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Occupational Injuries of Aquaculture Workers: Washington State

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ABSTRACT

Objective: To characterize occupational injuries of aquaculture workers in Washington State.
Methods: We reviewed accepted Washington State workers' compensation claims from January 1, 2006 to December 31, 2014. Trends in employment, worker demographics (including age, sex, and body mass index), claim rate, and injury characteristics were summarized for accepted claims in the Washington State risk classes that include aquaculture workers.
Results: During the nine-year study period, there were 1,180 accepted claims, 836 (65.1%) were medical-aid only and 344 (26.8%) were compensable. Most commonly reported injury types included being struck by/against an object (n = 420) and work-related musculoskeletal disorders (n = 310). Over the study period, there was no statistically significant change in claim rates in aquaculture (p = 0.77), though they were elevated compared to claim rates for all WA industries combined. A significant upward trend (p = 0.003) in aquaculture employment was observed during our study period.
Conclusions: Given the growth in aquaculture production, and that aquaculture workers in Washington are experiencing higher occupational injury rates compared to other workers in the state, our study suggests that the industry should devote greater attention to prevention of work-related injuries, especially those resulting in being struck by/against objects or work-related musculoskeletal disorders. Enhanced occupational safety and health programs for this industry could help reduce injuries, as well as the cost of workers' compensation claims.

KEYWORDS
Aquaculture; occupational health; safety

Introduction

The 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, feeding, and protecting farmed species from predators, and implies ownership (thus excluding wild caught species).[1] Global animal aquaculture production has increased steadily in recent decades and as of 2014 was valued at $160.2 billion and supplied more fish for human consumption than the capture fishing industry for the first time.[2] In 2005, food fish was the primary source of animal protein for approximately one billion people in 58 countries.[3]

An estimated 18,753,000 people were employed in aquaculture globally in 2014.[2] Most of these workers were in Asia, and only 19% were women (not including those involved in processing or trading).[2] American aquaculture directly employed approximately 10,519 persons in 2007; 12% of these positions were in Washington State.[4] Washington is the top producer of farmed clams, oysters, and mussels in the nation, and contributed $270 million to the economy in 2011.[5]

Despite the steady growth in the industry, little is known about the occupational safety and health of aquaculture workers.[2] 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. exceeded the national rate for all industries combined (13.6 per 100 full-time equivalent (FTE) employees and 3.3 per 100 FTE, respectively).[6,7] This trend was similar in Washington where the incidence rate of nonfatal occupational injuries and illnesses for animal production and

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aquaculture (NAICS code 112; 13.3 per 100 FTE) exceeded the 2015 rate for all state and local industries combined (4.5 per 100 FTE).[8]

Occupational hazards in aquaculture vary depending on factors such as species farmed, salt/freshwater production, and type of aquaculture system. Reported aquaculture-related occupational hazards include biological hazards such as exposure to the sun, extreme temperatures, eye traumas, dermatoses, and hearing damage.[9–15] Physical hazards reported in the aquaculture industry include tractor overturns, musculoskeletal injuries, slips/trips/falls, and needle-stick injuries.[16–19]

Despite general information on hazards present in the aquaculture industry, there is a lack of detailed analysis on the occurrence of injury. We therefore performed a study to better characterize the injuries experienced by this workforce in Washington State.

Methods

Washington state workers' compensation system

Washington State's Department of Labor and Industries (L&I) is the primary provider of workers' compensation (WC) insurance for employers in Washington State. L&I's industrial insurance program, the State Fund (SF), administers WC claims and covers approximately two-thirds of the workers in Washington.[20] Other entities may qualify to self-insure (generally large employers), be covered by alternative systems (e.g. federal workers), or be exempt from mandatory coverage (those enumerated in RCW 51.12 such as the self-employed).[21] Most tribal enterprises are not covered by the SF though tribes are a notable aquaculture employer in Washington State. Washington employers must report total hours employees worked within WC risk classifications quarterly, which are used as a basis for their insurance premium payments.

