

## Article

# Identifying Risk Factors and Evaluating Occupational Safety in South Korean Forestry Sector

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**Abstract:** The forestry industry poses a higher risk of occupational accidents than other sectors, and understanding the occurrence and characteristics of injuries and fatalities is crucial for improving the safety and health of workers and establishing future strategies. In South Korea, although occupational injuries have declined since 2010, the number of occupational accidents in forestry remains higher than that in other sectors. Occupational injuries and fatalities present considerable challenges, and thus, our objective was to analyze and compare forestry accidents between 2010 and 2020. The results indicate that the highest average number of injuries occurred among workers older than 51 years and those with less than 6 months of experience. Timber harvesting and silviculture are among the most dangerous operations in forestry. Based on the analyzed dataset, amputation and laceration injuries, as well as slip and trip injuries, were the most common, accounting for 29.2% and 22.3% of total annual occupational accidents, respectively. These results may be explained by the labor-intensive, steep terrain operations in forestry. Our findings represent an essential resource for improving worker safety and health.

**Keywords:** timber harvesting; safety; motor-manual felling and processing; fatal injuries; accident analysis



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## 1. Introduction

Forestry activities, particularly timber harvesting, are widely considered one of the most hazardous occupations across all industry sectors, mainly due to the steep terrain and extreme weather conditions of remote areas [1–4]. The International Labour Organization [5], Kaakkurivaara et al. [4], and Baek et al. [6] have reported that the rates of occupational accidents and fatal injuries are higher in the forestry industry than in other sectors, especially in countries such as the United States, Croatia, Turkey, Malaysia, Thailand, and South Korea (hereafter referred to as Korea). Forest operations are generally characterized as dirty, challenging, and dangerous, with workers often encountering unnatural and uncomfortable working conditions, including poor body postures and exposure to noise, vibration, and exhaust fumes [7,8]. Consequently, forest workers are highly prone to occupational accidents owing to the severity of their working conditions.

As of 2022, forests in Korea cover 6.3 million hectares (ha), which is approximately 63.2% of the total area [9]. Private forests cover 4.2 million ha, while national forests cover 2.1 million ha. In 2021, the area of timber harvested was 20,000 ha, and silviculture covered 56,000 ha [9]. The number of forest workers was 101,404 in 2020, and workers between the ages of 50 and 59 years represented the highest proportion (46%) compared to other age groups [10]. Although modern mechanized forest operations were introduced in Korea in the 1990s, trees were commonly felled and processed into 2- and 4-m long saw logs using motor-manual methods, with timber extraction carried out using small shovels, owing to

the highly productive nature of this method [11]. Most timber harvesting activities occurred in the winter months, particularly in January (39.1%), December (21.1%), and February (10.0%) in Korea in 2019 [10].

Forestry employs approximately 0.1 million workers, which constitutes almost 1% of the nation's total workforce [12]. The numbers of forest workers employed by private sub-contractors and the government were 84 and 17 thousand workers, respectively, in 2020 [9]. Forest operations depend on typical small shovel logging systems, using manual felling and processing, and extraction by small shovels and carriers [11]. Motor-manual felling and processing are physically demanding tasks that require handling and transporting equipment in difficult terrains and adverse weather conditions [3,13]. Various studies have indicated that chainsaw-related tasks, including pruning, manual loading, and winching, are among the deadliest in forestry [1,14–16]. Thus, chainsaw operators are exposed to hazardous and strenuous work processes during timber harvesting operations.

Korean forestry workers face the same occupational safety and health problems as their counterparts worldwide in the forest sector [9]. Occupational accidents and fatal injuries have presented significant challenges for the Korean forestry sector over the past few decades. The Serious Accidents Punishment Act, introduced in January 2021, aims to reduce fatal injuries [17]. According to statistics from the Korea Occupational Safety and Health Agency (<https://www.kosha.or.kr/>, accessed on 25 December 2022) [12], the fatality rate in the forestry sector was 1015 per 100,000 full-time workers in 2020, compared to the industry average of 571 per 100,000 workers. Although fatal injuries have decreased by approximately 63% since 2010, the number of occupational accidents has increased compared to other sectors. Furthermore, 15 workers died annually between 2016 and 2020. Therefore, worker protection has become a crucial issue during the harvesting process due to the unsafe working conditions and severe weather conditions that workers face.

