Accepted: 26 September 2017
DOI: 10.1002/ajim.22784

RESEARCH ARTICLE

WILEY AMERICAN JOURNAL OF INDUSTRIAL MEDICINE

Work-related injuries in the Alaska logging industry, 1991-2014

Yuri P. Springer PhD[1,2] | Devin L. Lucas PhD[3] | Louisa J. Castrodale DVM, MPH[1] | Joseph B. McLaughlin MD, MPH[1]

[1] Alaska Division of Public Health, Section of Epidemiology, Anchorage, Alaska

[2] Epidemic Intelligence Service, Division of Scientific Education and Professional Development, U.S. Centers for Disease Control and Prevention, Atlanta, Georgia

[3] National Institute for Occupational Safety and Health, Western States Division, Anchorage, Alaska

Correspondence
Yuri P. Springer, PhD, Alaska Division of Public Health, Section of Epidemiology, 3601C St., Suite 540, Anchorage, AK 99503.
Email: yurispringer@gmail.com

Funding information
State of Alaska; The United States Federal Government

Background: Although loggers in Alaska are at high risk for occupational injury, no comprehensive review of such injuries has been performed since the mid-1990s. We investigated work-related injuries in the Alaska logging industry during 1991-2014.

Methods: Using data from the Alaska Trauma Registry and the Alaska Occupational Injury Surveillance System, we described fatal and nonfatal injuries by factors including worker sex and age, timing and geographic location of injuries, and four injury characteristics. Annual injury rates and associated 5-year simple moving averages were calculated.

Results: We identified an increase in the 5-year simple moving averages of fatal injury rates beginning around 2005. While injury characteristics were largely consistent between the first 14 and most recent 10 years of the investigation, the size of logging companies declined significantly between these periods.

Conclusions: Factors associated with declines in the size of Alaska logging companies might have contributed to the observed increase in fatal injury rates.

KEYWORDS
chainsaw, helicopter, timber, Tongass National Forest, tree

1 | INTRODUCTION

Logging has consistently ranked among the most hazardous industries in the United States. During 1980-1988, the average annual work-related fatality rate for loggers in the United States was 162/100 000 workers,[1] 23 times the national all occupations average over the same period.[2] In 2014, loggers had the highest work-related fatality rate in the United States (111/100 000 workers), 33 times the all occupations rate.[3]

Among states, Alaska has historically had some of the highest occupational fatality rates across multiple industries, including logging. Alaska had the highest estimated annual occupational fatality rate of any state during 1980-1995 (24.3/100 000 workers, five times the national average),[2] while during 1980-1988 the work-related fatality rate estimated for the Alaska logging industry was 289/100 000 workers.[4] Concerns about worker safety in the Alaska logging industry are longstanding but peaked in 1993 after six helicopter logging crashes over 18 months. These resulted in 10 nonfatal and nine fatal injuries to loggers and an estimated fatality rate for helicopter logging pilots in Alaska of 5000/100 000.[5,6] In response, the National Institute for Occupational Safety and Health, Alaska Field Station convened an inter-agency helicopter logging safety working group that included representatives from the logging industry and multiple state and federal government agencies. The group updated safety recommendations for helicopter logging,[7,8] and after their implementation in late 1993, only a single logging-associated helicopter crash occurred in Alaska during the subsequent 7 years.[9]

Although historical precedents suggest that logging likely remains a high-risk industry in Alaska, no comprehensive, systematic review of injuries in the Alaska logging industry has been performed since 1995.[10] Here, we present results of an investigation examining nonfatal and fatal work-related injuries in the Alaska logging industry during 1991-2014. The goals of the investigation were to describe nonfatal and fatal injuries and characterize temporal changes in these injuries over this 24-year period.

2 | MATERIALS AND METHODS

Data on nonfatal work-related injuries in Alaska were obtained from the Alaska Trauma Registry. The Alaska Trauma Registry is a hospital-based injury surveillance system that collects information from acute-care hospitals in Alaska on the nature, cause, severity, treatment, and outcome of a variety of injury types.[11] To be recorded in the Alaska Trauma Registry, an injury must have occurred to a person admitted to an Alaska acute-care hospital, held for observation, transferred to another acute-care hospital, or declared dead in the emergency department within 30 days of sustaining that injury. Work-related injuries recorded in the Alaska Trauma Registry receive additional coding to classify the industry and occupation of the injured worker.

We obtained Alaska Trauma Registry data for 1991-2014 and identified nonfatal work-related injuries in the Alaska logging industry by searching for records associated with one of the following industry and occupation codes: 1) 2010 Standard Occupational Classification (SOC) codes 45-4020, 45-4021, 45-4022, 45-4023, and 45-4029; 2) 2012 North American Industry Classification System (NAICS) codes 1133, 11331, or 113310; 3) 2010 Census industry code 0270; and 4) 2010 Census occupations code 6130. To ensure that we did not miss any records as a result of coding errors, we searched two narrative injury description fields for all remaining records by using the following keywords: forest, log, logging, timber, and tree. We manually reviewed all records flagged by these two searches and categorized injuries into two types. Work-related injuries sustained by persons whose employment in the Alaska logging industry could be established with confidence were categorized as logging injuries. Work-related injuries sustained by persons performing logging-related tasks but whose employment in the Alaska logging industry could not be determined with confidence were categorized as logging-support injuries. Injuries that were either not work-related or were sustained by persons clearly not engaged in commercial logging (eg, injuries associated with processing firewood on personal property or injuries among arborists) were excluded from our analyses.

Data on fatal work-related injuries in Alaska were obtained from the Alaska Occupational Injury Surveillance System. The Alaska Occupational Injury Surveillance System is an active surveillance system that collects descriptive information on fatal work-related injuries compiled from multiple local, state, and federal organizations and media outlets. As with Alaska Trauma Registry data, we obtained Alaska Occupational Injury Surveillance System data for 1991-2014 and identified fatal work-related injuries in the Alaska logging industry using SOC and NAICS codes and keyword searches. We identified fatal logging and logging-support injuries for inclusion in our analyses.

