 23% of loggers injured on the job failed to file a claim due to reasons not described in the study. However, some possible explanations include: demographic characteristics such as age, organizational tenure, and employment status; personality characteristics, particularly, consideration of future safety consequences; level of trust in the employee-employer relationship; perceptions of an organization's workplace and gender climate; safety-related moral disengagement; perceived lack of management responsiveness; fear of reprisals or loss of workplace perks and pay incentives; and an acceptance that injuries are commonplace in certain lines of work (Probst et al., 2019). In a 2015 interview study of Spanish-speaking immigrant forestry workers in Oregon, 71% of respondents stated that the primary reason for them not reporting injuries was fear of retaliation (Wilmsen et al., 2015). Additionally, the survey found that the service contractors did not always follow the labor laws, and only 39% of the workers received safety training (Wilmsen et al., 2015). Moreover, the respondents reported that they never have all the PPE required for the job, and 95% reported that their PPE was sometimes or always worn out (Wilmsen et al., 2015). In a more recent study, non-management loggers in West Virginia reported that they felt the push from management on the importance of production and working at a quick pace decreased worksite safety (Lundstrom et al., 2021). One interviewee was quoted saying "*that pushes for production have negative* *implications for their workers' health and that their bosses fail to recognize this*" (Lundstrom et al., 2021). When asked to further elaborate on this topic of production pressure, a handful of respondents spoke on the rush of production can be tiring, when you are tired, mistakes happen, injuries happen… "*If you get tired, and you're dragging… sit down and take a break. [Take a] drink of water… Don't get carried away… cause if you're straining yourself, then you're less likely to be doing whatever you need to be doing.*" (Lundstrom et al., 2021). In contrast, the managers interviewed responded that the most common cause of unsafe work environments was due to the workers' inexperience and overconfidence to perform the job task (Lundstrom et al., 2021). Both groups (managers and non-managers) agreed that PPE was imperative for workplace safety (Lundstrom et al., 2021). Similar sentiments were recorded in an interview study of logging contractors located in Idaho (Newman et al., 2018). Respondents reported that production pressure, fatigue, and inexperience among the most-common factors contributing to logging injuries from the perspective of participants (Newman et al., 2018). Additionally, the survey found that barriers to utilizing new technologies were the 'potiential for distraction' and cost of these technologies (Newman et al., 2018).

Safety Hazards

An emerging area of study related to physical hazards is the threat that pine beetles have on tree structural integrity. Only one study was identified on this topic. The authors focused on how bark beetle infestations in trees pose a health and safety threat to forestry workers (Durbin, Bendixsen, Jensen-Ryan, Molzer, & Strauss, 2019). For context, bark beetles bore into conifer trees and lay eggs in the tree phloem. When the larva hatches from the egg it begins to eat the living tissues of the tree which can cut off the distribution of water and nutrients to the tree, causing the tree to die (Sauvard, 2007). Durbin et al. (2019) conducted a qualitative, ethnographic fieldwork (direct observation, participant observations, informal interviews, semi-structured interviews, and document collection) study that evaluated four sites. Sites were based on three criteria: 1) Presence of beetle-killed forest, 2) Presence of forest workers, and 3) Habitat and pine species diversity (Durbin et al., 2019). Durbin et al. (2019) conducted 20 semi-structured interviews of wildland fire crews, USFS rangers, forest safety managers, chainsaw coordinators, and lumber mill sawyers (Durbin et al., 2019). Participants were interviewed on their opinions of working in beetle-killed forests and one interviewee stated he would “never do it again” (Durbin et al., 2019). The wildland firefighters, non-production hand fellers, and foresters were those most concerned and these group are the most likely exposed to forests with beetle kill hazards (Durbin et al., 2019). One of the most significant hazards reported was an increase in falling limbs which is commonly referred to as ‘widow makers’ (Durbin et al., 2019). Another major safety concern was the severity of forest fires with respect to how the fires can weaken tree integrity (Durbin et al., 2019). In the 2019 study survey respondents reported that most injuries were caused by trees, logs, and limbs (Scott et al. 2019).

In a 2017 study that interviewed logging supervisors and front-line crew members in the southern US found that the participants identified log trucking-related incidents as the primary source of risk for fatal and nonfatal injuries at the work site (Conway et al. 2017). Scott et al. (2019) found in their survey that vehicles and heavy equipment were the second leading cause of injuries among the loggers surveyed. Lagerstrom (2017) found that respondent in a focus group made up of loggers from Montana and Idaho perceived identified job tasks involving felling trees, skidding, and truck driving as having highest risk. Furthermore, the study found in an analysis of worker compensation claims (of the same population), sprains/strains were the most common type of injury.

Table 17. Detailed comparison of Forestry/Logging Studies in the United States							
	First Author	*Year*	*Location*	*Study Population*	*Study Design*	*Exposure metric*	*Key findings*
Biological Hazards							
	Adjemian	2012	Great Smoky Mountains (GRSM) and Rocky Mountain National Parks (ROMO)	US National Park Service (NPS) Employees	Quasi-Experimental	Quantified background seroprevalence and measured incident infections to select zoonotic pathogens; questionnaires were also administered on potential risk factors and clinical features.	The study found incident infections with leptospirosis (5.7%), *B. henselae* (5.7%), spotted fever group rickettsiae (1.5%), *T. gondii* (1.5%), *B. anthracis* (1.5%), and La Crosse virus (1.5%) in staff members at GRSM, and with spotted fever group rickettsiae (8.5%) and *B. henselae* (4.3%) in staff at ROMO.
	Dillane	2019	US	Consulting/state foresters, parks and recreation employees, and national parks service employees	Survey	Self-reported Hymenoptera stings over 5-years	90% of participants in the study reported experiencing Hymenoptera stings at work.
	Kosoy	2016	Colorado, North Carolina, Tennessee, & Wyoming	US NPS and US Forest Service (USFS) employees	Quasi-Experimental	Serological surveys to investigate exposure to mosquito-borne bunyaviruses: La Crosse virus (LACV), Jamestown Canyon virus (JCV), snowshoe hare virus (SSHV), California encephalitis virus, and Trivittatus virus (TVTV) belonging to the California serogroup and Cache Valley virus (CVV)	One third of participants had neutralizing antibodies indicative of previous infection with mosquito-borne bunyaviruses. Participants in the eastern US had a higher seroprevalence to LACV and western participants had higher seroprevalence to (SSHV). Seroprevalence to JCV was found in all participants.