Previous studies in Korea have focused on occupational accidents in the forestry sector, providing data about metabolic rates and physiological workload during weed and kudzu (*Pueraria montana var. lobate*) removal operations [18], young tree tending operations [19], felling and processing operations [6], and cable yarding operations [2]. These studies have provided detailed information on the ergonomic conditions and physiological workload of forest workers. However, to manage and reduce occupational accidents and fatal injury rates, recent trends in occupational accidents must be considered. Rhee et al. [20] investigated the changing trends of occupational injuries in all industry sectors between 2001 and 2010; however, their report lacked detailed information about the risk factors and occupational safety failures in the forestry sector. Similarly, Kim et al. [21] identified occupational fatalities in forestry during the 2006–2010 period (5 years) using the Korea Occupational Safety and Health Agency database. Therefore, the objective of this study is to investigate the latest trends and risk factors related to work-induced injuries in the Korean forestry industry.

## 2. Materials and Methods

### 2.1. Data Source

To assess the trend of occupational accidents during the 2010–2020 period (11 years), we used the databases of the Korea Occupational Safety and Health Agency (KOSH) and the Korea Forest Service (KFS) internet homepages, which provide readily accessible, raw data. These data are published annually by the KOSH and the KFS. Production data from KOSH enabled us to estimate yearly incidence, frequency, and severity rates, such as the number of injuries and fatalities and days of temporary incapacity, allowing us to compare occupational accidents across all industries. The dataset provided by KFS included details on five categories: incident or accident level data (i.e., severe, minor, and fatal accidents), personal data (i.e., workers' age and experience), temporal data (i.e., month and day of accidents), operation activity data (i.e., timber harvesting and silviculture), and type of injury (i.e., amputation or laceration, and slip and trip). However, detailed information on the specific injured body parts is not available.

## 2.2. Data Collection and Analyses

The collected dataset was organized and analyzed in Microsoft Excel to display and describe the normal distribution of occupations in each category during the period of 2010–2020. In order to evaluate the severity of occupational injuries, we distinguished between severe (defined as 91 or more lost workdays), minor (defined as 90 lost workdays), and fatal (defined as death) injuries. In addition, safety indicators such as incidence, frequency, and severity rates were analyzed to understand occupational accidents more precisely. The incidence, frequency, and severity rates were defined according to Equations (1)–(3).

$$\text{Incidence rate} = (\text{number of accidents} \times 100,000) / \text{total workers} \quad (1)$$

$$\text{Frequency rate} = (\text{number of accidents} \times 1,000,000) / \text{total work hours} \quad (2)$$

$$\text{Severity rate} = (\text{number of days lost by labor disability} \times 1,000,000) / \text{total work hours} \quad (3)$$

We applied a chi-squared ( $\chi^2$ ) test to assess significant differences in the monthly and daily distribution of occupational injuries and fatalities. We also used statistical analyses to compare the differences between categorical variables among operational activities and injury patterns. In addition, Pearson's correlation test was conducted to evaluate how the amount of timber harvesting affects the number of accidents. All statistical analyses were performed using R software 4.1.2.