Workforce data for the Alaska logging industry were obtained from the Alaska Department of Labor and Workforce Development. Mandates associated with unemployment insurance require Alaska employers to report the number of employees on their payrolls each month to the state's census of employment and wages. Within this dataset, we enumerated employers (hereafter, companies) associated with the Alaska logging industry, on the basis of their classification with Standard Industrial Classification (SIC) code 241 ("logging," for years 1991-2000) or NAICS code 113000 ("forestry and logging," including workers in timber tract operations and forest nurseries and those gathering forest products, for years 2001-2014). For each month of the investigation, we calculated the total number of employees across all companies, and then averaged these monthly totals within years to estimate the average annual number of persons employed in the Alaska logging industry (hereafter, workers). For each year of the investigation, we divided the annual count of workers by the count of companies to estimate the average annual size of Alaska logging companies.

We quantified the frequency of injuries by the sex, age, and work-related occupation of the injured worker, the timing of (year and month) and location (geographic and work-related site type) where the injury occurred, and four injury characteristics: 1) injury source (object responsible for producing the injury); 2) injury event (manner in which the injury was produced by the source); 3) injury nature (physical characteristic of the injury); and 4) the part of the body primarily affected by the injury. We measured the severity of nonfatal injuries using the injury severity score.[12] The injury severity score ranges from 0 to 75 and is calculated using the Abbreviated Injury Scale, which ranges from 1 (minor injury) to 6 (unsurvivable injury). Within the Alaska Trauma Registry, each injury to a patient is assigned an Abbreviated Injury Scale score, and the injury severity score is calculated as the sum of squares of each Abbreviated Injury Scale score for the three most severely injured body regions.[13]

We calculated annual rates of nonfatal and fatal logging injuries using multipliers of 100 and 100 000 workers, respectively. Counts of logging-support injuries were excluded from these calculations because denominator data were specific to the logging industry. Because small sample sizes resulted in unstable rates in some instances, we calculated and plotted 5-year simple moving averages of annual logging injury rates to more clearly visualize interannual trends. Such averages are particularly useful in identifying trend reversals in variable data. To statistically evaluate interannual changes in rates, we analyzed annual counts of injuries by type (fatal, nonfatal) using Poisson regression with an offset term for annual counts of workers (log transformed). Year was coded such that 1991 was assigned a value of 1 and 2014 a value of 24. Models with and without a quadratic term were compared based on the change in the Akaike Information Criterion (ΔAIC). Finally, we compared characteristics of logging injuries reported during a 14-year early period (1991-2004) and a 10-year recent period (2005-2014). The year 2004 was chosen as the threshold separating these periods because annual logging injury rates (fatal and nonfatal injuries combined) and the associated 5-year simple moving averages both reached their minima in that year.

The United States Centers for Disease Control and Prevention (CDC) reviewed this investigation for human subjects protection and determined it to be non-research. Thus, neither institutional review board (IRB) approval or signed written informed consent from subjects were required.

3 | RESULTS

We identified a total of 467 logging injuries (intentional and unintentional) during 1991-2014; 416 (89%) were nonfatal and 51 (11%) were fatal. In the summaries that follow, percentages are relative to the total number of injuries for which the associated characteristic was specified.

3.1 | Nonfatal logging injuries

Annual counts of nonfatal logging injuries (mean = 17.3/year; range = 3-40/year) declined over the first 10 to 15 years of the investigation and gradually stabilized at relatively low counts thereafter (Figure 1A, Table 1). The annual rate of nonfatal logging injuries (mean = 2.1/100 workers) ranged from 0.7/100 workers to 3.9/100 workers (Figure 1B, Table 1). The magnitude of the associated 5-year simple moving averages oscillated during 1993-2004, increased to a high in 2009, and declined thereafter. When interannual changes in rates were evaluated using Poisson regression, we did not find either a significant linear or quadratic effect of year in analyses of nonfatal logging injuries (year coefficient ± standard error = −0.0098 ± 0.0285, $z = -0.34$, $P = 0.73$; year^2 coefficient ± standard error = 0.000729 ± 0.00124, $z = 0.59$, $P = 0.56$).

Nearly all workers associated with the 416 nonfatal logging injuries were male (Supplemental Table S1); median age was 38.5 years (range = 19-69 years). There was a significant increase in age of the injured worker over time, from an annual average of 36.6 years in 1991 to 45.2 years in 2014 ($F_{1,145} = 9.0$; $r^2_{adj} = 0.02$; $P = 0.003$). Injuries occurred most frequently during the summer months of June (14%) and August (13%) and in the southeast (72%) and Gulf Coast (24%) regions of Alaska (Supplemental Figure S1). Of the 389 injuries for which an injury severity score was specified, the median score was 4 (range = 1-34). Average annual scores ranged from 3.1 to 10.1; injury severity score values did not change significantly over time ($F_{1,388} = 2.0$; $r^2_{adj} = 0.003$; $P = 0.16$). The most frequently observed injury source and event were trees or logs (52%) and being struck by a falling object (33%), respectively (Table 2, Supplemental Table S2). The majority of injuries were fractures (50%), and the injured worker's trunk was the most frequently affected body part (31%).