A WC claim is initiated when an injured worker and their health-care provider complete a Report of Industrial Injury or Occupational Disease (RIIOD) Accident Form. Worker information includes personal, demographic, familial, and occupational information as well as a description of the work-related injury event. The health-care provider portion includes diagnosis information (including ICD-9 codes), work relatedness, and treatment recommendations. Characteristics of the injury (including the type, nature, source, and affected body part) from the RIIOD Accident Form 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 accepted SF WC claims with injury dates occurring from January 1, 2006 through December 31, 2014. An accepted claim is classified as compensable or medical aid only. Compensable claims generally involve payment of benefits in addition to medical benefits (e.g. wage replacement, disability, or death).

Extracted data variables included demographics (age at date of injury, sex, body mass index), claim status (compensable or medical aid only), year of injury, and injury characteristics (source, nature, affected body part, and type). 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.[20] Injury types discussed include "abraded" (removal of skin, mucous membrane, or superficial epithelium), "fall on the same level" ("impact between the injured person and the source of injury … at the same level or above the surface supporting the person" prior to a fall), "struck by/against" ("impact between the injured person and the source of injury"), and work-related musculoskeletal disorders (WMSDs) (OIICS 2007). WMSD injuries are defined as non-traumatic soft-tissue musculoskeletal disorders caused or aggravated by work activities (such as repetitive tasks, or awkward body postures).[22]

Data were analyzed by the available risk classifications of interest for aquaculture: 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.

There is no risk classification for aquaculture workers who work in open waters (i.e. net pens). All claims for the risk classes of interest were identified and extracted from the SF database on March 1, 2017. Hours reported in the selected aquaculture risk classes were summed across employer accounts over the nine-year study period.

Categorizing risk class

A reclassification of the risk classifications 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 the Farms: Finfish and Shellfish Hatcheries risk class as "hatchery workers."

Shellfish harvester tasks include preparing tanks/growing areas, spawning, seeding into aquatic tanks and deep water growing beds, harvesting (using hand-held tools or mechanical dredging), shucking, and packaging of shellfish (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. These workers can sell shellfish directly to the public from a stand near the aquaculture facility.

Hatchery worker tasks involve raising finfish and/or shellfish and include growing algae for feed, seeding shells in tanks, spawning finfish, harvesting (though not of mature shellfish), managing tank flow and temperature, 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). Work tasks of hatchery workers include fewer tasks in natural environments than shellfish harvesters, possibly reducing the potential for exposure to uncontrollable environmental hazards.

Data analysis

WC demographics and injury characteristic data of accepted claims were summarized for two aquaculture risk classes specific to Washington State for injuries that occurred from January 1, 2006 through December 31, 2014. Accepted claim counts and rates 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 based on working five 8-hour days per week, 50 weeks per year.

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 from further review.

Results

There were 1,285 occupational injury and illness claims for the two risk classes in the period of interest (the majority of claims regarded injury rather than illness, and will therefore be referred to as injuries). Accepted claims (1,180: 836 medical aid only, 344 compensable) were comprised primarily of shellfish harvesters (1,023: 723 medical aid only, 300 compensable) and the remaining 157 claims were hatchery workers (113 medical aid only, 44 compensable) (Figure 1). One claim was neither accepted nor rejected at the time of data extraction.

Table 1 summarizes the top four injury types by demographic characteristic for all accepted WC aquaculture claims. Men experienced the most injuries, regardless of injury type. Of the four most frequently reported injury types, males and females reported struck by/against injuries most commonly overall, though the 45–54 and 55–64 age groups most frequently reported WMSD injuries. The majority of claims were filed by the 25–34 age group, regardless of gender. Age was not reported in 2.3% of claims. Underweight, normal weight, and overweight claimants most frequently reported struck by/against injuries whereas obese claimants equally reported struck by/against and WMSD injuries. Body mass index (BMI) group was not recorded in 151 of the accepted claims (of which 83% were male). There were too few respondents to present results of injury type and age or BMI analysis by gender.