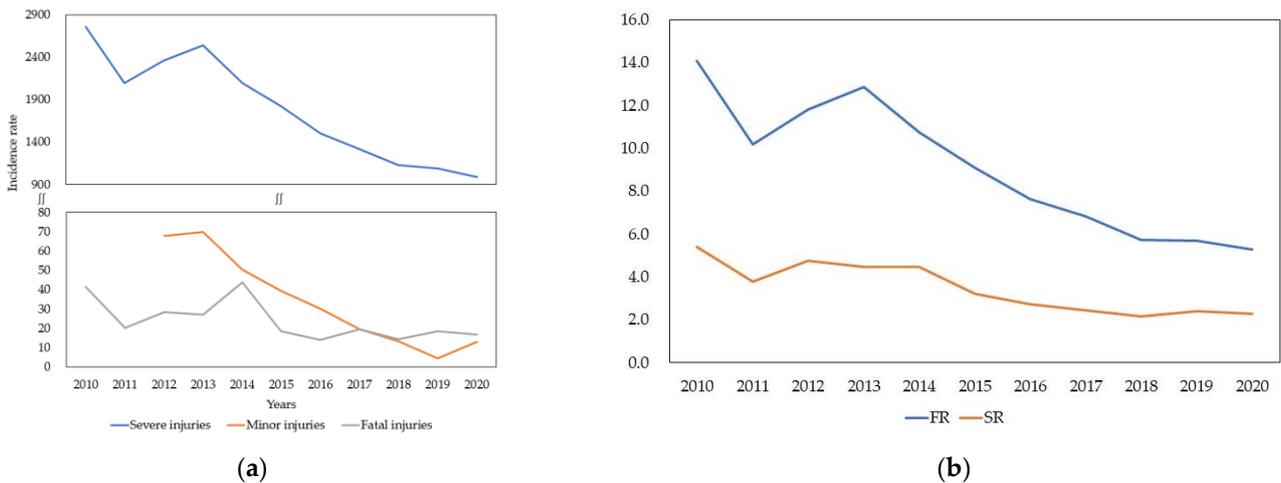
## 3. Results

The 11-year trend of occupational accidents in the forest sector is shown in Table 1. The total number of employees and contractors increased from 2010 to 2020. Forest workers experienced 15,878 occupational accidents during this period, of which 97.2% were severe injuries (defined as 91 or more lost workdays), 1.5% were minor (defined as fewer than 90 lost workdays), and 1.3% were fatal. On average, employees experienced 20 fatal accidents annually, ranging from 32 (in 2010) to 17 (in 2020). The number of injuries (severe + minor + fatal injuries) per 1000 employees ranged from 28.0 in 2010 to 10.2 in 2020. The incidence, frequency, and severity rates have decreased considerably over the past 10 years (Figure 1). On the other hand, the result of our correlation analysis indicated that the amount of timber harvesting and the number of accidents, including severe injuries ( $r = 0.8454$ ), minor injuries ( $r = 0.8541$ ), and fatal injuries ( $r = 0.3575$ ), were statistically significantly related ( $p < 0.001$ ).

**Table 1.** Summary of accident data for the forestry sector between 2010 and 2020.

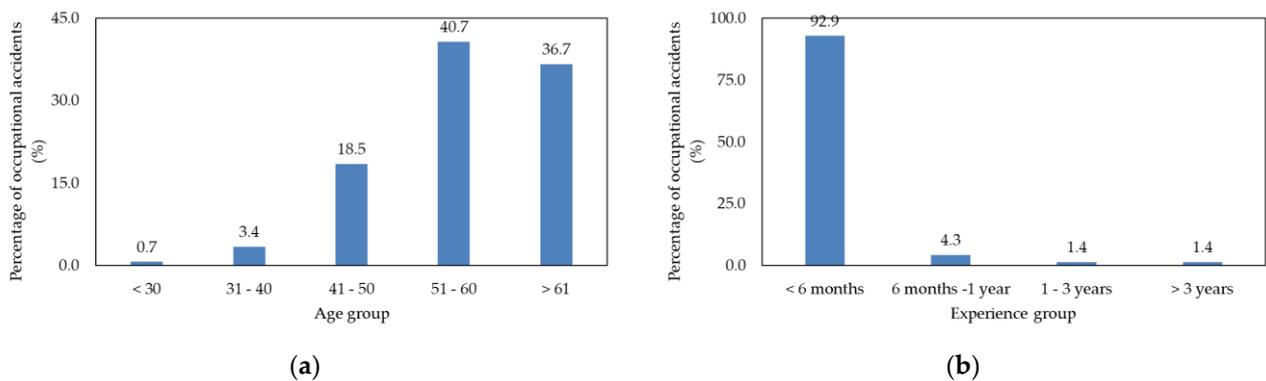
Year	Number of Workers	Severe Injuries <sup>1</sup>	Minor Injuries <sup>2</sup>	Fatal Injuries <sup>3</sup>	Total
2010	77,232	2132	-	32	2164
2011	93,814	1965	-	19	1984
2012	73,759	1745	50	21	1816
2013	74,389	1893	52	20	1965
2014	77,486	1623	39	34	1696
2015	86,486	1577	34	16	1627
2016	93,493	1403	28	13	1444
2017	82,773	1092	16	16	1124
2018	89,751	1016	12	13	1041
2019	91,682	996	4	17	1017
2020	101,404	1000	13	17	1030
Total	-	16,442	248	218	-
Average	85,661	1495	28	20	-

<sup>1</sup> 91 or more lost workdays, <sup>2</sup> 90 lost workdays, and <sup>3</sup> Death.