3.2 | Fatal logging injuries

Annual counts of fatal logging injuries (mean = 2.1/year; range = 0-12/year) declined over the first 10 to 15 years of the investigation, were zero for 5 years (2003-2007) and then oscillated between zero and two per year thereafter (Figure 1A, Table 1). The annual rate of fatal logging injuries (mean = 253.7/100 000 workers) ranged from 0/100 000 workers (in 10 of the 24 years examined) to 719.4/100 000 workers (Figure 1C, Table 1). The magnitude of the associated 5-year simple moving averages declined during 1993-2005, then increased to a high in 2010 and declined slightly thereafter. Thus, a temporal reversal in fatality rates was apparent around 2005. When interannual changes in rates were evaluated using Poisson regression, there was a significant quadratic effect of year for fatal logging injuries (year

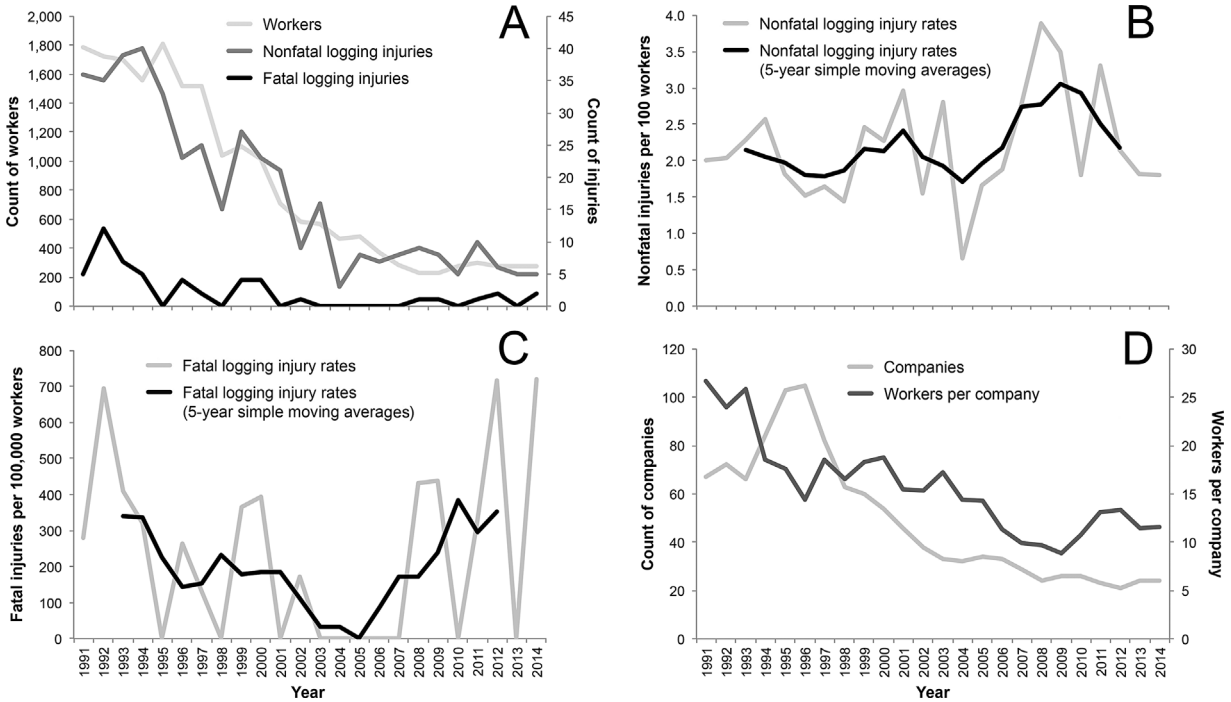

FIGURE 1 (A) Annual counts of workers, nonfatal logging injuries, and fatal logging injuries associated with the Alaska logging industry, 1991-2014, (B) annual nonfatal logging injury rates (per 100 workers) and 5-year simple moving averages calculated from these, (C) annual fatal logging injury rates (per 100 000 workers) and 5-year simple moving averages calculated from these, and (D) annual counts and average size (workers/company) of companies in the Alaska logging industry

TABLE 1 Annual counts of nonfatal and fatal logging injuries in Alaska, workers and companies in the Alaska logging industry, and amount of timber harvested in national forests in Alaska, 1991-2014

Year	Count of nonfatal logging injuries	Count of fatal logging injuries	Count of workers[a] in the Alaska logging industry	Count of companies in the Alaska logging industry	Amount of timber harvested in national forests in Alaska (millions of board feet cut)[b]	Average size of companies in the Alaska logging industry (workers per company)[c]	Rate of nonfatal logging injuries (per 100 workers)[c]	Rate of fatal logging injuries (per 100 000 workers)[c]	5-year simple moving averages of rate of nonfatal logging injuries[c]	5-year simple moving averages of rate of fatal logging injuries[c]
1991	36	5	1789	67	326.5	26.7	2.0	279.5		
1992	35	12	1724	72	395.3	23.9	2.0	696.1		
1993	39	7	1702	66	327.1	25.8	2.3	411.3	2.1	341.5
1994	40	5	1560	84	251.9	18.6	2.6	320.5	2.0	338.3
1995	33	0	1809	103	199.7	17.6	1.8	0.0	2.0	225.5
1996	23	4	1516	105	97.9	14.4	1.5	263.9	1.8	143.2
1997	25	2	1518	82	124.6	18.5	1.6	131.8	1.8	152.0
1998	15	0	1039	63	121.5	16.5	1.4	0.0	1.9	231.0
1999	27	4	1098	60	153.6	18.3	2.5	364.3	2.2	178.2
2000	23	4	1013	54	119.5	18.8	2.3	394.9	2.1	186.3
2001	21	0	710	46	44.4	15.4	3.0	0.0	2.4	186.3
2002	9	1	581	38	32.1	15.3	1.5	172.1	2.0	113.4
2003	16	0	569	33	48.1	17.2	2.8	0.0	1.9	34.4
2004	3	0	461	32	49.2	14.4	0.7	0.0	1.7	34.4
2005	8	0	484	34	46.6	14.2	1.7	0.0	2.0	0.0
2006	7	0	373	33	40.1	11.3	1.9	0.0	2.2	86.2
2007	8	0	286	29	22.7	9.9	2.8	0.0	2.7	173.5
2008	9	1	232	24	30.2	9.7	3.9	431.0	2.8	173.5
2009	8	1	229	26	28.5	8.8	3.5	436.7	3.1	239.8
2010	5	0	278	26	35.8	10.7	1.8	0.0	2.9	383.1
2011	10	1	302	23	31.8	13.1	3.3	331.1	2.5	296.9
2012	6	2	279	21	17.5	13.3	2.2	716.8	2.2	353.5
2013	5	0	276	24	41.3	11.5	1.8	0.0		
2014	5	2	278	24	36.7	11.6	1.8	719.4		