	Richards	2021	Central North Carolina	Foresters	Quasi-Experimental	The study looked at: the permethrin content of new and used long lasting permethrin impregnated (LLPI) clothing; how much permethrin workers absorbed into their body as a result of wearing LLPI; the lethality of the permethrin clothing (new vs. used) on nymphal black legged ticks.	The study found that 1/3 of the participants clothing at the one-year mark had no measurable permethrin. New LLPI pants had a lethality of 70% for the nymphal black legged ticks, however only two of the 12 pairs of used pants were still effective at killing <30% of ticks exposed. The median level of urinary permethrin metabolites from all study participants increased in concentration over baseline levels after wearing LLPI clothing at the one month and three to four month checkpoints; however at the one year check permethrin metabolites had decreased to baseline.
	Richards	2015	Appalachian Region	Foresters	Quasi-Experimental	Number of tick/mosquito bites reported in foresters who wore permethrin-treated clothing versus foresters who did not.	Tick exposures (crawling/attached) were reported more frequently in the group that wore treated clothing; however, they reported less mosquito exposures (flying/biting).

	Sullivan	2019	North Carolina	Foresters	Quasi-Experimental	This study asses the permethrin content of LLPI clothing after 3-months of routine use; lethality of clothing after use against mosquitoes and ticks; and determined the mean absorbed does of permethrin of workers over the three-month study period.	The study found the tick mortality was high for LLPI at the end of the study period (78-88% mortality depending on LLPI type). In contrast LLPI did not effectively impact mosquito mortality. The study found that worker absorbed less than 4 μg of permethrin per kg of body weight and that detectable metabolites of permethrin decreased over time.
	Vaughn	2014	North Carolina	State Divisions of Forestry, Parks & Recreation, and Wildlife Workers	Double-Blind Randomized Intervention	Incidence of work-related tick bites reported on weekly tick bite logs of workers who wore factory-impregnated with long-lasting permethrin (treatment group) versus those who did not wear treated clothing (control group).	The incidence of tick bites was significantly lower among subjects in the treatment group during the first year of follow-up, with a protective effectiveness of 82% against tick bites. Over the course of the trial, five subjects reported illness suspected to be caused by tik bites, two cases were confirmed (one case of ehrlichiosis and one case of spotted fever rickettsiosis) both subjects were in the control group. No adverse health events were reported by those in the treatment group.

	Wallace	2016	North Carolina	State Divisions of Forestry, Parks & Recreation, and Wildlife Workers	Randomized Controlled Trial	Evaluated the effectiveness of long-lasting permethrin-impregnated clothing & identified incident tick-borne infections and examined seroconversion (e.g., a fourfold rise in antibody IgG titer) risk factors.	The workers at the high risk (36%) were those in the NC Division of Forest Resources. The unadjusted risk of seroconversion among NC Division of Forest Resources workers was 1.73 times the risk among all other NC work divisions in the study.
	First Author	*Year*	*Location*	*Study Population*	*Study Design*	*Exposure metric*	*Key findings*
Chemical Hazards							
	Kim	2017	Virginia	Loggers	Cross-Sectional Assessment	Participants completed a self-administered questionnaire focusing on aspects of safety and health related to logging equipment	57.4% of respondents reported symptoms related to diesel exhaust exposure in their career
	Harper	2015	Libby, Montana	USFS Worker	Cancer Risk Assessment	Estimate the cancer risk of USFS workers, who are potentially exposed to asbestiform amphibole (a.k.a. Libby Amphibole)	USFS workers stationed in Libby, Montana is likely to be at low risk for developing cancer based on having a Hazard Index of <1.
	First Author	*Year*	*Location*	*Study Population*	*Study Design*	*Exposure metric*	*Key findings*
Ergonomic Hazards							
	Granzow	2018	Alabama	Southeastern Reforestation Hand Planters	Observational	Participants were assessed using surface electromyography (EMG) and inertial measurement units (IMUs) to characterize the muscle activation	Results indicated that hand planters are exposed to physical risk factors such as extreme trunk postures and high effort muscle exertions that may place them at increased risk for developing MSDs.

						patterns, upper arm and trunk postures, movement velocities, and physical activity (PA) of hand planters over one entire work shift.	
	Kim	2017	Virginia	Loggers	Cross-Sectional Assessment	Participants completed a self-administered questionnaire focusing on aspects of safety and health related to logging equipment	98% of respondents reported experiencing musculoskeletal symptoms.
	Lagerstrom	2019	Montana	Loggers	Standardized Nordic Questionnaire	A questionnaire was administered to loggers participating in a federally mandated annual emergency first-aid training workshop in Montana.	Loggers using conventional felling practices with chainsaws were more than twice as likely to report musculoskeletal disorder symptoms than those using mechanized logging equipment.
	Lynch	2014	Alabama, Georgia, Mississippi, & Tennessee	Logging Machine Operators	Survey	A survey was done to determine the incidence of self-reported pain, MSDs diagnosis, and the relationship these two factors have with known risk factors.	Survey found that 10.5% of respondents reported an MSDs diagnosis; 74.3% reported current mild back pain; and 71.7% reported mild back pain in the last year.
	Rodriguez	2019	Arkansas, Louisiana, and Texas	Loggers	Survey	Estimate the prevalence of musculoskeletal symptoms of logging machine operators over the course of 12-months	55.7% of participants reported having work related musculoskeletal symptoms in at least one body party during the study; 51.1% of participant attributed working in hot, cold, humid, or wet conditions as a job-related factor in experiencing musculoskeletal symptoms.
	First Author	*Year*	*Location*	*Study Population*	*Study Design*	*Exposure metric*	*Key findings*

Physical Hazards							
	Fonseca	2014	United States	Loggers	Quasi-Experimental	Hearing thresholds were evaluated in a group of loggers compared to average hearing thresholds.	The study found that years of exposure to forestry equipment can adversely affect hearing.
	Masterson	2018	United States	US workers within the Agriculture, Forestry, Fishing, and Hunting (AFFH) sector	Retrospective	Characterize the prevalence of hearing loss among AFFH industries	Forestry and logging had a higher prevalence rate (~21%) of physical hazards compared AFFH combined (19%). The sub-category of “Forest nurseries and gathering of forest products” had the highest rate of prevalence (36%) among all industries and sub industries.
	McLain	2021	Montana	Cable and mechanized operation loggers	Quasi-Experimental	Characterize noise exposures and hearing protector usage at small-scale logging operations.	33% of loggers who worked 12-hr shift were overexposed to noise.
	Spector	2014	Washington (State)	Forestry and agriculture workers	Time Trend Analysis	Heat-related illnesses claims & Heat Rule citations	73% of agriculture and forestry heat-related illness claims had a clinical diagnosis of heat syncope, heat cramps, heat exhaustion, heat edema, or heat fatigue. 15% of clinical diagnosis were attributed to heat stroke and renal failure; with 6% requiring intensive care. Only 1 death was reported.
	First Author	*Year*	*Location*	*Study Population*	*Study Design*	*Exposure metric*	*Key findings*
Psychosocial Hazards							