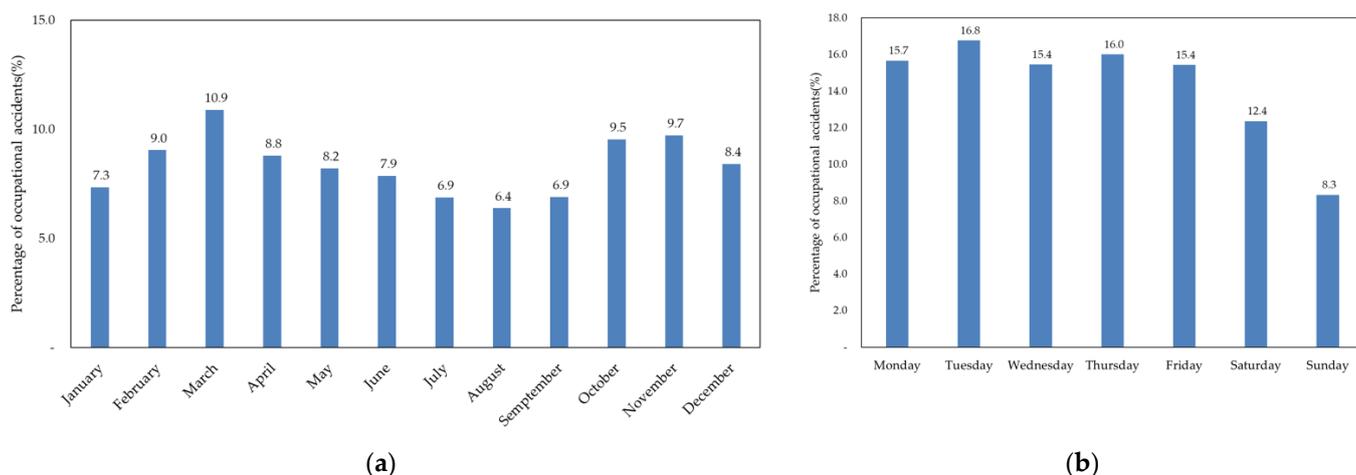
**Figure 1.** Incidence, frequency, and severity rates of forestry accidents between 2010 and 2020 in Korea: (a) incidence rate, and (b) frequency rate (FR) and severity rate (SR).

We observed the highest occupational accident rate among participants older than 51 years and with less than 6 months of experience (Figure 2). Workers aged between 51 and 60 years accounted for approximately 40.7% of the average total accidents during the 2010–2020 period. According to the incidence rate per 100,000 employees, accidents among the >60 years age group (13,898) were, on average, approximately 5.2 times more frequent than in of 50s age group (2685). The lowest occupational accident values were observed in the <30 years age group. Inexperienced workers (i.e., with less than six months of experience; 92.9% of the average total accidents) were considerably more susceptible to occupational accidents than other groups (Figure 2). Occupational accidents occur more frequently as workers’ experience decreases.



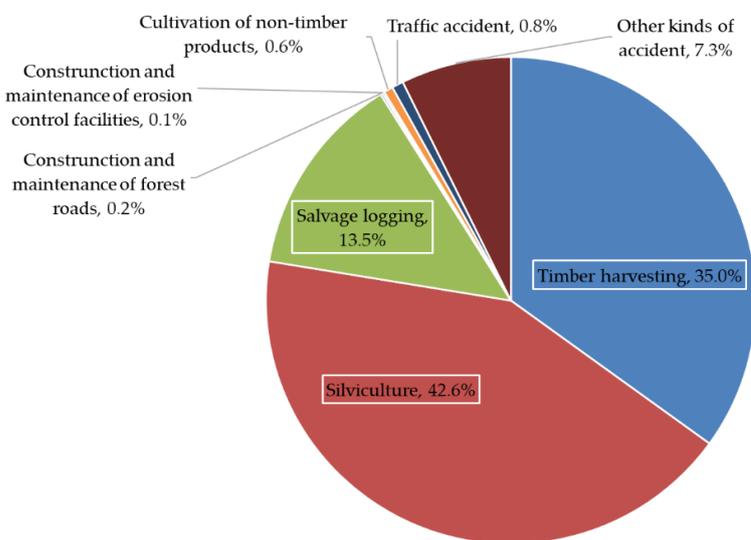
**Figure 2.** Distribution of occupational accident rates annually between 2010 and 2020: (a) age of workers and (b) experience of workers.

