

Occupational Injuries of Aquaculture Workers in Washington State

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Abstract

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Background

Little is known about the occupational health and safety risks of animal aquaculture workers. In 2015, the nonfatal occupational injury and illness incidence rate for aquaculture workers in the United States exceeded the national rate for all industries combined (13.6 and 3.3 injuries and illnesses, respectively, per 100 full-time employees), a trend echoed in Washington State (13.3 and 4.5 injuries and illnesses, respectively, per 100 full-time employees). Washington supports 12% of American aquaculture employment, the second highest aquaculture industry employer in the United States as of 2005.

Objective

The purpose of this study was to better characterize occupational injuries and illnesses facing aquaculture workers in Washington State from 2006-2014.

Methods

We extracted accepted workers' compensation claims from January 1, 2006 to December 31, 2014 from the Washington State Department of Labor and Industries' (L&I) State Fund (SF). Trends in employment, worker demographics (including age, gender, and body mass index (BMI)), claim rate, and injury

characteristics were summarized for Washington State aquaculture risk classes. We analyzed accepted claims.

Results

During the nine-year study period, 1,180 of 1,285 (91.8%) claims were accepted, of which 344 (26.8%) were compensable and 836 (65.1%) were medical-aid only. Men filed 85.3% of claims, 62.8% of claimants were overweight or obese (BMI > 25), and 53.3% of claimants were between ages 25 and 44. Most commonly reported injury types included being struck by/against an object (35.6%) and work-related musculoskeletal disorders (26.3%). There was no statistically significant change in claim rates from 2006 to 2014 ($p = 0.77$), however, there was a statistically significant change in full-time equivalent (FTE) employment ($p = 0.003$) when analyzed by both risk classes combined.

Conclusion

Given the growth in aquaculture production nationally and internationally, our study suggests that the industry should devote greater attention to prevention of work-related injuries. Additionally, aquaculture workers in Washington may be experiencing higher occupational injury and illness rates than compared to other workers in the state, and our study highlights the need for local efforts. Enhanced occupational safety and health programs for this industry could help to reduce injuries and illnesses, as well as the cost of workers' compensation claims. Employers should focus on interventions to protect workers from physical hazards in the workplace, especially those resulting in being struck by/against objects or WMSD injuries.

Contents

Introduction	6
Methods.....	9
Description of Washington State’s Workers’ Compensation System.....	9
Data ascertainment.....	10
Categorizing Risk Class	11
Data Analysis.....	12
Results.....	12
Discussion.....	15
Acknowledgement	20
Figures and Tables	21
Bibliography	29

Introduction

Aquaculture has been practiced for many years; some studies have estimated the first instance of freshwater aquaculture in 2000 BC in China, and marine aquaculture in 1400 AD in Indonesia (1). The 2013 Census of Aquaculture defines aquaculture as the “farming of aquatic organisms, including: baitfish, crustaceans, food fish, mollusks, ornamental fish, sport or game fish and other aquaculture products” (including algae and sea vegetables) in a controlled environment, involving intervention in rearing such as seeding, stocking, feeding or protecting farmed species from predators, and implies individual or corporate ownership (thus excluding wild caught species) (2). Global animal aquaculture production has increased steadily, and as of 2014 was valued at \$160.2 billion (3). For the first time in 2014, more fish for human consumption were supplied by aquaculture than from the capture fishing industry (3). Globally, ‘food fish’ is consumed more than other types of animal protein on a per capita basis because of the greater affordability of this protein source. As of 2005, food fish was the primary source of animal protein for approximately one billion people in 58 countries (4). In addition to providing high-quality proteins, unsaturated fats, and essential amino acids, consuming fish has been shown to protect vision and eye health, provide protection from some cancers and cardiovascular disease, and enhance brain and nervous system development in children (3; 5; 4). In 2014, 18,753,000 people were employed in aquaculture globally, most workers were in Asia, and only 19% were women (not including those involved in processing, trading, etc.) (3).

A global increase in farmed fish consumption has prompted the United States to implement offshore finfish aquaculture in federal waters off the coasts of California, Hawaii, Maine, New Hampshire, and Washington (6). Food fish sales in 2013 (\$732,147,000) were more than 2.5 times that in 2005 in the U.S. (2). According to the 2013 U.S. Census of Aquaculture, there were 3,093 aquaculture farms in 2013, down from 4,309 in 2005, a similar trend when examined by species type, and fresh/salt water production type (2). Louisiana had the most farms in the U.S. (n = 500) in 2013, though Washington had the highest sales (2). American aquaculture directly employed approximately 10,519 persons in 2007; 12% of these positions were in Washington (7). In 2013, Washington was ranked 7th in the number of farms in the U.S., and saw a decrease in freshwater aquaculture facilities, acreage, and saltwater facilities from 2005 to 2013, whereas saltwater acreage and total sales increased (2). This is likely due to increased marine

aquaculture production (especially mollusks) and more concentrated farming practices. Washington is the top producer of farmed clams, oysters, and mussels in the nation, and contributed \$270 million to the economy in 2011 (8). The shellfish industry alone employed more than 3,200 people (2). Aquaculture in Washington is a rising, profitable industry, and relatively little information on occupational health and safety of its workers exist, despite a growing population.

The federal Occupational Safety and Health Administration (OSHA) creates and enforces workplace safety and health rules for the U.S., but allows states to implement their own health and safety programs if their rules are as good or better than OSHA's standards. Washington's state plan, the Division of Occupational Safety and Health (DOSH), is part of the Department of Labor and Industries (L&I) that develops and enforces occupational safety and health rules as empowered by the Washington Industrial Safety and Health Act (WISHA). OSHA regulates aquaculture as an agricultural activity, but exempts operations with fewer than 11 non-family employees from inspections and OSHA enforcement (6). OSHA has jurisdiction over WA employees working on floating worksites that are not connected to the land (such as floating net pens and harvest barges). Occupational diving of aquaculture workers staged from a boat on navigable waters are covered by OSHA, whereas diving from fixed locations (such as shore or piers) are covered by DOSH.