	Lundstrom	2021	West Virginia	Logging company owners/operators (supervisors) and workers	Mixed methods approach using a combination of self-administered surveys and semi-structured telephone interviews.	The workplace safety perspectives of logging company owners/operators and workers operating within West Virginia	Worker (non-supervisors) survey responses indicated that workers revealed they associate pushes for production and working quickly with decreased jobsite safety. Supervisors of operations disagreed with this finding and respond that 'worker inexperience and overconfidence as casual to unsafe work'.
	Newman	2018	Idaho	Logging Contractors	Survey/Interviews	1) characterize current perceptions of in-woods hazards and the human factors that lead to injuries; (2) understand their perspectives on using technology-based location-sharing solutions to improve safety in remote work environments. (3) identify logging hazard scenarios that could be mitigated using location-sharing technology.	1) Production pressure, fatigue, and inexperience among the most-common factors contributing to logging injuries from the perspective of participants; 2) 'potiential for distraction' and cost were reported to be the main limitations for new technology; 3) participants identified several situations where technology would be useful, including: a.) alerting workers of potential hand-faller injuries due to lack of movement; b.) helping rigging crews to maintain safe distances from yarded trees and logs during cable logging; c.) providing a means for equipment operators to see approaching ground workers
	Scott	2020	Maine	Loggers	Longitudinal Cohort Study	Assessment of the health and safety of the logging industry	On average mechanized loggers worked longer days (11.8 vs 9.7 hours) and had longer commutes from home to the woodlot (72.6 vs 40.7 minutes) than conventional loggers. Rates of health insurance coverage were 79.8% conventional and 74.3% mechanized loggers.

	Wilmsen	2015	Oregon	Foresters	Survey	Interviews were conducted by two trained interviewers who had previous forestry industry experience. Interview questions focus on workplace practices, injuries, working conditions across contracting companies, wages and income, fear of reprisals, and H-2B workers.	The survey results suggested that many forestry service contractors licensed within two of the counties surveyed did not always follow labor laws. 39% of the 150 people surveyed reported that they received safety training. 95% reported that their PPE was sometimes or always worn out. Most workers reported that they never have all the PPE required for the job. 71% of workers who were injured on the job stated they did not report injuries due to fear of losing their job.
	First Author	*Year*	*Location*	*Study Population*	*Study Design*	*Exposure metric*	*Key findings*
Safety Hazards							
	Conway	2017	Arkansas, Louisiana, and Texas	Logging supervisors and front line crew members	Survey	Perceptions of safe work practices in logging.	Log truck-related incidents were widely identified as the primary source of risk for injury and death on logging work sites. Human error, in general, and being out of the machinery on the work site were highlighted as additional sources of risk.
	Durbin	2019	South Dakota, Wyoming, Montana, & Idaho	Foresters	Qualitative, ethnographic fieldwork	Semi-structured interviews and documentary sources.	Participants mentioned that trees that were killed by the bark beetle had an increased risk for "widow makers" (e.g., falling limbs). A common thread between all interviews was a perceived increased risk of injury and forest fires related to beetle-killed trees.

	Lagerstrom	2017	Montana & Idaho	Loggers	Mixed Methods	Analyses of workers' compensation claims and focus groups to identify factors associated with injuries and fatalities in the logging industry.	Inexperienced workers (<6 months experience) accounted for over 25% of claims. Sprain/strain injuries were the most common, accounting for 36% of claims. Focus groups identified job tasks involving felling trees, skidding, and truck driving as having highest risk.
	Scott	2019	Maine & New Hampshire	Loggers	Identifying logging injuries using pre-hospital care reports (administrative data sets).	Passive data collection system approach of hospital and pre-hospital case reports. Cases were categorized as not a case, true case, traumatic injury/suspected logging case, and suspected injury/logging case.	Results were both qualitative and quantitative in nature. The study found that the majority of true cases of logging injuries were caused by trees, logs, and limbs, followed by heavy machinery. Fractures were the most reported injury type. The study also noted that most cases reported a difficulty of removing patients due to the location of injury site and communication was difficult with the patient due to language barriers.

CHAPTER 5: DISCUSSION & CONCLUSION

Fatalities & Non-Fatal Injuries

Results here showed that 'contact with objects and equipment' was the leading cause for non-fatal injuries and fatalities in forestry and logging in the US from (2003-2018) (fatalities) and 2005-2019 (nonfatal injuries). These findings are supported by evidence found in previous studies (Scott et al., 2019). The second leading cause of death was found to be transportation-related incidents. Conway et al. (2017) reported that, among the forestry workers surveyed, log truck-related incidents were widely identified as the primary source of risk for injury and death on logging work sites. Similar findings were reported by Scott et al. (2019), in which respondents identified the second most common source of injury as heavy equipment and vehicles. For non-fatal injury nature, this study identified '*Sprains, strains, tears*' to be the leading nature of injury followed by '*All other natures*' (non-classifiable natures), and '*fractures*' was ranked third most common over the last ten years. In a survey of injury cause perceptions, workers reported that fractures were the most common nature of injury (Scott et al., 2019). In a study regarding occupational tree-felling fatalities over a 10-year period (2010-2020), 'struck by' was the number one cause of injury and 'head' was the number one body part involved in fatalities (Michael & Gorucu, 2021). A separate study of US arboricultural operation fatal and nonfatal incidents (2001-2017) showed that the four leading causes of death were (tree) climber falls, workers struck by a falling tree, workers making indirect contact with an electric current, and workers struck by a falling branch (Ball et al., 2020). For severe, but nonfatal injuries, climber falls were also the leading incident, followed by ground workers struck by a falling branch, workers struck by a chain saw, and falls by aerial device operators (Ball et al., 2020).