The most dangerous month of the year was March (accounting for 10.9% of the total annual operational accidents), followed by November (9.7%), October (9.3%), and February (9.0%; Figure 3). Comparing accidents by month shows that summer months, such as July and August, are the least hazardous. According to the statistical analysis results, the number of monthly occupational accidents showed significant differences ( $\chi^2 = 402.62$ ,  $df = 11$ ,  $p < 0.001$ ). The number of accidents occurring during weekdays (Mondays through Fridays) was considerably greater than those that occurred on weekends (Figure 3). The differences between the daily frequency of accidents were significant ( $\chi^2 = 626.23$ ,  $df = 6$ ,  $p < 0.001$ ), with the highest number occurring on Tuesday compared to other working days.



**Figure 3.** Distribution of occupational accident rates annually between 2010 and 2020: (a) month and (b) day of week.

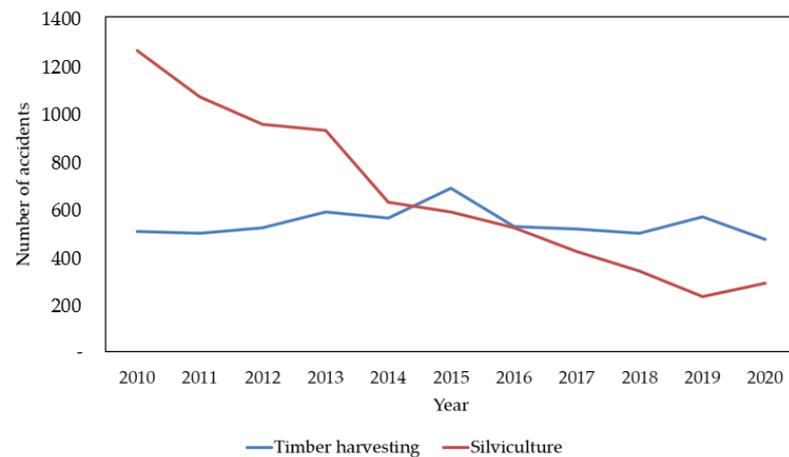
Silviculture and timber harvesting activities were the most hazardous during the period of 2010–2020, accounting for 42.6% and 35.0% of the total annual operational accidents, respectively (Figure 4). The chi-square test revealed significant differences in the number of accidents by month ( $\chi^2 = 273.83$ ,  $df = 7$ ,  $p < 0.001$ ). Over the last decade, a total of 218 forest workers died due to occupational injuries, with 90 and 66 of these deaths resulting from timber harvesting and silviculture, respectively. Furthermore, the number of occupational accidents in silviculture operations dropped dramatically, while the number of accidents in timber harvesting showed no clear trend (Figure 5). The figures for timber harvesting indicate an increase after 2015 compared to silviculture.