In 2015, the nonfatal occupational injury and illness incidence rate for aquaculture workers (North American Industry Classification System (NAICS) code 1125) in the U.S. (13.6 per 100 full-time equivalent [FTE] employees) exceeded the national rate for all industries combined (3.3 per 100 FTE) (9; 10). This trend was similar in Washington State where the incidence rate of nonfatal occupational injuries and illnesses for animal production and aquaculture (NAICS code 112; 13.3 per 100 FTE) exceeded the rate for all state and local industries combined (4.5 per 100 FTE) (11). The NAICS code used to calculate the nonfatal occupational injury and illness incidence rate for the national rate is different than that used in WA State calculations. NAICS code 112 (animal production) is not restricted to aquaculture (like NAICS 1125), and includes cattle, pig, poultry, sheep, and goat farming, among other activities. Though the injuries and job tasks are likely similar in the agriculture industry, and more so within the animal production industry, this difference in classifications used to calculate the incidence rates makes them not directly comparable. These numbers may not reflect the true incidence rate of occupational injury and

illness in aquaculture workers in Washington State, which has not been characterized previously at this amount of detail.

Farmed fish production has increased at a rate of 9% per year from 1987 to 1997, and has become a major food-producing sector globally (12). This industry growth has resulted in an increasing workforce, and thus occupational injuries and illnesses in this industry are important to recognize. Occupational hazards in the aquaculture industry can vary depending on factors such as species farmed, salt/fresh water production, water temperature, and type of aquaculture system. Commonly reported aquaculture-related occupational injuries and illnesses in the literature include musculoskeletal injuries, dermatoses, needle-stick injuries, and slips/trips/falls (6; 13; 14).

Biological hazards presented to this workforce include exposure to the sun and ultraviolet light, extreme temperatures (hot and cold), eye traumas, and hearing damage (15; 14; 1; 16). A recent study found that wet-work (including tasks in which workers immerse their hands in liquid for >2 hours per shift, wear waterproof gloves, or wash hands >20 times per shift) is a main risk factor of contact dermatitis of the hand(s) (17). Aquaculture workers have frequent water exposure, particularly of the hands, and wet macerated skin conditions lead to an increased risk for skin warts and contact dermatitis (1; 17; 15). Contact dermatitis accounts for 80% of skin diseases, the second most common occupational disease internationally (17). Microbial agents of concern to aquaculture workers include *Leptospira* sp., *Erysipelothrix rhusiopathiae*, *Vibrio* sp., *Mycobacterium marinum*, and *Pfiesteria piscicida* (18; 19; 20; 21). Occupational asthma has been recorded in turbot farm workers and workers exposed to organic dust from crustaceans used in feed, including artemia and shrimp (22; 23; 24). Whether decompression sickness results from repeated ascents and descents while SCUBA diving in shallow waters is controversial in the fish farming industry (25; 26; 27).

Physical hazards reported in the aquaculture industry have largely focused on tractor overturns. Tractor overturns resulting in crush injuries are higher in aquaculture (especially on catfish farms) than on traditional farms due to levees, banks and water (28; 29). Needle-stick injuries are a common injury when vaccinating fish. Workers that receive high pressure injection of vaccines are at risk for hand injury and anaphylaxis, and require medical attention as fish vaccines often contain a pharmaceutical grade oil as an adjuvant that can result in digit loss (30; 31). Aquaculture workers face potential exposure to various

chemicals used for water treatment, anesthetizing fish, and disinfection, including formaldehyde and 2-phenoxyethanol, as well as natural radon from groundwater than can cause cognitive impairment (32). Hazards from hydrogen sulfide gas may also be present from the decomposition of organic matter. Interviews with several aquaculture farmers found low rates of glove and respirator use when handling chemicals as well as reports of nausea, burns, rashes, and eye and respiratory tract irritation because of chemical handling (33).

Despite general information on hazards present in the aquaculture industry, there is a lack of quantitative data on the occurrence of injury and illness in this rapidly growing industry, in the U.S. overall, and in Washington State. The objective of this study was to better characterize the injuries and illnesses experienced by this workforce in Washington State during 2006-2014.

Methods

We extracted workers' compensation (WC) claims from injuries and illnesses that occurred between January 1, 2006 and December 31, 2014 from the Washington State Department of Labor and Industries' (L&I) State Fund (SF). Trends in employment, worker demographics, claim rates, and injury characteristics for aquaculture workers by risk classes specific to Washington State (Farms: finfish and shellfish hatcheries, Farms: shellfish-hand harvesting, and Farms: shellfish-mechanical harvesting) are described.

Description of Washington State's Workers' Compensation System

Washington State's Department of Labor and Industries (L&I) is the primary provider of workers' compensation insurance for employers in Washington State. L&I's industrial insurance program, the State Fund (SF), administers workers' compensation claims, and covers approximately two-thirds of the workers in Washington State (34). While the SF covers the majority of employment in Washington, some employment may be covered under other programs such as the Longshore & Harbor Workers' Compensation Act (LHWCA) and the Jones Act, and some may be eligible to self-insure (RCW 51.14). The LHWCA specifically excludes aquaculture workers from coverage, and the Jones Act primarily covers captains/crew of maritime vessels. Some employment may be exempt from mandatory coverage (those

enumerated in RCW 51.12), but may choose voluntary coverage. Most tribal enterprises are not covered by the SF; however, tribes are a notable employer in Washington State (including finfish and shellfish aquaculture on tribal land/waters), and the lack of information on these employers constitutes a limitation. The risk classes extracted for this analysis also exclude workers from the Washington State Department of Fisheries and the Washington State Department of Wildlife because state agency risk classes do not distinguish those engaged in aquaculture from their peers performing other activities. Due to these limitations, the results of this analysis may not be generalizable to all populations of aquaculture workers.

Each quarter, employers must report hours of exposure within risk classifications using the Washington Industrial Classification (WIC) system, which is the basis for their insurance premium payments. A worker has one year to file a claim for an injury and two years to file an illness claim. The injured worker and their healthcare provider complete the Report of Industrial Injury or Occupational Disease (RIIOD) Accident Form addressing worker and provider information. Worker information includes personal, demographic, familial, and occupational information as well as a description of the work-related injury or illness event. The healthcare provider portion requests diagnosis information (including ICD-9 codes), treatment recommendations, and whether they thought the condition was caused by a novel occupational injury or incident. Characteristics of the injury/illness (including the type, nature, source, and affected body part) from the RIIOD are coded per the Bureau of Labor Statistics' Occupational Injury and Illness Classification Manual (v.1.01 OIICS 2007) by coders at L&I.

Data ascertainment

Analysis was limited to SF workers' compensation claims with injury dates occurring from January 1, 2006 through December 31, 2014. Years chosen were limited based on two factors to allow uniformity of claims: a) the availability of OIICS coding and b) the need to allow claims to come to common maturity from which to compare costs (typically 18 months).