The total number of injuries and fatalities, along with injury and fatality incidence rates help define where future intervention studies should focus their efforts. A significant relationship was observed between 'internal injuries' and 'contact with objects and equipment' as well as between 'traumatic injuries' and 'falls, slips, trips'. Hence, when these types of causes ('contact with objects and equipment' and 'falls, slips, trips') occur, they are likely to result in a major injury (internal and other traumatic injuries) that may lead to fatality. This underscores the importance of implementing safety measures and training related to the primary fatal injury causes to decrease work-related fatalities in foresters and loggers. State do have logging safety training programs, however information on who is taking these trainings is limited. Also, some of the barriers to these trainings for the workers who need them include knowing that they are available, the language they are offered in, technology that may be required to participate in the training (e.g., computer and internet).

Prevention strategies can range from nontangible changes (e.g., work safety culture) to physical changes (e.g., providing new PPE such as gloves at the start of the harvesting season). A change in safety culture starts from the top and works its way down (Lagerstrom et al., 2017). It is essential for management to encourage the implementation of safe-worker practices (Lagerstrom et al., 2017). Workplaces should work on creating environments where non-management workers feel encouraged to speak up to fellow workers and communicate with each other when they see a situation that could lead to injury or death (Lagerstrom et al., 2017). Small achievable goals such as having workers who participate in the transportation aspect of forestry/logging taking a defensive driving and incident prevention course. Also, implementing regular safety briefings at the start of each new project or when terrain changes to refresh safety knowledge for the situation can help create a safer working environment (Lagerstrom et al., 2017). Also, having a portion of the driver's license exam that new drivers must take includes a section regarding how to safely drive around semi-trucks like the ones used in transporting the logs to the sawmills may help reduce accidents. Moreover, physical intervention strategies to increase worker safety at the worksite, as recommended by the Timber Harvesting & Transportation Safety Foundation (THATS), includes: 1). Keeping the steps of heavy machinery relatively clean so that the worker's foot has traction on the step to prevent slipping; 2.) Replacing PPE when it becomes damaged or worn out; 3) Enforcing workers to wear PPE such as steel toed shoes, hard-hats, reflective gear; 4) Performing regular maintenance audits on all equipment; and 5). Putting trackers on logging transport trucks to ensure operators are obeying traffic laws such as speed (THATS, 2017).

Data from the BLS and NIOSH provide a basis for surveillance studies which are strengthened using other sources (e.g., aginjurynews.org) that geolocate injuries and fatalities in US foresters. Our study found that most forester injuries and fatalities were clustered near the east or west coast of the US. This finding is not surprising as the Pacific Northwest and the South are prominent regions in the logging sector (Oswalt et al., 2014). Other sources that could help future analyses would be utilizing worker compensation claims via private insurance agencies. However, this may be challenging as each state has a variety of insurance companies that handle worker compensation claims and data access may be limited or nonexistent. The communication of safety and health information is crucial to pinpoint industry and worker needs. It may be that worker compensation data would support the findings in this study reported by US DOL, but that remains to be determined. It would be beneficial if there was a publicly accessible (but de-identified) national- and/or state-level database of work-related insurance claims categorized by type of industry.

Okun et al. (2001) discussed a resource guide for small businesses with references and contacts (phone numbers, addresses, websites) that provided safety and health information for small business owners and managers (Okun, et al., 2001). This resource guide may be beneficial for forestry/logging businesses as it could pinpoint areas that would benefit from new polices and/or more training that could reduce injuries and fatalities. The idea behind this guide is that would create a one stop shop for owners/operators of harvesting companies to find the latest information on the trends occurring in the industry and other resources (Okun et al., 2001). For example, a small operation may be unaware of new training system for new employees. Small business owners and operators must track the same tasks that bigger businesses are more easily able to delegate (e.g., safety/OSHA training, payroll, shift scheduling). By eliminating the need to scour through multiple websites and sources for industry updates and contact information, the guide could streamline the owner/operators search for information (Okun et al., 2001).

Some have suggested that increased mechanization of the forestry/logging industry will decrease incidence rates of injuries and fatalities (Lefort Jr, De Hoop, Pine, & Marx, 2003). However, without access to worker compensation claims (perhaps providing more details about injury/fatality than national databases), this is unclear. For example, the most prevalent cause of injury or fatality in the current study was 'contact with objects or equipment', which could include a variety of issues including but not limited to a falling limb or a machine-related incident. One of the most frequently violated federal safety standards is a lack of adequate logging operations training (Lagerstrom et al., 2017). It is important to use a participatory approach with the end-user to develop and customize relevant safety training for each industry/business (Lagerstrom et al., 2017). However, there are still only a handful of published studies focusing on implementation and evaluation of training programs in the forestry/logging industries using a participatory approach. Nieuwenhuis and Lyons (2002) showed that 45% of forest harvesting contractors (in Ireland) surveyed suggested topics including enhanced safety training when asked about reducing on-the-job injuries.

In the US, there are few surveillance systems in place regarding musculoskeletal disorders, injuries, and deaths related to logging (Lagerstrom et al., 2019). Most of these MSDs studies are inadequate, which makes comparisons and data aggregation difficult (Lagerstrom et al., 2019). Countries such as New Zealand have had success using their country-wide Forest Industry Accident Reporting Scheme (ARS) – a forestry injury surveillance system maintained by the Centre for Human Factors and Ergonomics (COHFE) – to identify key risk areas for intervention studies. The ARS also reported that some fatalities related to contact with machinery were due to workers not being 'seen' by the operator of the machinery (Bentley, Parker, Ashby, Moore, & Tappin, 2002). After this risk area was identified, a study was performed assessing loggers' clothing to establish which colors are most visible in pine forests to drivers and fallers

(Bentley et al., 2002; Sullman, Kirk, & Parker, 1996). Sulleman et al. (1996) suggested that high visibility clothing be mandatory to increase safety. This is one example of how using injury data to identify trends can be used to induce change in an industry to increase safety. Contact with heavy machinery and equipment is still a key risk factor, despite it being roughly 30-years since the Sullman et al. 1996 study.

Systematic Review

As evidenced by the few studies available on the biological, chemical, ergonomic, physical, psychosocial, and safety hazards, more research needs to be done. Most of the current literature on occupational hazards has the forestry sector combined with other agriculture related occupations. However, this does a disservice to identifying the hazards of these different occupations. For instance, non-logging industry forester workers perform a wide range of tasks such as thinning forests and clearing underbrush to prevent catastrophic wildfire; pre-commercial thinning; planting trees; combatting insects, pests, and diseases harmful to trees; restoring wildlife habitat; building erosion and water control structures (NWFW, 2021). These tasks each have their own potential occupational health hazards that require specific control measures. More research needs to be done to bridge the knowledge gap and protect worker health. One area of study that was missing from occupational health studies across all four categories was female workers. In the forestry sector, female workers only make up 2.8% of the population (Krajnak, 2018). This makes for a very limited pool for researchers to draw from when conducting research studies. Thus, female workers are rarely considered when it comes to safety precautions, due to the forestry sector being male dominated. Safety issues can arise for female foresters due to the lack of adequate PPE (FAO, 2021). For instance, tools and equipment tend to be made to fit male workers, creating ergonomic problems for female workers (FAO, 2020). An additional concern is that pregnant and lactating women are a greater risk for negative health effects surrounding bites from insects/pests and other health hazards (FAO, 2020).