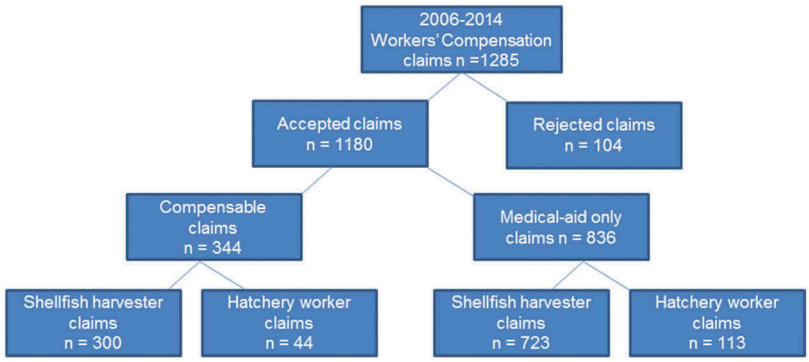

Figure 1. Classification of workers' compensation claims for shellfish harvesters (WA state risk classes WAC 296-17A-4805-08 farms: Shellfish and WAC 296-17A-4808-10 shellfish-mechanical harvesting) and hatchery workers (WAC 296-17A-4812-00 farms: finfish and shellfish hatcheries) for injuries occurring in Washington State from 2006 through 2014.

Table 1. Top four injury types by demographic characteristics for all accepted WC aquaculture claims (shellfish harvesters and hatchery workers combined) in Washington State, 2006–2014.

	Abraded	Fall on same level	Struck by/against	Work-related muscular disorders	Total aquaculture claims*
	n (% row)	n (% row)	n (% row)	n (% row)	n (% total)
Gender					
Female	<10	20 (11.6)	58 (33.5)	49 (28.3)	173 (14.7)
Male	52 (5.2)	63 (6.3)	362 (35.9)	261 (25.9)	1007 (85.3)
Age					
Missing	<10	<10	12 (44.4)	<10	27 (2.3)
Age 16–19	<10	<10	30 (48.4)	11 (17.7)	62 (5.3)
Age 20–24	<10	<10	88 (45.4)	38 (19.6)	194 (16.4)
Age 25–34	19 (5.0)	21 (5.6)	133 (35.3)	106 (28.1)	377 (32.0)
Age 35–44	12 (4.7)	25 (9.9)	84 (33.2)	68 (26.9)	253 (21.4)
Age 45–54	12 (6.7)	17 (9.4)	49 (27.2)	54 (30.0)	180 (15.3)
Age 55–64	<10	<10	18 (23.4)	28 (36.4)	77 (6.5)
Age 65+	0	0	<10	<10	10 (0.9)
Body mass index					
Underweight (<18.5)	0	<10	<10	<10	12 (1.2)
Normal (18.5–25)	20 (5.4)	23 (6.2)	149 (40.2)	91 (24.5)	371 (36.1)
Overweight (≥25)	17 (4.0)	27 (6.3)	142 (33.1)	118 (27.5)	429 (41.7)
Obese (≥30)	12 (5.5)	23 (10.6)	62 (28.6)	62 (28.6)	217 (21.1)

* Total aquaculture claims = all WC accepted claims (n = 1,180); BMI missing from 151 claims; categories with less than 10 claims were reported as "<10" for privacy.

A linear regression of reported FTE across time indicated that there was a statistically significant increase in hours worked for shellfish harvesters ($p < 0.05$), though not for hatchery workers ($p = 0.10$), over the study period. There was no statistically significant change in number of accepted claims or claim rates by risk classes combined ($p = 0.75$ and $p = 0.77$, respectively; Table 2), or by individual risk class, using linear regression. 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 (neither was statistically significant over time; $p = 0.91$ and 0.63, respectively). Claim rates for each risk class were higher when compared to all SF accepted WC claims in Washington State, regardless of industry, per 100 FTE (Washington State Department of Labor & Industries Workers' Compensation administrative data May 2017) (Table 2).