Extracted data variables included demographics including (age at date of injury, gender, body mass index), claim status (compensable or medical-aid only), year of injury, and injury characteristics. Injury characteristics included injury type, source of injury, nature of injury, and affected body part(s). OIICS defines the source of injury (the factors responsible for the injury), nature of injury (the principal physical characteristic(s) of the injury), and affected body part (body part directly affected by the nature of

injury). Injury type is a broad grouping of the injury event (defined by OIICS as how the injury occurred by the source of injury) and is grouped by a previously established method (34).

Hours reported in the selected aquaculture risk classes were summed across employer accounts over the nine-year study period. Analysis was restricted to accepted claims. An accepted claim is classified as compensable or medical-aid only. Compensable claims generally involve time-loss and benefits beyond compensation for medical bills (e.g. disability or death).

Data were analyzed at the risk classification level as coded by the Washington State Industrial Risk Classes (WIC) system. Three risk classes were of interest: WAC 296-17A-4805-08 Farms: Shellfish, WAC 296-17A-4812-00 Farms: Finfish and Shellfish Hatcheries, and WAC 296-17A-4808-10 Shellfish-Mechanical Harvesting. All claims in the risk classes of interest were identified and extracted on March 1, 2017.

Categorizing Risk Class

A reclassification of the WIC codes in 2006 resulted in the elimination of the Shellfish-Mechanical Harvesting risk class, of which there were six claims filed in 2006 prior to the reclassification. For our analysis, we merged risk classes Shellfish-Mechanical Harvesting and Farms: Shellfish, and refer to this class as “shellfish harvesters”, and termed risk class Farms: Finfish and Shellfish Hatcheries as “hatchery workers.”

Shellfish harvester tasks include preparing tanks/growing areas (including chemical treatments of these areas), spawning, seeding into aquatic tanks and into deep water growing beds, harvesting, shucking, and packaging grown shellfish for sale using hand-held tools as well as mechanical dredging in non-navigable waters (Washington Administrative Code Title 296 Chapter 296-17A). Husbandry is an integral part of aquaculture and is what distinguishes this risk class from one that harvests wild shellfish from natural areas. Furthermore, these workers can sell shellfish directly to the public from a stand at or near the aquaculture facility.

Hatchery worker tasks include spawning larvae, growing algae for shellfish food, seeding shells in tanks, spawning finfish, harvesting (though not of mature shellfish), managing tank flow and temperature, laboratory work and the sale of seeded shells, larvae, fish eggs, and whole fish (Washington Administrative Code Title 296 Chapter 296-17A). Though shells are seeded in tanks and loaded for

transport, these workers do not place seeded shells or larvae into natural waters (shellfish harvesters have this task).

Data Analysis

WC data were summarized for all claims (accepted, rejected, compensable and medical-aid only) for Washington State aquaculture employees in the two risk classes of interest. Accepted claim counts and rates (by injury type) by FTE (using reported hours) were compared across the two risk classes. Rates were expressed as the number of claims per 100 FTE. One FTE is defined as 2,000 hours per year (working five 8-hour days/40 hours per week, 50 weeks per year). Demographics (including age, gender, and body mass index (BMI)) and injury characteristics as defined by OIICS codes were summarized for the aquaculture risk classes specific to Washington State for injuries and illnesses that occurred from January 1, 2006 through December 31, 2014 for all accepted claims.

Statistical analyses were performed using SAS and R Software evaluated at the 0.05 significance level (SAS Proprietary Software Version 9.4, SAS Institute Inc. Cary, NC, USA 2001; R v.3.2.4, R Core Team (2016), R Foundation for statistical Computing, Vienna, Austria). The Washington State Institutional Review Board determined the study protocol exempt.

Results

There were 1,285 workers' compensation claims for occupational injuries and illnesses that occurred between January 1, 2006 and December 31, 2014 in the two aquaculture risk classes of interest. Of these, 1,180 (91.8%) claims were accepted, of which, 344 (26.8%) were compensable and 836 (65.1%) were medical-aid only (Figure 1). One claim was not accepted nor rejected at the time of data extraction. The shellfish harvester risk class had 1,023 accepted claims (300 compensable and 723 medical-aid only), and 157 accepted claims were submitted for the hatchery worker risk class (44 compensable and 113 medical-aid only). Most aquaculture claims were filed by men (85.3%) (Table 1). Most claimants were in the 25-34 age group (32.0%) followed by the 35-44 age group (21.4%). Of accepted claims, 41.7% of claimants were classified as overweight (BMI \geq 25) and 21.1% were obese (BMI \geq 30).

There was a statistically significant change in reported FTE hours over the nine-year period ($p < 0.05$; Figure 2) for both risk classes combined and for shellfish harvesters ($p < 0.05$), though not for hatchery workers ($p = 0.10$). There was not a statistically significant change in number of accepted claims from 2006 to 2014 by both risk classes ($p = 0.75$; Figure 3, Table 8), or by individual risk class. There were no fatal injuries reported in this time period. There was no significant change in claim rates from 2006 to 2014 by both risk classes combined ($p = 0.77$), nor by shellfish harvesters ($p = 0.91$) or hatchery workers ($p = 0.63$) (Figure 4). The average yearly claim rate in shellfish harvesters was 12.5 injuries per 100 FTE compared to 11.4 injuries per FTE in hatchery workers during this time period (neither was statistically significant; $p = 0.91$ and 0.63 , respectively).

The four most common injury types include being struck by/against an object ($n=420$; 35.6%), work-related musculoskeletal disorders (WMSD) ($n=310$; 26.3%), falls on the same level ($n=83$; 7.0%), and abrasions ($n=59$; 5.0%) (Table 2). These injury types account for 81.1% of accepted claims. Knives were the most commonly reported source of injury for both risk classes combined ($n=152$; 12.9%), followed by bodily motion/position of worker ($n=129$; 10.9%), sources that were non-classifiable ($n=120$; 10.2%), and 'floors, walkways, ground surfaces' ($n=46$; 3.9%) (Table 3). Table 4 notes the four most frequently reported nature of injury categories, and includes sprains/strains/tears ($n=346$; 29.3%), cuts/lacerations ($n=155$; 13.1%), punctures (except bites) ($n=149$; 12.6%), and bruises/contusions ($n=79$; 6.7%). The most commonly reported affected body parts were finger(s), fingernail(s) ($n=197$; 16.7%), the lumbar region ($n=136$; 11.5%), hand(s) ($n=123$; 10.4%), and eye(s) ($n=93$; 7.9%) (Table 5).