[a]Annual counts are the average of monthly counts of total number of employees across all companies associated with the Alaska logging industry.
[b]Data downloaded from http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd511209.xlsx on August 1, 2017.
[c]Variables derived from counts of injuries, workers, and companies include the average annual size of companies in the Alaska logging industry (workers/company), the annual rates of nonfatal and fatal logging injuries (per 100 and 100 000 workers, respectively), and 5-year simple moving averages of annual nonfatal and fatal logging injury rates.

coefficient ± standard error = −0.267 ± 0.08, $z = -3.34$, $P = 0.00083$; year^2 coefficient ± standard error = 0.011 ± 0.0034, $z = 3.13$, $P = 0.0017$). The significant quadratic effect indicates that the interannual change in rates predicted by the model follows a parabolic path and thus provides statistical support for the rate reversal apparent in the associated 5-year simple moving averages. When compared to the linear model (ie, no quadratic term), the ΔAIC was 7.

All 51 fatal injuries involved male workers (Supplemental Table S1); median age was 42.0 years (range = 19-73 years). Injuries occurred with relatively equal frequency across months within years and exclusively in the southeast (94%) and Gulf Coast (6%) regions of Alaska (Supplemental Figure S1). Trees or logs and helicopters were the sources of 46% and 24% of injuries, respectively (Table 2, Supplemental Table S2). The most frequently observed injury events were being struck by a falling object (31%) and aircraft-related injuries (27%). A total of 54% of injuries were classified as multiple traumatic injuries and 49% affected multiple body parts.

3.3 | Logging-support injuries

We identified 53 nonfatal and 13 fatal logging-support injuries during 1991-2014 (Appendix S1, Supplemental Table S3). The majority of

TABLE 2 Counts of nonfatal and fatal logging injuries among workers in the Alaska logging industry, 1991-2014, and separately across periods 1991-2004 and 2005-2014, by injury source, injury event, injury nature, and primarily affected body part

	1991-2014			1991-2004			2005-2014		
	Nonfatal logging injuries (*N* = 416)	Fatal logging injuries (*N* = 51)	All injuries combined (*N* = 467)	Nonfatal logging injuries (*N* = 345)	Fatal logging injuries (*N* = 44)	All injuries combined (*N* = 389)	Nonfatal logging injuries (*N* = 71)	Fatal logging injuries (*N* = 7)	All injuries combined (*N* = 78)
Source									
Trees or logs	205	23	228	168	20	188	37	3	40
Heavy machinery or equipment	66	6	72	55	4	59	11	2	13
Chainsaw	49	0	49	40	0	40	9	0	9
Helicopter	4	12	16	4	12	16	0	0	0
Truck or trailer	12	1	13	11	1	12	1	0	1
Other specified[a]	55	8	63	46	7	53	9	1	10
Unspecified	25	1	26	21	0	21	4	1	5
Event									
Struck by falling object	136	16	152	111	13	124	25	3	28
Injuries caused by cutting/piercing instruments/objects	66	0	66	56	0	56	10	0	10
Struck by or against object	52	7	59	40	6	46	12	1	13
Falls	55	0	55	47	0	47	8	0	8
Machinery-related	43	0	43	34	0	34	9	0	9
Aircraft-related	7	14	21	7	14	21	0	0	0
Caught in or between objects	18	3	21	15	2	17	3	1	4
Motor vehicle-related	15	5	20	14	4	18	1	1	2
Other specified[a]	23	6	29	21	5	26	2	1	3
Unspecified	1	0	1	0	0	0	1	0	1
Nature									
Fracture	204	0	204	169	0	169	35	0	35
Open wound	78	0	78	66	0	66	12	0	12
Intracranial injury	32	14	46	24	14	38	8	0	8
Multiple traumatic injuries	0	27	27	0	23	23	0	4	4
Strains and sprains	25	0	25	25	0	25	0	0	0
Internal injury	18	0	18	13	0	13	5	0	5
Contusion	17	0	17	16	0	16	1	0	1
Crushing injury	15	1	16	10	0	10	5	1	6
Other specified[a]	18	8	26	16	7	23	2	1	3
Unspecified	9	1	10	6	0	6	3	1	4

(Continues)

TABLE 2 (Continued)

	1991-2014			1991-2004			2005-2014		
	Nonfatal logging injuries (*N* = 416)	Fatal logging injuries (*N* = 51)	All injuries combined (*N* = 467)	Nonfatal logging injuries (*N* = 345)	Fatal logging injuries (*N* = 44)	All injuries combined (*N* = 389)	Nonfatal logging injuries (*N* = 71)	Fatal logging injuries (*N* = 7)	All injuries combined (*N* = 78)
Primarily affected body part									
Trunk	126	3	129	106	2	108	20	1	21
Lower extremities (excluding foot/ankle)	92	0	92	72	0	72	20	0	20
Head	64	13	77	54	12	66	10	1	11
Foot or ankle	51	0	51	44	0	44	7	0	7
Hand or wrist	38	0	38	32	0	32	6	0	6
Upper extremities (excluding hand/wrist)	38	0	38	34	0	34	4	0	4
Multiple body parts	3	23	26	2	20	22	1	3	4
Other specified[a]	0	8	8	0	7	7	0	1	1
Unspecified	4	4	8	1	3	4	3	1	4

[a]Includes characteristic categories for which the value of all injuries combined over the investigation was <10. Counts associated with these categories are provided in Supplemental Table S2.

logging-support injuries occurred at water transport-related sites (30/64, 47%) or road transport-related sites (19/64, 30%). The leading injury event was motor vehicle-related (20/66, 30%), followed by falls (16/66, 24%) and water transport-related (9/66, 14%).

3.4 | Early versus recent period comparisons

There were 345 nonfatal and 44 fatal injuries reported during the early period (1991-2004) and 71 nonfatal and 7 fatal injuries reported during the recent period (2005-2014).