Occupational-related skin diseases and disorders are the most reported non-trauma-related (acute or cumulative) category of occupational illnesses in the US (Lushniak, 2003). Occupational dermatoses in forestry workers have been reported principally from the Pacific Northwest of the US and British Columbia in Canada (Schmidt, 2000). Forestry workers can develop skin irritation from contacting chemical substances from the trees in their work environment (Schmidt, 2000). Allergic contact dermatitis caused by plants such as poison ivy and poison oak are another biological occupational hazard that was completely missing in recent research. In a 2019 review of forestry workers across the globe, the authors found that occupational dermatitis attributed to plant irritants is the most common cause of sick leave among forestry workers in California (Haeberle, 2020). Additionally, the authors noted that the sap or latex from trees can cause acute reactions such as vesicular irritant dermatitis and conjunctivitis especially to those felling tropical trees (such as the rengas tree (*Gluta renghas*)) in the rain forest (Schmidt, 2000) (Haeberle, 2020).

Rabies is a lethal encephalitis caused by prototypical lyssavirus rabies virus (Fisher, Streicker, & Schnell, 2018). Between 1975 and 2010, wildlife accounted for more than 80% of rabies infected animals in the US (Blanton, Palmer, Dyer, &

Rupprecht, 2011). Despite this statistic, no US studies have been conducted in the last 10-years to assess the risk of rabies posed to forestry workers. A recent study in Serbia noted that rabies is a potential occupational health risk for those in the forestry sector (Banović et al., 2021).

Fully mechanized, whole tree harvesting systems are the most common and productive systems (Conrad et al., 2018). Yet only one study within the US in recent years has investigated forestry worker exposure to the diesel exhaust produced by the mechanized harvesting machines. Diesel engine exhaust (DEE) exposure constitutes a threat to worker health. DEE has been linked to acute reactions such as asthma and allergic reaction as well as chronic ailments such as chronic obstructive pulmonary disease and lung cancer (Kim et al., 2017). Chainsaws and brush-cutters are other common sources of exhaust emissions in the forestry industry (FAO, 2021). Emissions from these tools can include the suspected carcinogens benzene and formaldehyde (FAO, 2021). Aerosols from the oils used in these machines can cause irritation to skin, eyes, and the respiratory system (FAO, 2021). Moreover, exposure to herbicides and pesticides in forestry can lead to a variety of health problems including skin and respiratory effects (FAO, 2020). Current research has also looked at the association between high exposures to pesticides experienced by agricultural workers and an elevated risk of experiencing psychiatric disorders and suicidal behavior (Freire & Koifman, 2013). Evidence of this association is currently limited and inconclusive and warrants more study (Freire & Koifman, 2013). Pesticide exposures in forestry workers linked to the development of cancer has been described in multiple studies outside of the United States (Mayo et al., 2000; Navas-Acién et al., 2002; Wiklund et al.1986). One study postulated the link between exposure to glycol ethers and hydraulic fluids elevates risks of stomach cancer, but this line of research has not been further expanded (Parent et al., 1998).

Several epidemiologic studies using self-reports and/or crude measurements of heat exposure have suggested a relationship between HRIs and injuries (Jackson & Rosenberg, 2010; Spector et al., 2014; Tawatsupa et al., 2013). Another study using worker surveys attributed working in hot, cold, humid, or wet conditions as a job-related factor in experiencing musculoskeletal symptoms (Rodriguez et al., 2019). Also, forestry workers in some US regions (including Pacific Northwest [e.g., Alaska]) are prone to severe winter/cold-related illnesses such as hypothermia and frostbite, and this has not been adequately addressed by occupational health research (Quandt et al., 2013). Moreover, cold weather can reduce workers' dexterity, blood flow, muscle strength, and balance (FAO, 2020). Additionally, acute cold exposure of ≤50°F has been shown to cause declines in working memory, choice reaction time and executive function (Muller et al., 2012). These impairments remain for at least an hour after the participants were moved from the 50°F testing environment to an area of 77°F to warm up (Muller et al., 2012). Workers who spend time in <50°F are therefore more likely to be at risk for injury even after removal from the cold working conditions (Muller et al., 2012). Even though it has been established that weather can impact forestry worker health, no study based within the US was located that has looked at how cold weather impacts worker health (Fonseca et al., 2014; Jackson & Rosenberg, 2010; McLain et al., 2021; Spector et al., 2014; Tawatsupa et al., 2013). This knowledge gap is surprising as winter is the preferred working season for many forestry workers (Wooster, 2004).

Occupational noise exposure has been a well-established causative factor for permanent, irreversible hearing loss (Lie et al., 2016; Weier, 2020). Yet there are limited studies that evaluate this issue in the forestry sector (Fonseca et al., 2014; McLain et al., 2021). In a recent meta-analysis, evidence of noise exposure induced hypertension stemming from a stress response through the automatic nervous and endocrine system was identified (Bolm-Audorff et al., 2020; Banser et al., 2014). Previously mentioned in this paper is the exclusion of studies that grouped forestry and logging workers together with other agro-occupations as farming, fishing, and hunting. Masterson et al. (2017) compared noise exposure prevalence among the different AFFH occupations, and this underscores the rationale of not combining these occupations when evaluating/assessing occupational injuries and illnesses (Masterson et al., 2017). Their study showed that as a whole, the AFFH industry experienced only a 15.3% prevalence rate in noise-related health issues; however, when broken down by industry and sub industry levels, forestry noise-related issues were 21.2% for forestry and logging grouped, 21.9% for timber tract operations, 36.1% for forest nurseries and gathering of forest products, and 16.9% for logging alone (Masterson et al., 2017).