Table 6 presents injury characteristics for the top four injury types (including the most frequently reported source and nature of injury, and affected body part) for shellfish harvesters. Categories presented in this table are restricted to those with more than five reports. Struck by/against injuries were the most commonly reported injury type ($n=379$; 37.0%), followed by WMSD injuries ($n=263$; 25.7%). Of the struck by/against injuries, finger(s) and fingernail(s) were the most affected body part ($n=135$), being struck by a slipping handheld object was the most frequently reported event leading to injury ($n=164$), and punctures (except bites) were the most frequently reported nature of injury ($n=139$). Knives were the most common source of injury ($n=149$; 14.6%). The most frequently reported nature of injury for shellfish

harvesters included sprains, strains and tears (n=292; 28.5%), and the most commonly affected body part(s) of shellfish harvester claims were of the finger(s) and fingernail(s) (n=176; 17.2%).

Injury characteristics of hatchery workers by the top four most commonly reported injury types are presented in Table 7. Presented categories of each characteristic consisted of categories with more than five reports for claimant privacy. If less than five reports existed for each category, reports were aggregated (this only occurred for hatchery workers). The most commonly reported injury types of hatchery workers were WMSD injuries (n=47; 29.9%) followed by “struck by/against” injuries (n=41; 26.1%). The most common source of injury was bodily motion or position of injured, ill workers for WMSD injuries (n=14). Finger(s) and fingernail(s) were the most frequently affected body part in struck by/against injuries (n=15), and the lumbar region (n=14) in WMSD injuries. Of the nine abrasion injuries, eight cited eye(s) as the affected body part, and six attributed the nature of injury to foreign bodies. Sprains, strains and tears were the most frequently reported nature of injury for WMSD and struck by/against injury types, (n=31 and n=5, respectively).

Of abrasion injuries, chips, particles, and splinters were the most common source of injury in both risk classes, most commonly affecting the eye(s), and foreign bodies were cited as the most common nature of injury. Of note, there were seven reports of non-viral conjunctivitis. Eye injuries were also reported as the source of 17 struck by/against injuries. WMSDs were a commonly reported injury type for both risk classes, and bodily motion/position of the injured/ill worker was the most common source of injury, most frequently affecting the lumbar region. Sprains, strains, and tears were reported for the top four injury types, except for abrasion injuries, in both risk classes.

Review of the claim descriptions, self-reported by the claimants and their employers, provided descriptive information on the events resulting in injury or illness (unpublished data). For example, descriptions of injury or illness events included environmental exposures such as “too much sun”, “slipped on wet slimy dock and landed on ribs”, and tearing “rotary cuff lifting fish nets.” Eight claimants preferred communicating with the agency in a language other than English, and seven were related to driving accidents.

Discussion

From 2006 to 2014, 1,285 workers' compensation claims were filed in Washington State, of which 1,180 were accepted. The true number of occupational injuries and illnesses is likely to be an underestimate as underreporting of injuries and illnesses is a well-documented limitation to the workers' compensation system (35; 36). Reasons for not filing WC claims include medical treatment cost that was paid directly by the employer, no treatment was necessary, concerns of employer retaliation, or lack of knowledge about WC or the filing process (36; 35).

Most accepted claims were medical-aid only (65.1%). These claims tend to be less expensive, as compensable claims generally involve more severe injuries with greater time loss. In both medical-aid and compensable claim categories, there were more claims in the shellfish harvester risk class, likely due to the nature of work. Work tasks in this risk class involve preparing aquatic tanks or natural areas for shellfish, seeding and placing shellfish in deep water growing beds (including care of beds and chemical treatments), harvesting, shucking, and packaging of shellfish, and work in non-navigable waters. Work tasks of hatchery workers include fewer tasks in natural environments, possibly reducing the potential for exposure to uncontrollable environmental hazards.

We found the majority of claims were filed by men (84.4%), regardless of risk class, a trend consistent in fish farming globally (3). Our finding is larger than the overall male civilian noninstitutionalized workers in Washington State (64.2%) (37). Data were not available on the sex distribution of the aquaculture workforce in Washington. However, of fisheries and aquaculture workers worldwide, when secondary processing activities are considered, approximately half of the workforce are women (3). This shows that women are present in the aquaculture industry, though may have different job tasks, and thus risk classifications than were analyzed in this study. A broader analysis of aquaculture-related risk classes (including secondary processing activities) would likely alter the claim rates, injury characteristics, and worker demographics found in this study. Additional studies should characterize the differences in claim rates and characteristics by sex in the aquaculture industry overall, and in WA.

Most claimants (32%) were between 25 and 34 years old when their injury occurred. FTE hours are not reported by age, prohibiting analysis of the relationship between age and risk of injury or illness.

Compared to the 2014 employment status in Washington, aquaculture claimants in Washington are younger than the general employment workforce in the state (37).

Body Mass Index (BMI) was included in this study as some studies have indicated overweight (BMI \geq 25) and obese workers (BMI \geq 30) are at higher risk of experiencing workplace injury compared to normal weight coworkers (38; 39). Our analysis showed 41.7% of claimants were overweight, and 21.1% were obese in comparison to 61.1% and 25.5%, respectively, of the general Washington population in 2012 (data collected from all U.S. citizens who participated in the 2012 Behavioral Risk Factor Surveillance System (BRFSS) survey). These findings could indicate that this worker population may be of healthier weight than the general population in Washington. Data on obesity of aquaculture workers in WA was not available for comparison, and thus distinguishing whether our results are a reflection of the aquaculture industry population in Washington or whether excess weight may have contributed to increased occupational injury or illness and subsequent claim reporting is not possible to determine (40). Height and weight used to determine BMI are self-reported on RIIOD Accident Forms, and thus results should be interpreted cautiously.

A linear regression of reported FTE hours across time indicated that there was a statistically significant change for shellfish harvesters ($p < 0.05$) and both risk classes combined ($p < 0.05$) (Figure 2). The majority of accepted claims in the shellfish harvester risk class may be attributed to the growing shellfish production industry in Washington State. Shellfish farming in WA has been practiced since the mid-1800s, and as of 2015 produced the most farmed shellfish in the United States with annual sales of approximately \$150 million (8). Pacific oysters, Manila clam, and mussels are the most produced shellfish in WA, though geoduck is an important farmed species due to their high dollar value (8). A 2015 report projects the shellfish aquaculture industry will continue to grow, suggesting the workforce will grow with it, as reflected in our analysis of increasing reported FTE hours (8). Workforce projections alone indicate that this workforce is worth further research to prevent increasing numbers of injury and illness claims.