3.5 | Injury source

The rank order and relative contribution of the three most common injury sources were consistent between periods. Among all injuries (fatal and nonfatal combined) trees and logs were the leading source in both periods (51% vs 55%, respectively), followed by heavy machinery or equipment (16% vs 18%), and chainsaws (11% vs 12%) (Table 2, Supplemental Table S2). In both periods, trees and logs were the leading source for fatal (45% vs 50%) and nonfatal (52% vs 55%) injuries. Helicopters were the source of 27% of early-period fatalities but no recent-period injuries.

3.6 | Injury event

Being struck by a falling object was the leading injury event in both early (32% of all injuries) and recent (36%) periods (Table 2, Supplemental Table S2). It was associated with the highest number of fatalities in the recent period (3/7, 43%) and the second highest number (13/44, 30%) in the early period. All of these fatalities involved trees or logs. Injuries caused by cutting or piercing instruments or objects and being struck by or against objects represented either the second or third most frequently observed injury events in both periods. Injuries caused by cutting or piercing instruments or objects accounted for 14% of early period and 13% of recent period injuries, all of which were nonfatal. Among these, 68% (38/56) in the early period and 90% (9/10) in the recent period involved chainsaws. Being struck by or against objects was associated with 12% of all injuries in the early period and 17% in the recent period. This event type accounted for 14% of fatalities in both periods. Aircraft-related injuries accounted 32% of early-period fatalities but no recent-period injuries.

3.7 | Nature of injury

The rank order and relative contribution of the three most common injury nature categories were consistent between periods. Fractures represented the majority of all injuries in both the early period (44%) and recent period (47%) (Table 2, Supplemental Table S2). Second to fractures, open-wound injuries accounted for 17% of early period and 16% of recent period injuries. All fractures and open-wound injuries were nonfatal. Intracranial injuries consistently represented the third most common injury nature category, accounting for 10% and 11% of early- and recent-period injuries, respectively. These accounted for

32% of early-period fatalities but no recent-period fatalities. Strains and sprains accounted for 7% of all early-period injuries but no recent-period injuries. Injuries classified as multiple traumatic injuries were always fatal; they represented only 6% of all injuries, but accounted for 52% of early-period and 67% of recent-period fatalities.

3.8 | Primarily affected body part

The rank order of the body parts most frequently affected by injuries was consistent between periods. A total of 28% of all injuries in both periods primarily affected the worker's trunk (Table 2, Supplemental Table S2). Approximately one-half of these injuries in both the early period (54/108) and the recent period (10/21) involved the injured worker being struck by a falling object. Following the trunk, the percentage of injuries that primarily affected the lower extremities (excluding foot or ankle) ranged from 19% (early period) to 27% (recent period). Among these lower extremity injuries in the recent period, 35% (7/20) were associated with being struck by a falling object and 25% (5/20) with being struck by or against objects. Injuries primarily affecting the head accounted for 17% of all early-period injuries and 29% of early-period fatalities. A total of 64% of recent period head injuries (7/11) involved being struck by a falling object. A total of 11% of early period and 9% of recent-period injuries primarily affected the foot or ankle. Injuries associated with multiple body parts represented 6% of early period and 5% of recent-period injuries, but accounted for 49% and 50% of the fatal injuries in these periods, respectively.

3.9 | Summary of Workforce Data

Annual counts of workers in the Alaska logging industry (mean = 837.8/year; range = 229-1809/year) declined significantly over the investigation ($F_{1,23} = 171.6$; $r^2_{adj} = 0.88$; $P < 0.0001$) (Figure 1A, Table 1). Significant declines over time also occurred in both the annual count of Alaska logging companies (mean = 48.7/year; range = 21-105/year; $F_{1,23} = 63.8$; $r^2_{adj} = 0.73$; $P < 0.0001$) and their average annual size (mean = 15.6 workers/company; range = 8.8-26.7 workers/company; $F_{1,23} = 57.3$, $r^2_{adj} = 0.71$, $P < 0.0001$) (Figure 1D, Table 1). Similarly, there were significantly more companies in the early period (mean ± stdev = 64.6 ± 23.4/year) compared to the recent period (mean ± stdev = 26.4 ± 4.3/year) ($F_{1,23} = 25.8$; $P < 0.0001$), and companies were significantly larger in the early period (mean ± stdev = 18.7 ± 4.0 workers/company) compared to the recent period (mean ± stdev = 11.4 ± 1.7 workers/company) ($F_{1,23} = 28.7$, $P < 0.0001$).

4 | DISCUSSION

After declining during 1991-2004, the 5-year simple moving averages of fatality rates in the Alaska logging industry rose during 2005-2014. The decline during 1991-2004 was not entirely unexpected given the relatively high number and percentage of fatalities associated with helicopter logging during 1992-1993 (9 of 19 over the whole period, ie, 47%). By comparison, only three fatalities were attributed to helicopters over the remaining 21 years of the investigation. Yet the 5-year simple moving averages of annual fatality rates increased in 5 of 7 years during 2005-2014 and reached a 24-year high in 2010. The annual fatality rate in 2014 (719.4/100 000 workers) exceeded the rate in every other year of the study, including 1992 (696.1/100 000 workers) and 1993 (411.3/100 000 workers), the years when decisive actions were taken to bolster safety protocols after the helicopter logging crashes.[7,8] These differentials in annual rates and the increase in fatality rates during 2005-2014 observed in the 5-year simple moving averages (and supported by results of the Poisson regression) suggest that actions to promote worker safety in the Alaska logging industry are warranted.

Comparison of injuries between the early and recent periods did not suggest an obvious explanation for the observed increase in fatality rates during the latter. Across all four injury characteristics, the rank order and relative contribution of the three to four most frequently observed categories were generally consistent between periods. Assuming that injuries are a proxy for logging methods, this consistency suggests that the manner in which logging is conducted in Alaska was largely unchanged over the investigation. Comparisons of early and recent period injuries did identify at least three noteworthy exceptions. First, helicopters were the source of 27% of early-period fatalities but no recent-period injuries. This could reflect improvements in helicopter logging safety or reductions in the use of helicopters for logging in Alaska due to safety concerns and financial constraints. Second, although intracranial injuries accounted for ~10% of injuries over the investigation, they constituted 32% of early-period fatalities and no recent-period fatalities. This apparent decline in the severity of head injuries could be a result of changes in hazards (eg, reductions in average size of falling objects or distance of falls) or improved safety protocols. Third, strains and sprains accounted for 7% of early-period injuries but no recent-period injuries. Because of the nature of logging work, and published reports that strains and sprains can account for a large portion of nonfatal logging injuries,[14,15] this result might reflect a decline in reporting or care-seeking behavior by injured workers rather than a complete disappearance of injuries of this type.