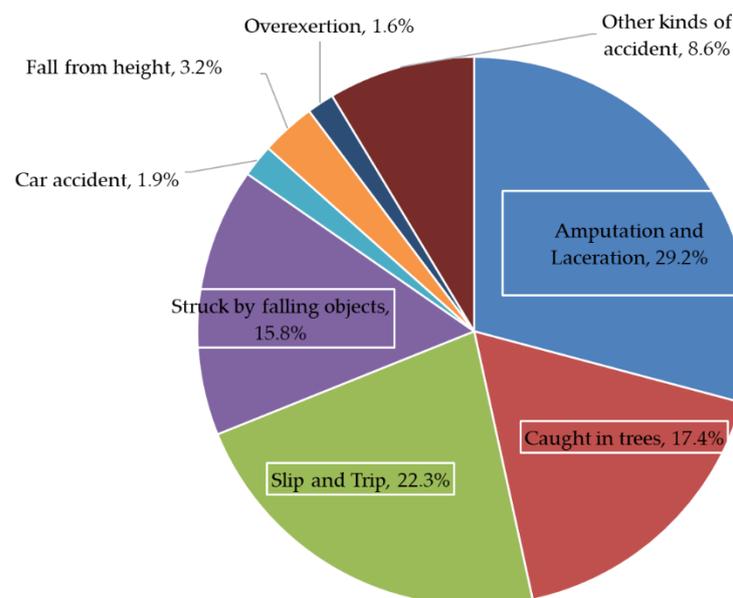
**Figure 4.** Distribution of occupational accident rates by operation type.

The occupational injuries that occurred between 2010 and 2020 are shown in Figure 6. The highest average number of occupational accidents was observed in the “amputation and laceration” and “slip and trip” categories. A comparison of fatalities resulting from different injury patterns suggests that being “caught in trees” (comprising 45.0% of total deaths during the observed period) presents the greatest risk, whereas the “slip and trip” type did not result in death. There was a statistically significant difference in accident causes ( $\chi^2 = 100.37$ ,  $df = 7$ ,  $p < 0.001$ ); less than 10% of the accidents were caused by “car accidents”, “falls from heights”, or “overexertion”. Hence, forest workers are more likely

to experience accidents related to being “caught in trees” and “amputation and laceration” than other types of accidents.



**Figure 5.** Distribution of occupational accidents by operation type.



**Figure 6.** Distribution of occupational accident rates by injury patterns.

#### 4. Discussion

Forestry remains one of the most physically hazardous industries in the world, and Korean forestry workers are not immune to occupational safety and health issues. According to data from KOSH and KFS, 1100 occupational accidents (18,434 per 100,000 full-time workers; 13 deaths) occurred annually in Korea between 2010 and 2020 [12,16]. Although the number of accidents in forestry showed a decreasing trend, it was higher than that in other industries. Forest work is not controlled by environmental conditions, such as terrain, weather, and unstable exposure positions. Occupational accidents and related deaths may be an important challenge for Korean forestry. Therefore, we analyzed the latest trends and risk factors related to forestry accidents in an attempt to minimize occupational hazards and improve the workplace safety culture. The KOSH and KFS databases were used to identify occupational fatalities in the forestry sector between 2010 and 2020. The results showed that the highest average injury rates occurred among workers aged over 51 years and with less than 6 months of experience. Silviculture and timber harvesting were responsible for 77.6% of the total annual accidents. Additionally, the most frequent types of injuries were

“amputation and laceration”, “slip and trip”, and “caught in trees”. Our findings may provide valuable insights for improving worker safety and health.

Most occupational and fatal injuries occur during timber harvesting. Forest operations, including timber harvesting (particularly manual harvesting) and silviculture, are dangerous [22,23]. If motor-manual felling activities are conducted in steep terrains, these technologies are associated with a high accident risk [24,25]. For example, in Croatia, Landekić et al. [7] reported that 51.4% of the total annual accidents between 2014 and 2020 occurred during motor-manual felling. In Austria, the occupational and fatal accident rates for manual tree felling and processing were 45.0% and 19.3%, respectively, during the 2000–2009 period [24]. Arman et al. [14] and Baek et al. [6] reported that motor-manual felling and processing activities were classified as heavy workloads and had negative impacts on workers’ health, as the heart rate increased by up to 87.9% during work. In Korea, a labor-intensive timber harvesting method is commonly used on steep slopes [26]. Our results indicate that the number of accidents during timber harvesting may increase. It may therefore be concluded that motor-manual felling activities are hazardous to workers’ occupational safety and health, and a shift from manual activities to mechanized operations is needed to improve safety [27].