Another understudied area of research was the effects of vibrations on foresters using machinery (e.g., chainsaws and other machinery). Forestry workers may develop hand–arm vibration syndrome symptoms which are characterized by disturbances in the circulation of the fingers (vibration white finger) and peripheral nerves of the hands and arms (Haeberle, 2020). This is dependent upon the frequency with which the chainsaw or other handheld machinery is used (Haeberle, 2020). This condition is often referred to as hand-arm vibration syndrome. Both exposure to cold in winter and the duration and intensity of woodwork enhance the risk of hand–arm vibration syndrome (Haeberle, 2020). Another form of vibration exposure is whole body vibration (WBV) which stems from workers who are seated while using equipment (Neitzel & Yost, 2002). WBV has been linked to increased risk of degenerative lumbar spine injuries, central nervous system disturbances, and possibly damage to the digestive and genital/urinary systems (Neitzel & Yost, 2002).

Only one study related to HRI was identified in this study that specifically evaluates loggers/forestry workers in the US. Most studies found forestry and logging workers were lumped in with other agriculture occupations including fishing and hunting (Hesketh et al., 2020). It should be noted that we excluded the studies that lumped forestry workers and loggers with other agriculture because of the wide variation of working environment. It is documented that tree coverage can decrease HRI (Sinha et al., 2022). Thus, farmers would more than likely have higher rates of HRI than loggers surrounded by tree cover; and when those numbers of HRI are combined it may lead to the skewing of HRI case for foresters (Gauer & Meyers, 2019). In a recent study of Washington State worker compensation HRI claims, “Agriculture, Forestry, Fishing, and Hunting” sector was ranked second largest number of HRI claims from 2006-2017 (Hesketh et al., 2020). Several studies have been conducted on forestry workers and exposure to heat stress and UV radiation in other countries outside of the US (Bauer et al., 2015; Łastowiecka-Moras et al., 2014; Rother et al., 2019; Surdu et al., 2013; Wright & Norval, 2021; Xiang et al., 2014).

Current research has primarily focused on the physical hazards of the job. While this is an important area to study, another equally important area is the health of these workers, including both acute and chronic health problems associated with this industry. The focus on physical injuries is on part due to the visibility of these injuries and that they are usually recorded in more than one way (in house records, state workers-compensations records, and national records e.g., BLS). Health caused by exposure to noise, heat, particulate matter, and other exposure types are not a clearly defined due to the nature of long-term study some of these exposures would require in order to track. These chronic exposure illnesses have a lower visibility making the perception of risk lower. Another challenge to this area of study is chronic illness can take years before they become noticeable and when they are diagnosed are not linked to the job. One way to increase awareness for this overlooked area of study is to shine a light on the lack of knowledge and start to incorporate this issue in future grant proposals. Also, bringing awareness to this issue in conversations with policy makers and safety committees could be effective. In New Zealand the shift from physical to health hazards has been spurred by the government's recently released 10-year 'Healthy Work' strategic plan which aims to ensure employee health is given the same priority as physical safety (NZ, 2022).

Conclusion

The findings outlined in this study are further underscored by a logger who was quoted saying "*You could probably avoid them [injuries], but you wouldn't be able to do your job productively, I would say. It's pretty much a choice you've got to make.*" (Conway et al., 2017). Foresters and loggers are prone to physical injuries, development of MSDs, frequently exposed to pesticides, and extreme temperatures (Quandt et al., 2013; Krajnak, 2018). Additionally, these workers can become exposed to various particulate matter including diesel exhaust and wood dust (Kachuri et al., 2017). These mixed exposures may act additively or synergistically with vibration exposure to contribute to the development of many diseases and may increase the risk of cancer (Kachuri et al., 2017), respiratory problems (Kachuri et al., 2017), and neurodegenerative diseases (Anderson et al., 2018; Kachuri et al., 2017). The forestry and logging sector faces several challenges when addressing occupational injury and fatalities including terrain, remoteness of work site, and availability of emergency services (Lagerstrom et al., 2017). The bulk of the current literature on the complexities forestry and logging occupational hazards are based on self-reported data or administrative databases (Scott et al., 2022). Few studies exist that go beyond survey and questionnaire to collect physical health measurements for forestry and logging workers in the US (Scott et al., 2022). This assessment is in line with the systematic review performed here. Literature found that research linking occupational health outcomes to work organization in the forestry/logging industry within the US is limited. While physical injury made up the majority of recent studies, the other occupational hazard categories have not been prioritized. Future research should focus on these areas with a focus on intervention strategies that eliminate or substantially mitigate the deleterious health effects of occupational exposures. Injury and mortality prevention efforts should focus on the key areas identified in this study, especially in workers new to the industry. The development of a positive safety culture including increased risk communication, as well as implementing prevention strategies can reduce death and injury and improve worker health. Future studies should investigate the causes that fall under the heading of ‘contact with equipment and heavy machinery’ to further define the area of need for intervention studies. Additionally, future research should continue to investigate the availability of worker compensation data as it is likely an underutilized resource that could improve risk assessments and positively impact the safety of this industry. Some studies have been done on the more generalized agriculture sector which includes a variety of sub-sectors like farming, fishing, and logging. However, these grouped studies can lead to discrepancies in the risks, injuries, and fatalities experienced by workers in those sub-sectors due to the generality of the population that is being assessed. Future research should focus on the subset of the various occupations that fall under agriculture, including logging and forestry. By identifying specific needs of this industry, more appropriate interventions and aids can be designed to benefit workers' health and safety. Here, we have identified several areas of research that need to be addressed in the future. The areas identified here need to be addressed in a collaborative effort between researchers and workers within the industry to promote a safer and healthier profession for both the current and future workforce.

Contribution to the Field of Public Health

This study has underscored the excessive risk for occupational fatalities and nonfatal injuries that logging and forestry workers experience. By highlighting the areas that research is lacking future research can be directed so that they fill these gaps. A detailed list of areas of future study can be found in Table 18. The creation of the educational pamphlet is the first step towards bring awareness of the risk described here in. The prevention of worker injury, fatality, and illness is crucial for not only the worker's overall health but also the well being of his or her family.

Table 18. Areas of Study for Future Research

Chronic Illness Caused by Exposures To:
Chemicals (E.G., Pesticides, Diesel Exhaust)
Particulate Matter Exposure (E.G., Saw Dust)
Female Worker Health & Safety
Proper Fitting PPE
Ergonomic Issue Created by Equipment
Skin Diseases & Disorders
Caused By Chemical Exposure (e.g., Pesticides)
Caused By Biological Exposure (e.g., Plants, Insects)
Noise Exposure
Vibration Exposure
Hand–Arm Vibration Syndrome
Whole Body Vibration
Weather Related Illnesses
Heat Related Illness/ UV Radiation Exposure
Cold Stress
Zoonotic & Vector-Borne Diseases
Rabies - Transmitted by Infected Animals
Arboviruses (Transmitted Primarily by Mosquitoes)
Bacterial Pathogens (Transmitted Primarily by Ticks)

Additional Resources

An educational safety pamphlet has been created, based on the findings of the current study, and will be distributed to the local logging/forestry industries via the North Carolina Agromedicine Institute, a partnership of East Carolina, NC Agricultural & Technical State and NC State Universities (Appendix II).