Analyses of injury characteristics identified the preeminent importance of falling or rolling trees and logs in the epidemiology of logging injuries. Being struck by a falling object was the most frequently reported injury event, accounting for 33% of all nonfatal and 31% of all fatal injuries. Trees and logs were the source of all struck-by-falling-object fatalities (16/16) and approximately 71% of all struck-by-or-against-object fatalities (5/7). Evidence of relatively frequent and severe injuries associated with strikes by falling or rolling trees and logs is consistent with findings of other investigations of logging injuries[1,14–21] and provides strong motivation for safety interventions. Protocols that promote clear and regular communication among members of logging crews are critical for situational awareness when trees are being felled. Use of high-visibility clothing has been shown to reduce rates of struck-by-falling-object injuries.[22,23] Well-designed and properly worn hard hats can provide protection from smaller falling objects,[16] and increased mechanization (eg, use of feller bunchers) can confer a similar protective

effect as workers are sheltered from larger falling objects while working in cabs of logging vehicles.[24]

The significance of chainsaws for nonfatal logging injuries was also apparent. Chainsaws were the source of 71% of all nonfatal injuries caused by cutting or piercing instruments or objects (47/66). Chainsaws have been identified as an important source of nonfatal logging injuries by similar investigations in other settings[16,17,21] and represent an injury source that is relatively amenable to safety-related interventions. Training in safe operation of equipment and use of protective clothing and chainsaw guards have been shown to reduce the frequency and severity of chainsaw-related injuries.[23,25] The use of cutting techniques appropriate for the timber resources being harvested and regular equipment maintenance should also increase safety when chainsaws are used. Rates of chainsaw-related injuries have also been shown to decline in association with increased mechanization.[24,26]

A review of historical changes in the Alaska logging industry provides context for the observed temporal changes in fatality rates during 1991-2014. Since the start of the 20th century, logging in Alaska has occurred almost exclusively in the state's southeast region, the majority of which was designated as the Tongass National Forest (TNF) in 1907. During the first half of the century, the small-scale commercial logging operations in the TNF selectively targeted the most accessible and valuable timber resources. These were generally associated with stands of large, old-growth trees growing close to water into which they could be felled and floated to a sawmill for processing.[27,28] Passage of the Tongass Timber Act in 1947 allowed the U.S. Forest Service, which manages logging in the TNF, to issue 50-year contracts to commercial logging companies. These contracts provided guaranteed long-term access to volumes of timber sufficient to make the operation of large, high-volume timber processing facilities economically viable. Two large pulp mills, one in Ketchikan and the other in Sitka, began operating during the 1950s, driving up logging rates until output peaked in 1973 (Supplemental Figure S2).

As high-value timber was increasingly located in less accessible inland areas, thousands of miles of logging roads were constructed within the TNF to provide trucks and heavy machinery with access to these locations, resulting in the harvest of most of the remaining old growth trees.[27,28] During the 1970s and 1980s, shrinking global markets and increasing competition with the logging industry in the Pacific Northwest reduced demand for Alaska wood products. Facing declining profitability and requirements for costly upgrades to mitigate environmental impacts, the two large pulp mills closed in the 1990s. This initiated a precipitous contraction of the Alaska logging industry and a concomitant decline in production; by the turn of the century, logging rates had fallen to levels observed prior to the opening of the pulp mills[27,28] (Supplemental Figure S2).

The increase in fatality rates observed during 2005-2014 might be explained by two long-term changes in the Alaska logging industry. The first involves changes in the volume and spatial distribution of high-value timber resources in the TNF. By the early 1990s, the majority of old growth trees and stands had been removed. The high value timber that remained was confined to areas that were difficult to access (eg, far from logging roads) and where environmental conditions made work challenging and dangerous (eg, steep and rugged terrain). As a result, the economic incentive for loggers to work in areas associated with greater risk of injury has steadily increased over time. In some instances, the use of relatively dangerous methods to overcome access and environmental challenges (eg, helicopter logging) further increased risk.

The second change involves reductions in the size of logging companies in Alaska since closure of the two large pulp mills in the 1990s. We found that between the early and recent periods, the average size of logging companies in Alaska declined by 39%, from 18.7 to 11.4 workers/company. In a review of logging injuries in Washington State during 1977-1983, Paulozzi[18] demonstrated a significant negative relationship between logging company size and associated proportionate injury mortality ratios. The average mortality ratio of companies employing 12 or fewer workers was twice that of companies employing between 13 and 50 workers. During the roughly four decades during which the large pulp mills operated in Alaska, they created the foundation for a large, economically stable industry consisting of companies that were formally structured and operated. Many of these companies were relatively large and likely had well-developed worker safety programs including dedicated staff, codified, and enforced workplace safety policies, and routinely implemented employee safety trainings and equipment safety inspections. Because they offered steady employment and high wages, these companies supported a stable workforce consisting of permanent, local employees who developed extensive experience with local methods, conditions, and hazards. The prioritization of safe practices by employers, and their ability to retain experienced, high-quality workers, both likely contributed to reduced occupational risk.