The four most common injury types for both risk classes of aquaculture workers were struck by/against an object (n = 420), WMSDs (n = 310), falls on the same level (n = 83), and abrasions (n = 59). Tables 3 and 4 present the four most common injury types, source and nature of injury, and affected body part by shellfish harvesters and hatchery workers, respectively.

Shellfish harvesters most commonly reported struck by/against injuries (n = 379) and WMSD injuries (n = 263). Of struck by/against injuries, the most frequently reported source of injury was knives (n = 146), citing punctures and cuts/

Table 2. Numbers of accepted workers' compensation claims, company reported full-time equivalent (FTE) hours, and claim rates (per 100 FTE) by Washington State risk class and year of injury, 2006–2014.

	Shellfish harvesters			Hatchery workers			All aquaculture			All WA workers*
Injury year	*n* = 1,023	FTE	Claim rate	*n* = 157	FTE	Claim rate	*n* = 1,180	FTE	Claim rate	Claim rate
2006	109	844.1	12.9	20	144.5	13.8	129	988.6	13.0	7.7
2007	110	845.3	13.0	18	154.4	11.7	128	999.7	12.8	7.3
2008	108	839.3	12.9	13	143.6	9.1	121	982.8	12.3	6.7
2009	87	832.3	10.5	11	137.2	8.0	98	969.6	10.1	5.9
2010	104	910.5	11.4	14	153.7	9.1	118	1064.2	11.1	5.7
2011	130	933.0	13.9	24	162.6	14.8	154	1095.5	14.1	5.5
2012	113	958.0	11.8	17	165.0	10.3	130	1123.0	11.6	5.5
2013	131	989.9	13.2	15	153.9	9.7	146	1143.9	12.8	5.3
2014	131	1032.5	12.7	25	157.0	15.9	156	1189.5	13.1	5.3

All aquaculture includes shellfish harvesters and hatchery workers combined.
*All WA workers claims data from all SF accepted Workers' Compensation claims in Washington State, collected from the Washington State Department of Labor & Industries Workers' Compensation administrative data May 2017.

Table 3. Top four injury types of shellfish harvesters by injury characteristic, 2006–2014[1].

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				
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		

[1]Only categories with more than five reports are presented.

lacerations as the most common natures of injury (*n* = 139 and *n* = 118, respectively), and finger(s)/fingernail(s) and hand(s) being the most affected body parts (*n* = 135 and *n* = 94, respectively). Of WMSD injuries, the most frequently reported source of injury was bodily motion or position of

Table 4. Top four injury types of hatchery workers by injury characteristic, 2006–2014[1].

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

[1]Only categories with more than five reports are presented.
[2]Claim categories have been clustered to protect privacy.

injured/ill worker (n = 61), citing sprains, strains, and tears as the most common nature of injury (n = 173), and the lumbar region being the most affected body part (n = 97).

Hatchery workers most commonly reported WMSD injuries (n = 47) and struck by/against injuries (n = 41). Of WMSD injuries, the most frequently reported source of injury was bodily motion or position of injured/ill worker (n = 14), citing sprains, strains, and tears as the most common nature of injury (n = 31), and the lumbar region and shoulder being the most affected body parts (n = 14 and n = 10, respectively). Of struck by/against injuries, the most frequently reported source of injury was cutting hand tools (including knives) (n = 8), citing cuts and lacerations as the most common nature of injury (n = 15), and finger(s)/fingernail(s) and hand(s) being the most affected body parts (n = 15 and n = 8, respectively).

Of the 59 abrasion injuries in both risk classes, chips, particles, and splinters were the most common source of injury, foreign bodies were cited as the most common nature of injury, and eye(s) were the most commonly affected body part. Shellfish harvesters also reported seven reports of non-viral conjunctivitis and eye injuries as the source of 17 struck by/against injuries.