Limitations of the Study

The most significant limitation of the study was the lack of surveillance systems in place regarding musculoskeletal disorders, injuries, and deaths related to forestry/logging. Another limitation was the generic nature of the BLS reports on injuries and fatalities with little details about related incidents. The absence of data fields that allow identification of injury contributing factors (e.g., slippery footing leading to a fall), injury mechanisms (e.g., cable or tree branch causing injury), and task-related data is necessary to determine relative risk (Bentley et al., 2002). Another limitation is the lack of recent studies on the forestry/logging industry in the US, with most research being conducted from 1960-2000. This could be due to researchers not seeing this field as novel, lack of funding, or possibly not being able to obtain consent from the harvesting operations to study their workers. Another challenge was that for 2003-2004, injury data for forestry/logging was only provided as summary analysis (not raw data as in the other years) by the BLS and thus could not be included in the study. Also, data for injuries by nature for the years 2011 and 2016 was not available. Moreover, in the BLS data categories, ‘transportation’ was not defined. The logging industry uses several modes of transportation including trucks, but also utilizes helicopters and sometimes horses. The BLS data used here in did not break down the injuries by ethnics/residency status. This demographic information would be useful when developing intervention strategies. The studies that met the search criteria for the systematic review were few. Some of the studies that were excluded were due to the generalization of the study population.

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Appendix I

Figure 16. Top Three Causes of Nonfatal Injuries Rates of Forestry/Logging Combined, US, 2005-2019

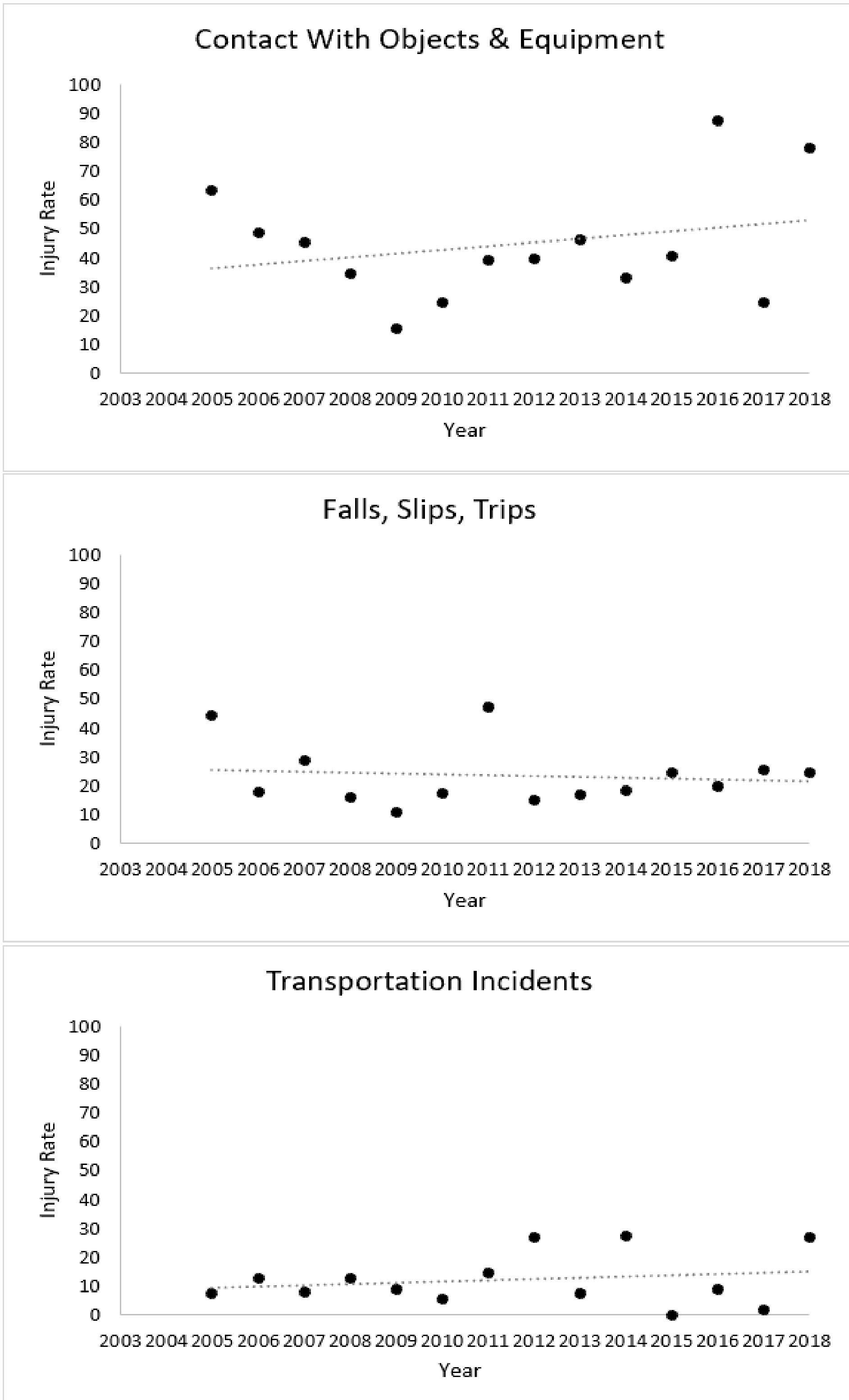
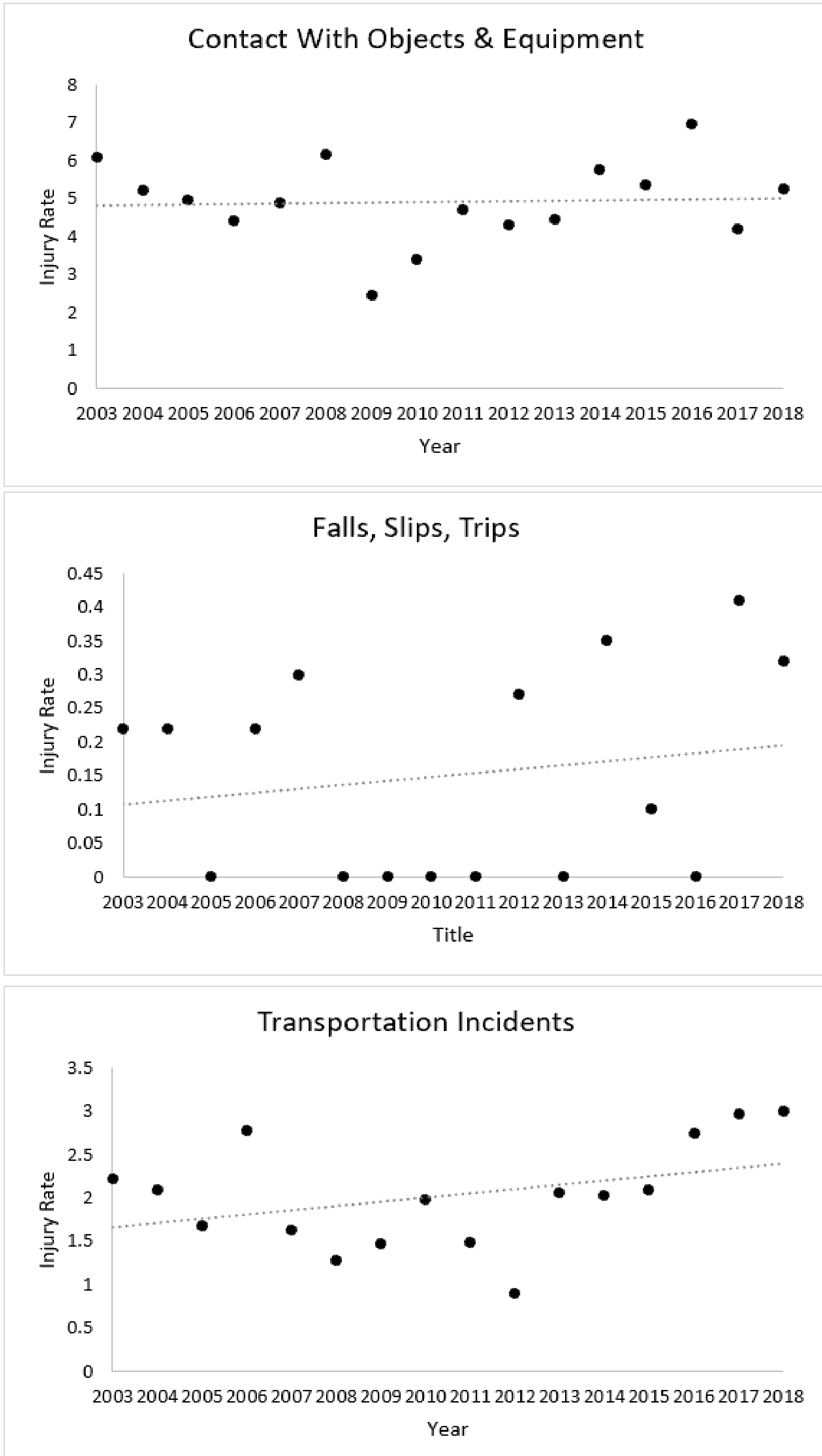