Closure of the two pulp mills in the 1990s coincided with a significant decline in market demand for Alaskan timber products. As larger companies exited the Alaska logging industry to following closure of the mills, a handful of smaller companies filled what remained of the shrinking economic niche. Given their tight financial margins, these smaller companies might have had a lean structure that would not have included formal safety programs or trained and experienced workers. Out of financial necessity, they likely operated in a more improvised manner; deviation from safe practices and postponement of equipment repairs might have occurred more often. As their work became less consistent and profitable, it would have become harder to recruit and retain high-quality workers. Information obtained through interviews with a convenience sample of current and former Alaska loggers suggested that workers were often seasonally employed, imported from outside of Alaska, and less experienced and knowledgeable about local hazards than their mill-era predecessors. Our analyses additionally indicate that these workers were increasingly older persons. In spite of the potential for older workers to be more experienced, there is evidence that both the rates and severity of injuries increase with age among loggers.[19,29,30] As many of these changes occurred after the closure of the two pulp mills near the turn of the century, it seems likely that one or more of them might have contributed to the observed increase in fatality rates during 2005-2014.

Our investigation had at least four limitations. First, our counts of nonfatal logging injuries likely underestimated the true injury burden because the Alaska Trauma Registry only captures injuries treated at a hospital. Injured loggers might not seek hospital care for reasons including

geographic isolation (many logging activities occur in remote areas far from hospitals), economic considerations (cost of hospital treatment can be high for persons with minimal or no medical insurance), or workplace culture (eg, an expectation of under-reporting minor injuries to maintain work continuity). As a result, reported rates of nonfatal injuries likely underestimate the true rates. In contrast, it is unlikely that logging-related fatalities were missed or misclassified in the Alaska Occupational Injury Surveillance System; thus, reported counts and rates of fatal logging injuries should more accurately reflect true values. Second, based on qualitative descriptions of injury events present in the datasets, we assume that some proportion of injuries classified as logging-support were probably sustained by persons who were, in fact, employed in the logging industry. Their exclusion from our calculation of fatal and nonfatal logging injury rates would have biased both toward underestimation.

Third, small sample sizes constrained on our ability to conduct statistical analyses. Since categorical comparisons of injury characteristics involving three or more factors were untenable, we limited our analyses to basic summary statistics involving one to two factors. Assessment of temporal trends in injury rates were similarly complicated by small rate numerators. This issue was particularly acute for fatal injuries, and readers should be mindful of this constraint when interpreting associated results and conclusions. We used the 5-year simple moving averages as a way to buffer our temporal analyses against the sensitivity of crude annual rates to low injury counts. Finally, neither of the databases used as sources for our injury data contain detailed information about the size or safety practices of the companies that employed the injured workers. Such information, together with data on any deviations from these practices that occur in association with injuries, represents the critical link between our findings and the specific safety recommendations that should follow from them.

5 | CONCLUSIONS

Our results demonstrate that logging in Alaska continues to be associated with high injury rates. Actions to promote safe practices, including educational outreach and safety monitoring efforts, are warranted and can readily achieve broad coverage given the small size (numbers of companies and workers) of the industry. This being said, different logging methods and settings will often require unique approaches to improve safety, and the diversity of both in Alaska may necessitate a variety of action plans. In addition to focusing on the major and longstanding hazards identified in our analyses (eg, falling or rolling objects, work involving heavy machinery and handheld cutting equipment), evolution in safety programs in needed to reflect changes in industry practices and associated occupational risks. For example, the Alaska logging industry will increasingly focus on harvest from second-growth forests in the years ahead.[31,32] Differences between old- and second-growth forests in the height, girth, and density of standing trees, or the size and number of snags or rotting logs on the forest floor, could drive changes in logging methods that alter the types and magnitude of risks experienced by loggers.

Logging safety programs should be developed in collaboration with industry partners to closely track these changes and their consequences for worker safety. Such collaborations could also provide information about company safety practices and deviations from them that contextualize data on injury epidemiology and enable effectively targeted programs to increase workplace safety. Finally, focused injury investigations, like those conducted as part of the National Institute for Occupational Safety and Health's Fatality Assessment and Control Evaluation (FACE) program,[33] can generate detailed and comprehensive information about the circumstances associated with injuries. Resulting insights often elucidate the factors that contributed to injuries and thereby make valuable contributions to efforts to improve workplace safety.

AUTHORS' CONTRIBUTION

YPS and DLL conceived the study, gathered data, and performed analyses. YPS drafted the manuscript. All authors revised the manuscript critically for important intellectual content, approved the final version for publication, and agree to be accountable for all aspects of the work.

ACKNOWLEDGMENTS

We thank C. Bell, D. Hull-Jilly, A. Rodriguez, A. Romig, S. Saxon, and C. Schultz for their assistance in obtaining data, P.T.J. Johnson and B. Robinson for help with statistical analyses, and D. Fosbroke, T. Gardner, T. Haegerich, and P. Siegel for editorial contributions. O. Graham, N. Grewe, D. Harris, and J. Mackovjak shared personal experiences with and historical insights into the Alaska logging industry that helped to contextualize investigation findings. Y.P.S thanks S. Milne for sharing his enthusiasm for forestry and thereby motivating this work.

FUNDING

This work was funded by the State of Alaska and the United States Federal Government.

ETHICS APPROVAL AND INFORMED CONSENT

The United States Centers for Disease Control and Prevention (CDC) reviewed this investigation for human subjects protection and determined it to be non-research. Thus, neither institutional review board (IRB) approval or signed written informed consent from subjects were required.

DISCLOSURE (AUTHORS)

The authors report no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

Rodney Ehrlich declares that he has no conflicts of interest in the review and publication decision regarding this article.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the U.S. Centers for Disease Control and Prevention.