Younger workers had a particularly decreased accident frequency compared to older workers (age 50+); in Korea, the average age in forest workers is 50 years. This finding is consistent with previous studies, such as those by Tsioras et al. [25], Wilhelmson et al. [28], and Jankovský et al. [29]. Workers aged over 50 years suffered the most occupational accidents, as they may be more easily distracted and tend to lose vigilance during operations [30]. Additionally, if they sustain injuries, they may require a longer recovery period [31]. Therefore, older workers may have a higher occupational risk.

Workers with low education appeared to be notably vulnerable. The trend of increasing injury frequency as workers’ experience decreases is evident in studies by Tsioras et al. [25] and Jankovský et al. [29]. Inexperienced workers (i.e., with less than 2 years of experience) often lack the necessary skills and experience to work carefully and are more prone to injury [27,32]. However, if workers have more than five years of experience, they plan their operations to limit fatigue and avoid dangerous and stressful situations that can lead to accidents [29,33]. Therefore, experienced workers may be safer and more protected from accidents than inexperienced ones. Thus, low-education (i.e., with less than 2 years of experience) workers tend to suffer more from lethal accidents compared to other groups, even in the older age groups (age 50+). To successfully reduce accident risk, workers must be properly trained, regardless of their age [34,35].

Timber harvesting is most intensive during the winter months (from late November to mid-March) in Korea due to the dormancy of trees and the need to protect the forest floor. This is related to an increased accident frequency in March and November. For example, Tsioras et al. [25] found that most injuries in Austria occur during the winter season because winter felling is preferred. In contrast, Lagerstrom et al. [27] reported different results, with accidents distributed from July to September in Montana and Idaho, United States, where timber harvesting is extremely intensive during the summer months. Therefore, the annual occupational injury rates may be affected by the months in which timber harvesting occurs.

The most frequent accidents were in the “amputation or laceration” and “slip-and-trip” groups. A large number of these accidents were listed because of workers operating in steep terrain where motor-manual felling and processing are used, consistent with Lindroos and Burström [36] and Tsioras et al. [25]. For example, Lagerstrom et al. [27] indicated that laceration injuries increased due to falls from chainsaws. Slip and trip accidents are the most frequent in countries with steep terrain, particularly in Austria, where forests have slopes greater than 30% [37]. During labor-intensive operations, unstable, steep terrain surface conditions, where mechanized felling is not possible, may result in a higher number of “amputation or laceration” and “slip and trip” injuries than other types of injuries. An alternative approach which may improve safety is to use a mechanized felling operation, as this results in a reduction in the occupational fatality rate [34].

## 5. Conclusions

This study aimed to understand the occurrence and characteristics of injuries and fatalities in the forestry sector in South Korea. Although forestry injuries in Korea have decreased over the last 10 years, the occupational fatality rate for forestry workers was 10.2 per 1000 employees in 2020, which is still higher than that in all other industries. Workers aged 51–60 years accounted for the highest percentage of accidents (40.7%). Approximately 92.9% of accidents occurred among employees with less than six months of experience. Therefore, it may be necessary to provide safety training and improve communication to workers to prevent serious injury and fatalities. The highest number of accidents occurred in March (10.9%) and November (9.7%), while the lowest number of claims occurred in the summer months, such as July, August, and September. This is because timber harvesting is most demanding in November and March in Korea. When evaluating specific incident types for job tasks, including felling, extraction, forwarding, and truck driving, it was challenging to observe trends using our data. Furthermore, during forest operation activities, the most frequent accidents were in the “amputation or laceration” and “slip-and-trip” categories. However, we did not evaluate the injured body parts (e.g., head, neck, back, and upper and lower extremities) due to limited information on the number of accidents by body part. Therefore, future research is needed to collect and understand the latest operational trends in fatalities and injured body parts.

**Author Contributions:** Conceptualization, E.L.; methodology, M.-J.C., Y.-S.C. and E.L.; formal analysis, M.-J.C. and Y.-S.C.; investigation, M.-J.C., Y.-S.C. and E.L.; resources, M.-J.C. and Y.-S.C.; data curation, M.-J.C., Y.-S.C. and E.L.; writing—original draft preparation, M.-J.C., Y.-S.C. and E.L.; writing—review and editing, E.L.; visualization, M.-J.C., Y.-S.C. and E.L.; supervision, E.L.; project administration, E.L.; funding acquisition, E.L. All authors have read and agreed to the published version of the manuscript.

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