Figure 17. Top Three Causes of Fatal Injuries Rates of Forestry/ Logging Combined, US, 2003-2018



Appendix II

Pamphlet (pg.1)

Logger Safety : Key Findings From A 15-year Review of United States Bureau of Labor Statistics

ECU

NORTH CAROLINA AGROMEDICINE INSTITUTE

Central Appalachian Regional ERC

Pamphlet (pg. 2-3)

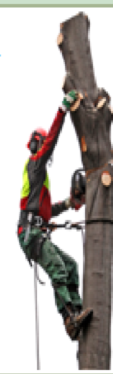
Causes of Injuries and Deaths

#1 Contact with objects and/or equipment (Injuries & Deaths)

2 Transportation-related (Deaths)

#2 Falls, slips, & trips (Injuries)

Reduce Risk of Harm From Objects & Equipment:

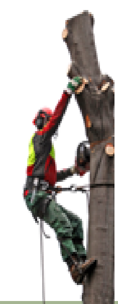


- Always wear a hard hat, hearing and eye protection.
- Be aware of your surrounding and where you stand in relation to the falling tree.
- Confirm that machinery cabs have rollover and falling object protective structures, overhead guards and operator restraint devices.

Reduce Risk of Harm During Transportation:

- Confirm the load is positioned to prevent slippage during transport.
- Always wear a seat belt.
- Do not exceed load capacity.
- Obey all highway safety signs

Reduce Risk of Falls, Slips, Trips:



- Keep machinery surfaces (e.g., vehicle cab and step-up) free of debris.
- Wear proper footwear.
- Routinely check climbing gear and replace gear that is broken or damaged.

References

OSHA. (n.d.). *eTool : Logging*. eTool : Logging | Occupational Safety and Health Administration. https://www.osha.gov/etools/logging.

National Timber Harvesting and Transportation Safety Foundation . (2016). *General Rules of Safety*. Logging Safety. https://loggingsafety.com/timber-harvesting-safety-manual/i-general-rules-of-safety/.

Appendix III

DrPH Environmental and Occupational Health Concentration Competencies

Two foundational competencies will be addressed here in. The first is to Communicate public health science to diverse stakeholders, including individuals at all levels of health literacy, for purposes of influencing behavior and policies. This will be accomplished by publishing the findings of this project in both scientific circles as well as providing to the Agromedicine institute to be passed out to local partners in the Forestry and logging industry then given to workers in the industry. The second foundational competency that will be addressed is to propose human, fiscal and other resources to achieve a strategic goal. This competency will be achieved by designing educational tools with the aim to increase awareness of the most common and/or severe injuries in forestry workers and to provide action steps that the workers can take to prevent/mitigate potential injuries.

Three EOH competencies will be addressed here in. The first Apply the "One Health" approach of recognizing the interconnection between animals, humans and their shared environment. This will be addressed by connecting how the forestry and logging industries are intimately connected to their environment and by addressing this connection in our educational material may be key in achieving change. The second EOH competency addressed is to interpret results of data analysis for public health research and policy. The results from the data analysis will be used to form educational/informational tools on forestry and logging related industries. The third and final EOH competency addressed is to synthesize and evaluate research on an environmental/occupational public health topic conducted by others. The raw data used in this project are obtained from databases and then evaluated.