Our analysis did not find a statistically significant change in claim rates from 2006 to 2014 by risk class. Compared to the 2015 national nonfatal occupational injury and illness rate for aquaculture workers in the U.S. (NAICS code 1125; 13.6 injuries and illnesses per 100 FTE) and in Washington State (NAICS code 112; 13.3 injuries and illnesses per 100 FTE), our analysis found comparable results for the shellfish

harvester risk class (12.5 injuries per 100 FTE), and in the hatchery worker risk class (11.4 injuries per 100 FTE). This indicates that though the production size and value of Washington aquaculture may vary from other states, the hazards and injury and illness rates in the aquaculture industry may not be so different. It is important to note the different NAICS codes used in calculating the nonfatal occupational injury and illness rate for workers nationally (NAICS code 1125 is the specific animal aquaculture industry group) and in Washington State (NAICS code 112, a broader subsector of animal production, including cattle ranching, pig farming, egg production, etc.) presented in this paper. Though work-place injuries in aquaculture are similar to the agriculture industry (but include the added risk factor of working around water), we cannot directly compare the national and Washington State occupational injury and illness rates as the rate in Washington State has also factored in other agriculture workers (13). However, given this consideration, the occupational injury and illness claim rates of aquaculture workers in our study are similar to the overall industry, regardless of specific NAICS code classification, though may be higher than for all Washington industries combined.

The most common injury types of accepted claims included “struck by/against” injuries, work-related musculoskeletal disorders (WMSD), falls on the same level, and abrasions (Table 2). This is the same for shellfish harvesters and hatchery workers, regardless of the difference in number of claims by risk class (n=1,023 and n=157, respectively). The most common type of injury in shellfish harvesters were “struck by/against”, whereas WMSDs were most common in hatchery workers. Of interest, two claims reported ‘pressure changes underwater’, likely associated with scuba diving. Reports of decompression sickness (due to quick pressure changes) from repeated short dives (‘yo-yo diving’) have been reported in the occupational aquaculture literature (1; 13; 6).

Most commonly reported injury characteristics of the “struck by/against” injury type for shellfish workers included knives as sources of injury, finger(nail) and hand injuries, and puncture and cut injuries (Table 6). Shellfish harvester work involves shucking oysters, which may explain some of these frequently reported injury characteristics (and is supported by unpublished self-reported event descriptions). This finding is supported by other studies documenting oyster shucking injuries. A cross-sectional study of 340 oyster shuckers in Taiwan found that 75% of participants had a history of cut or abrasion injuries caused by a shucking knife or by oyster shells (41). These data suggest an intervention aimed at improving

oyster shucking equipment or techniques, such as wearing cut resistant gloves, may greatly reduce the number of struck by/against injuries in this workforce.

A review of individual reports of injury descriptions cite many accidental eye injuries from shucking oysters. This may also explain the number of non-viral conjunctivitis claims (N=17) and the number of eye injuries (n=80) in the shellfish harvester risk class. Corneal ulcers due to *Vibrio vulnificus* resulting from shellfish trauma to the eye have been reported in the literature, as has eye trauma from finfish bile (42; 43; 16; 21). These results highlight the potential for zoonotic disease transmission for shellfish and finfish workers, and suggest that eye protection while in close contact with fish and shellfish, particularly during oyster shucking, could potentially decrease eye injuries and illnesses, and reduce the number of WC claims and associated costs.

WMSDs are defined as non-traumatic soft-tissue musculoskeletal disorders caused or aggravated by work activities (such as repetitive tasks, or awkward body postures) (36). They were the most commonly reported injury type of hatchery workers, and the second most common reported injury type of shellfish harvesters. The most frequently reported nature of injury for both risk classes was sprains, strains, and tears, which may have attributed to the high incidence of WMSDs. Of WMSD injuries, bodily motion or position of the worker was the most commonly reported source of injury, and the two most commonly affected body part(s) included the lumbar region and shoulder (including the clavicle and scapula), regardless of risk class (Tables 6 and 7). A 2015 report in Washington State found WMSDs were a significant and expensive problem for employers, a finding supported by our research on the aquaculture industry (36). Within the aquaculture industry, frequency counts can be used to identify the most commonly reported injury characteristics to target effective prevention efforts. To reduce WMSD injuries, efforts may include modifying body position or motion during manual and/or repetitive tasks, and reducing or eliminating manual job tasks involving contact with the most frequently reported sources of injury such as bags, sacks, totes, buckets, baskets, pails, boxes, crates, and cartons (Tables 6 and 7).

Risk classes presented here are unique to WA and thus results are not directly generalizable to other states. Trends and patterns in injuries and illnesses may be similar as job tasks and aquaculture production types are likely to be similar across the industry. However, as land for protein production

becomes limited, fish farms are likely to be pushed further out to sea introducing new, and potentially more extreme, hazards to the aquaculture workforce, particularly those in coastal states (5).

To our knowledge, there are no data on aquaculture workers in Washington (regarding sex, BMI, age distribution, nor population size) in which to compare the results of our analysis on workers' compensation claims, a limitation of this study. WC claims data underestimate the true incidence of occupational injuries and illnesses due to underreporting (as previously described), and the WC system does not cover all workers in Washington State.

Despite these limitations, our study has a number of strengths. It uses quantitative data to characterize the injuries and illnesses in this occupation, and therefore represents an extension of knowledge beyond previous reports that only identified potential hazards. It also provides greater details about injury risks that have been noted in national data. The use of Washington State's unique and comprehensive WC database and risk classification system allows us to characterize hazards based on occupational exposure, a more specific approach than using NAICS codes based on a business's primary economic activity. Given the growth in aquaculture production nationally, our study suggests that the industry should devote greater attention to prevention of work-related injuries. Additionally, aquaculture workers in Washington may be experiencing higher occupational injury and illness rates than compared to other workers in the state, and our study highlights the need for local efforts.

Our analysis highlights several opportunities for prevention. Frequently reported injury types and characteristics of this workforce can be used by employers to protect workers from physical hazards in the workplace and reduce injuries and cost of workers' compensation claims. Enhanced occupational safety and health programs for this industry should focus on interventions preventing struck by/against and WMSD injuries. Proper personal protective equipment use such as cut resistant gloves and eye protection may prevent commonly reported injuries affecting finger(s), hand(s), and eye(s). Future research conducting safety site evaluations at aquaculture production sites will help determine whether the types of claims we report from the WC database reflect the same injuries and illnesses most commonly seen at the worksite. Because aquaculture involves the safety and health of workers, consumers, finfish, shellfish, and the environment, a "One Health" approach to aquaculture should be

considered to optimize occupational safety and health programs for this important industry in Washington State.