Figure 2 compares all SF injury claims to the combined aquaculture risk classes of interest, including by the two most commonly reported injuries (struck by/against and WMSD). Combined aquaculture risk classes had the highest injury claim rate in the period of interest (for all injuries), followed by all accepted claims in the SF, regardless of industry, though this rate appears to be declining. Struck by/against and WMSD claim rates for aquaculture risk classes increased, whereas these injuries for all SF risk classes remained relatively stable. Figure 3 shows animal aquaculture claim rates are higher when compared to agriculture and to all SF claims combined.

Discussion

Our analysis of WC claim data found that aquaculture workers are reporting injuries at rates in excess of the general worker population in Washington State, though there was no change in rates from 2006 through 2014. We found that struck by/against injuries and WMSDs were the most common types of injury claims for shellfish harvesters and hatchery workers, regardless of age, BMI, or gender. These findings have implications for aquaculture workplace health and safety.

The majority of claims were filed by men which is likely due to their predominance in this workforce, a trend seen in fish farming in Washington State (by NAICS code 112) and globally.[2,23,24] However, of fisheries and aquaculture workers worldwide, when secondary processing activities are considered, approximately half of the workforce is women (these activities were not considered in the present study).[2] Therefore, 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 would likely alter the claim rates, injury characteristics, and worker demographics found in this study. However, struck by/against

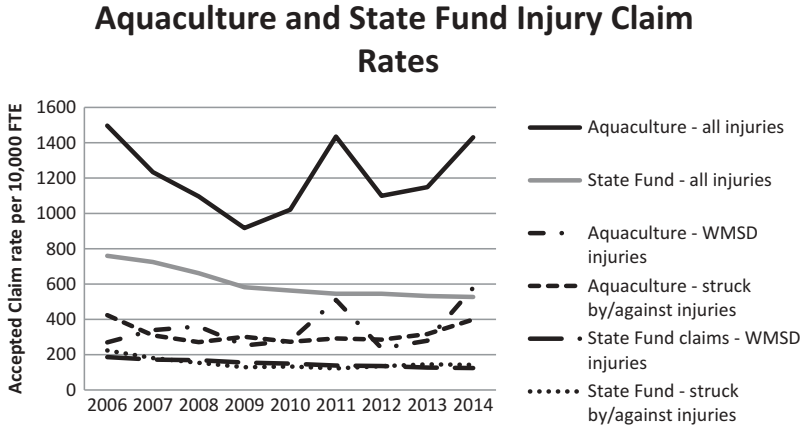

Figure 2. All accepted claim rates for aquaculture risk classes compared with all state fund risk classes, and two of the most common injuries, work-related musculoskeletal disorders and struck by/against injuries, Washington State, 2006 through 2014. 'Aquaculture' refers to the aquaculture risk classes presented in this study.

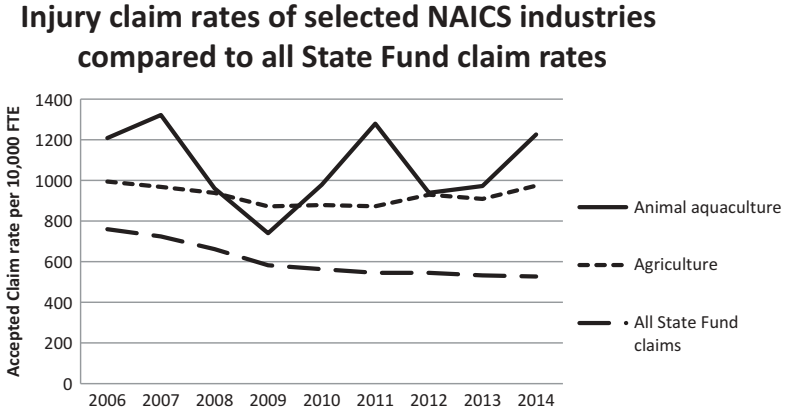

Figure 3. Injury claim rates for agriculture (NAICS 11) and animal aquaculture (NAICS 1125) industries compared to all state fund claim rates, Washington State, 2006 through 2014.

injuries followed by WMSD injuries were the most common injury types for men and women.