ORCID

Yuri P. Springer http://orcid.org/0000-0001-9254-7203

REFERENCES

1. Myers JR, Fosbroke DE. Logging fatalities in the United States by region, cause of death, and other factors—1980 through 1988. *J Safety Res*. 1994;25:97–105.
2. Marsh SM, Layne LA. 2001. Fatal injuries to civilian workers in the United States, 1980–1995. NIOSH publication number 2001-129S Cincinnati, OH: National Institute for Occupational Safety and Health. 377 p.
3. United States Department of Labor Bureau of Labor Statistics. 2014. National census of fatal occupational injuries in 2014. Available online at: https://www.bls.gov/iif/oshwc/cfoi/cfoi_rates_2014hb.xlsx.
4. Helmkamp JC, Kennedy RD, Fosbroke DE, Myers ML. Occupational fatalities in the fishing, logging and air transport industries in Alaska, 1991. *Scand J Work Environ Health*. 1992;18:55–57.
5. Centers for Disease Control and Prevention. Risk for traumatic injuries from helicopter crashes during logging operations—southeastern Alaska, January 1992–June 1993. *Morb Mortal Wkly Rep*. 1994;43:472.
6. Manwaring JC, Conway GA, Garrett LC. Epidemiology and prevention of helicopter external load accidents. *J Safety Res*. 1998;29:107–121.
7. Conway GA, Klatt M, Manwaring J. Effective injury prevention using surveillance data: helicopter logging, Alaska, 1992–1995. *Int J Circumpolar Health*. 1997;57:518–526.
8. Klatt ML. ed. *Helicopter Logging Safety*. NIOSH publication number 98–147. Cincinnati, OH: United States Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health; 1998:288.
9. Conway GA, Lincoln JM, Husberg B, Manwaring J, Bensyl D, Choromanski D. Alaska's model program for occupational injury prevention: applying surveillance for effective public health practice. *Int J Circumpolar Health*. 2001;60:714–723.
10. Husberg BJ, Conway GA, Moore MA, Johnson MS. Surveillance for nonfatal work-related injuries in Alaska, 1991–1995. *Am J Ind Med*. 1998;34:493–498.
11. Kilkenny SJ, Moore MA, Simonsen BL, Johnson MS. The Alaska trauma registry. *Alaska Med*. 1991;34:127–134.
12. Baker SP, O'Neill B, Haddon WJ, Long WB. The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. *J Trauma Acute Care Surg*. 1974;14:187–196.
13. Peng J, Wheeler K, Shi J, Groner J, Haley K, Xiang H. Trauma with injury severity score of 75: are these unsurvivable injuries? *PLoS ONE*. 2015;10:e0134821.
14. Smith S, De Hoop C, Marx B, Pine J. Logging injuries in Louisiana: nature, trends, and rehabilitation considerations. *Work*. 1998;12:261–273.
15. Sygnatur EF. Logging is perilous work. *Comp Working Cond*. 1998;3:3–9.
16. Holman RG, Olszewski A, Maier RV. The epidemiology of logging injuries in the northwest. *J Trauma*. 1987;27:1044–1050.
17. Marshall SW, Kawachi I, Cryer P, Wright D, Slappendel C, Laird I. The epidemiology of forestry work-related injuries in New Zealand, 1975–88: fatalities and hospitalisations. *NZ Med J*. 1994;107:434–437.
18. Paulozzi LJ. Fatal logging injuries in Washington state, 1977 to 1983. *J Occup Med*. 1987;29:103–108.
19. Rodriguez-Acosta RL, Loomis DP. Fatal occupational injuries in the forestry and logging industry in North Carolina, 1977–1991. *Int J Occup Environ Health*. 2013;3:259–265.
20. Scott DF. A study of logger fatalities from 1992–2000. *Inj Prev*. 2004;10:239–243.
21. Thelin A. Fatal accidents in Swedish farming and forestry, 1988–1997. *Safety Sci*. 2002;40:501–517.
22. Bentley TA, Parker R, Ashby L, Moore D, Tappin D. The role of the New Zealand forest industry injury surveillance system in a strategic ergonomics, safety and health research programme. *Appl Ergon*. 2002;33:395–403.
23. Sullman MJ, Kirk PM, Parker RJ, Gaskin JE. New Zealand logging industry accident reporting scheme: focus for a human factors research programme. *J Safety Res*. 1999;30:123–131.
24. Bell JL. Changes in logging injury rates associated with use of feller-bunchers in West Virginia. *J Safety Res*. 2002;33:463–471.
25. Kawachi I, Marshall S, Cryer C. Trends in work-related chainsaw injury among forestry workers in New Zealand, 1979–1988. *J Occup Health Saf Aust NZ*. 1995;11:145–152.
26. Laflamme L, Cloutier E. Mechanization and risk of occupational accidents in the logging industry. *J Occup Accid*. 1988;10:191–198.
27. Mackovjak JR. 2010. *Tongass Timber: A History of Logging and Timber Utilization in Southeast Alaska*. Durham, North Carolina: Forest History Society.
28. Sisk J. 2007. The southeastern Alaskan timber industry: historical overview and current status. In: Schoen J Dovichin E, eds. *The Coastal Forests and Mountain Ecoregion of Southeastern Alaska and the Tongass National Forest*. Anchorage, Alaska: Audubon Alaska and The Nature Conservancy. Chapter 9.6.
29. Frazier TM, Coleman PJ. Occupational injuries and deaths among loggers, United States. *Morb Mortal Wkly Rep*. 1983;32:31SS–36SS.
30. Slappendel C, Laird I, Kawachi I, Marshall S, Cryer C. Factors affecting work-related injury among forestry workers: a review. *J Safety Res*. 1993;24:19–32.
31. Brackley A, Rojas T, Haynes R. 2006. Timber products output and timber harvests in Alaska: projections for 2005–25. General Technical Report PNW-GTR-677. Portland, OR: United States Department of Agriculture, Forest Service, Pacific Northwest Research Station. 33 p.
32. Daniels JM, Paruszkiewicz MD, Alexander SJ. 2016. Tongass National Forest timber demand: projections for 2015 to 2030. General Technical Report PNW-GTR-934. Portland, OR: United States Department of Agriculture, Forest Service, Pacific Northwest Research Station. 53 p.
33. Higgins DN, Casini V, Bost P, Johnson W, Rautiainen R. The Fatality Assessment and Control Evaluation program's role in the prevention of occupational fatalities. *Inj Prev*. 2001;7:i27–i33.

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

How to cite this article: Springer YP, Lucas DL, Castrodale LJ, McLaughlin JB. Work-related injuries in the Alaska logging industry, 1991-2014. *Am J Ind Med*. 2018;61:32–41. https://doi.org/10.1002/ajim.22784