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Figures and Tables

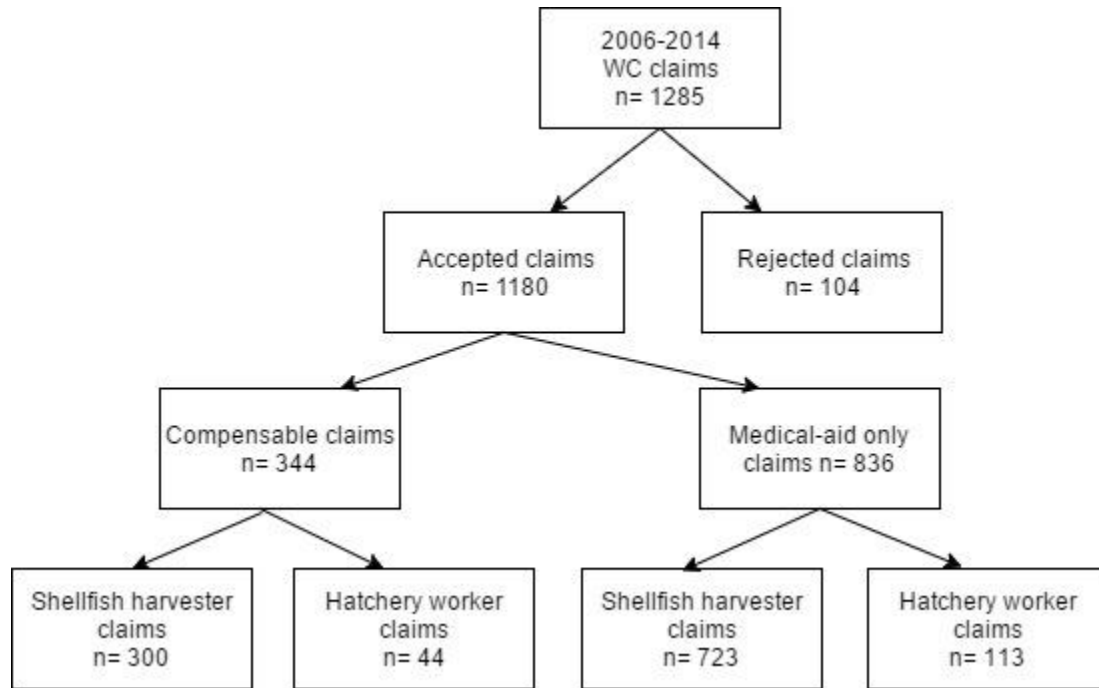


Figure 1. Classification of workers' compensation claims for shellfish harvesters (WA State risk classes WAC 296-17A-4805-08 Farms: Shellfish and WAC 296-17A-4808-10 Shellfish-Mechanical Harvesting) and hatchery workers (WAC 296-17A-4812-00 Farms: Finfish and shellfish hatcheries) for injuries and illnesses occurring between 2006-2014.

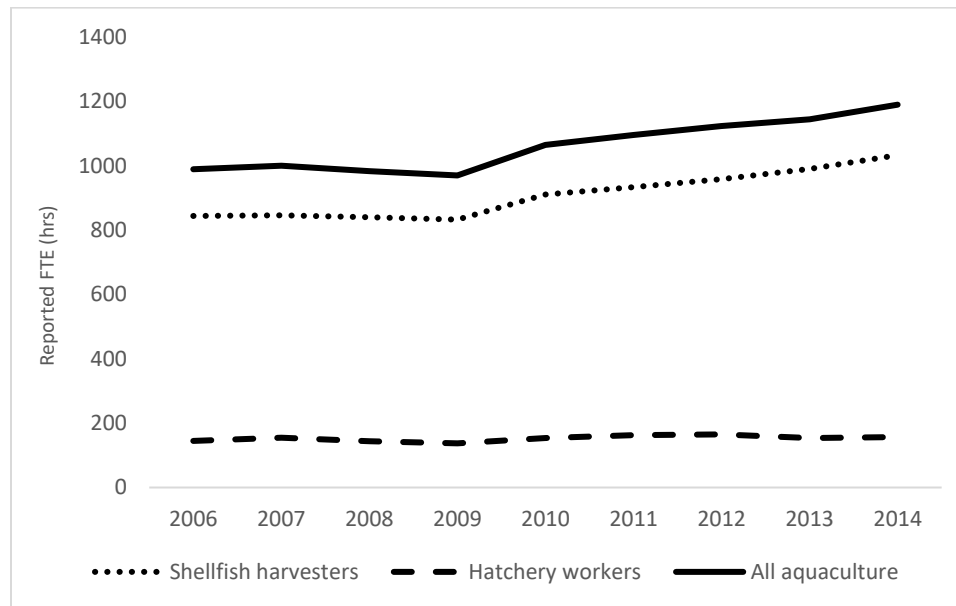


Figure 2. Company reported number of full-time equivalent (FTE) hours by Washington State Risk Class over time, 2006-2014. All aquaculture includes shellfish harvesters and hatchery workers combined.

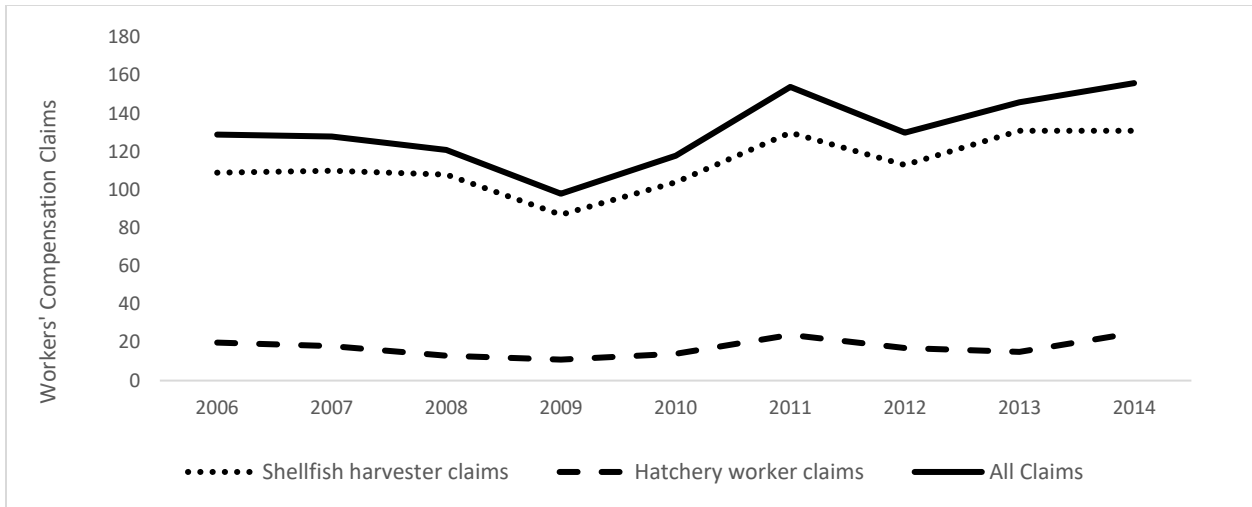


Figure 3. Number of reported WC claims in aquaculture employees by Washington State risk class over time, 2006-2014. All aquaculture includes shellfish harvesters and hatchery workers combined.

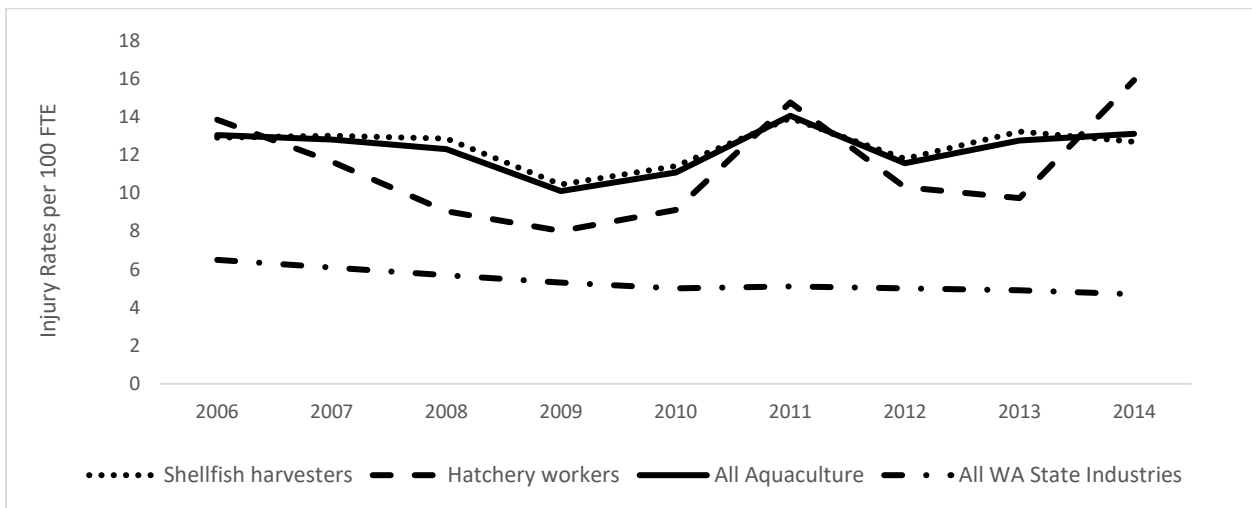


Figure 4. Work-related claim rates (per 100 FTE) in aquaculture employees by Washington State risk class over time, 2006-2014. All aquaculture includes shellfish harvesters and hatchery workers combined. All WA State industries data collected from the Bureau of Labor Statistics survey.

Table 1. Demographics of WC accepted aquaculture claims by risk class, 2006-2014.

	Shellfish harvesters n (%)	Hatchery workers n (%)	Total n (%)
	n = 1,023	n = 157	n = 1,180
Sex			
Men	863 (84.4)	144 (91.7)	1007 (85.3)
Women	160 (15.6)	13 (8.3)	173 (14.7)
Age Group			
Age 16 - 19	56 (5.5)	6 (3.8)	62 (5.3)
Age 20 - 24	178 (17.4)	16 (10.3)	194 (16.4)
Age 25 - 34	317 (31.0)	60 (38.5)	377 (32.0)
Age 35 - 44	223 (21.8)	30 (19.2)	253 (21.4)
Age 45 - 54	151 (14.8)	29 (18.6)	180 (15.3)
Age 55 -64	62 (6.1)	15 (9.6)	77 (6.5)
Age 65+	10 (1.0)	0 (0.0)	10 (0.9)
Missing/Excluded	26 (2.5)	1 (0.6)	27 (2.3)
Body Mass Index (BMI)			
Underweight (BMI < 18.5)	12 (1.2)	0 (0.0)	12 (1.2)
Normal weight (BMI 18.5-24.9)	332 (32.5)	39 (24.8)	371 (36.1)
Overweight (BMI 25.0-29.9)	360 (35.2)	69 (43.9)	429 (41.7)
Obese (BMI ≥ 30)	180 (17.6)	37 (23.6)	217 (21.1)
Missing	139 (13.6)	12 (7.6)	151 (12.8)

Table 2. Most commonly reported injury type by Washington State risk class, 2006-2014.

	Shellfish harvesters	Hatchery workers	All Aquaculture
Total n	n = 1,023	n = 157	n = 1,180
Injury Type	n (%)	n (%)	n (%)
Struck By/Against	379 (37.0)	41 (26.1)	420 (35.6)
Work-related Musculoskeletal Disorder (WMSD)	263 (25.7)	47 (29.9)	310 (26.3)
Other	74 (7.2)	11 (7.0)	85 (7.2)
Fall on Same Level	68 (6.6)	15 (9.6)	83 (7.0)
Abraded	50 (4.9)	9 (5.7)	59 (5.0)

Table 3. Most commonly reported source of injury by Washington State risk class, 2006-2014.

	Shellfish harvesters	Hatchery workers	All Aquaculture
Total n	n = 1,023	n = 157	n = 1,180
Source	n (%)	n (%)	n (%)

Knives	149 (14.6)	3 (1.9)	152 (12.9)
Bodily Motion or Position of Injured, Ill Worker	107 (10.5)	22 (14.0)	129 (10.9)
Non-classifiable	112 (11.0)	8 (5.1)	120 (10.2)
Floors, Walkways, Ground Surfaces, Unspecified	41 (4.0)	5 (3.2)	46 (3.9)
Buckets, Baskets, Pails	33 (3.2)	2 (1.3)	35 (3.0)

Table 4. Most commonly reported nature of injury by Washington State risk class, 2006-2014.

	Shellfish harvesters	Hatchery workers	All Aquaculture
Total n	n = 1,023	n = 157	n = 1,180
Nature of Injury	n (%)	n (%)	n (%)
Sprains, Strains, Tears	292 (28.5)	54 (34.4)	346 (29.3)
Cuts, Lacerations	135 (13.2)	20 (12.7)	155 (13.1)
Punctures, except Bites	145 (14.2)	4	149 (12.6)
Bruises, Contusions	71 (6.9)	8 (5.1)	79 (6.7)
Other Combinations of Traumatic Injuries and Disorders, Not Elsewhere Classified	37 (3.6)	5	42 (3.6)

Table 5. Most commonly reported affected body part by Washington State risk class, 2006-2014.

	Shellfish harvesters	Hatchery workers	All Aquaculture
Total n	n = 1,023	n = 157	n = 1,180
Body part	n (%)	n (%)	n (%)
Finger(s), Fingernail(s)	176 (17.2)	21 (13.4)	197 (16.7)
Lumbar Region	120 (11.7)	16 (10.2)	136 (11.5)
Hand(s), except Finger(s)	112 (11)	11 (7.0)	123 (10.4)
Eye(s)	80 (7.8)	13 (8.3)	93 (7.9)
Shoulder, including clavicle, scapula	57 (5.7)	13 (8.3)	70 (5.9)

Table 6. Top four injury types of shellfish harvesters by injury characteristic, 2006-2014¹.

Injury Type	n	Most frequently reported source of injury	n	Most frequently reported nature of injury	n	Most frequently affected body part	n
Struck	379	Knives	146	Punctures, except bites	139	Finger(s), fingernail(s)	135
		Non-classifiable	38	Cuts, lacerations	118	Hand(s), except finger(s)	94
		Nails, brads, tacks	14	Bruises, contusions	39	Foot(feet), except toe(s)	26
		Cutting hand tools-nonpowered	12	Sprains, strains, tears	9	Forearm(s)	17
		Fish, shellfish	9	Cuts, abrasions, bruises	8	Eyes	17
		Other	8	Fractures	8	Wrist(s)	13
		Buckets, baskets, pails	8	Abrasions, scratches	7	Scalp	9
		Bars, rods, reinforcing bar-rebar	7	Other combinations of traumatic injuries and disorders	7	Knee(s)	8
		Bones, shells	7	Cellulitis and abscess	6	Toe(s), toenail(s)	5
		Boxes, crates, cartons	5	Open wounds	6	Multiple body parts	5
Forklift	5	Foreign bodies (superficial splinters, chips)	5				
WMSD	263	Bodily motion, or position of injured, ill worker	61	Sprains, strains, tears	173	Lumbar region	97
		Non-classifiable	39	Dislocations	20	Shoulder, including clavicle, scapula	38
		Bags, sacks, totes	28	Soreness, pain, hurt, except the back	16	Wrist(s)	36
		Buckets, basket, pails	18	Injuries to muscles, tendons, ligaments, joints, etc.	12	Multiple back regions	21
		Boxes, crates, cartons	16	Tendonitis	10	Back, including spine, spinal cord	17
		Other	14	Carpal tunnel syndrome	9	Knee(s)	10
		Shovels	7	Back pain, hurt back	8	Multiple truck locations	8
		Pots, pans, trays	6	Tenosynovitis	5	Elbow(s)	8
		Tanks, bins, VATs	5			Hand(s), except finger(s)	6
		Seafood	5				

Injury Type	n	Most frequently reported source of injury	n	Most frequently reported nature of injury	n	Most frequently affected body part	n
Falls - Same Level	68	Floors, walkways, ground surfaces	28	Sprains, strains, tears	21	Multiple body parts	12
		Ground	8	Bruises, contusions	15	Lumbar region	7
		Floor of building	5	Cuts, lacerations	6	Knee(s)	6
				Sprains and bruises	6	Shoulder, including clavicle, scapula	6
				Fractures	5	Ankle(s)	5
				Other combinations of traumatic injuries and disorders	5		
Abrasion	50	Chips, particles, splinters	22	Foreign bodies (superficial splinters, chips)	23	Eyes	47
		Dirt particles	6	Abrasions, scratches	14		
		Bones/shells	5	Conjunctivitis - non-viral	7		

¹Only categories with more than five reports are presented.

Table 7. Top four injury types of hatchery workers by injury characteristic, 2006-2014¹.

Injury Type	n	Most frequently reported source of injury	n	Most frequently reported nature of injury	n	Most frequently affected body part	n
WMSD	47	Bodily motion or position of injured, ill worker	14	Sprains, strains, tears	31	Lumbar region	14
						Shoulder, including clavicle, scapula	10
						Knee(s)	5
						Wrist(s)	5
Struck	41	Cutting hand tools, including knives ²	8	Cuts, lacerations	15	Finger(s), Fingernail(s)	15
				Sprains, strains, tears	5	Hand(s), except finger(s)	8
Falls - Same Level	15	Ground/floors of buildings and walkways ²	8	Sprains, strains, tears, bruises and contusions ²	8	Joints, including knee(s) and shoulder(s), clavicle, and scapula ²	7
Abrasion	9	Chips, particles, splinters ²	6	Foreign bodies (superficial splinters, chips)	6	Eyes	8

¹Only categories with more than five reports are presented.

²Claim categories have been clustered to protect privacy.

Table 8. Numbers and claim rates (per 100 FTE) by Washington State Risk Class and year of injury, 2006-2014.

	Shellfish harvesters		Hatchery workers		Total		WA¹
Injury Year	n=1,023	Claim Rate	n=157	Claim Rate	n=1,180	Claim Rate	Injury Rate
2006	109	12.9	20	13.8	129	13.0	6.5
2007	110	13.0	18	11.7	128	12.8	6.1
2008	108	12.9	13	9.1	121	12.3	5.7
2009	87	10.5	11	8.0	98	10.1	5.3
2010	104	11.4	14	9.1	118	11.1	5
2011	130	13.9	24	14.8	154	14.1	5.1
2012	113	11.8	17	10.3	130	11.6	5.0
2013	131	13.2	15	9.7	146	12.8	4.9
2014	131	12.7	25	15.9	156	13.1	4.7

¹Incidence rates of nonfatal occupational injuries and illnesses for all industries (including state and local government) in Washington and excludes farms with fewer than 11 employees; numbers not available.

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