There are slight differences in aquaculture injuries when analyzed by age group. Most claimants (32%) were between 25 and 34 years old when their injury occurred. Compared to the 2014 employment statistics in Washington, aquaculture claimants were younger than the general employment workforce in the state.[23] The youngest and oldest age groups reported struck by/against injuries most commonly, regardless of gender (data not shown). However, the 45–54 age group experienced more WMSD injuries which may be due to their amount of time working in aquaculture and conducting repetitive tasks. FTE are not reported by age, prohibiting analysis of the relationship between age and risk of injury with time at work.

Some studies have indicated overweight (BMI ≥ 25) and obese workers (BMI ≥ 30) are at higher risk of experiencing workplace injury compared to normal weight coworkers.[25,26] Our analysis showed 62.8% of aquaculture claimants were overweight or obese compared to 86.6% of the general Washington population (data collected from U.S. citizens who participated in the 2012 Behavioral Risk Factor Surveillance System Survey (BRFSS)). These findings do not indicate that obesity is a major driver of injury in this worker population. Because height and weight used to determine BMI are self-reported on RIIOD Accident Forms and in the BRFSS, results should be interpreted cautiously. To our knowledge, there are no data on BMI of aquaculture workers in Washington in which to compare the results of our analysis.

Our results show an increase in hours worked for shellfish harvesters and both risk classes combined over the study period by reported FTE, suggesting the workforce grew, although we did not have direct workforce statistics. A 2015 report found WA produced the most farmed shellfish in the U.S. with annual sales of approximately $150 million, and projected that the shellfish aquaculture industry, and its workforce, will continue to grow.[5]

Our analysis found similar occupational injury and illness rates for the shellfish harvester risk class (12.5 injuries per 100 FTE), and the hatchery worker risk class (11.4 injuries per 100 FTE) 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). 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 resemble those in other locations. However, the occupational injury and illness claim rates of aquaculture workers in our study are higher than for all Washington industries combined (Table 2).

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 (due to a small sample size and confidentiality issues, only a 3-digit NAICS code is reported, NAICS code 112, a broader subsector of animal production, including aquaculture, cattle ranching, etc.). Though workplace 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 because of different NAICS codes.[15] When all SF WC claim rates are compared to the agriculture (NAICS 11) and animal aquaculture (NAICS 1125) industries, the all SF claim rate steadily declined and had the lowest claim rates, agriculture remained relatively steady, and animal aquaculture varied and appeared to be increasing (Figure 3).

Shellfish harvesters most commonly reported struck by/against injuries, knives as the most common source of injury, punctures and cuts/lacerations as the most common natures of injury, and finger(s)/fingernail(s) and hand(s) being the most affected body parts. Shellfish harvester work involves shucking oysters, which may explain some of these frequently reported injury characteristics (and is supported by unpublished self-reported RIIOD event descriptions). 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.[27] 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.

Furthermore, a review of injury descriptions from claims included in this study cited many accidental eye injuries from shucking oysters (data not shown). This may also explain the number of non-viral conjunctivitis claims and eye injuries 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.[12,28–30] These results highlight the potential for zoonotic disease transmission for aquaculture 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 were the most common injury type for hatchery workers, and the second most common reported injury type of shellfish harvesters. Both risk classes experienced similar injury characteristics for WMSD injuries: bodily motion or position of the worker was the most commonly reported source of injury, while sprains, strains, and tears were the most common nature of injury, and the lumbar region was the most commonly affected body part. 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.[22] To reduce WMSD injuries, efforts may include modifying body position or motion during manual and/or repetitive tasks, and redesigning how tasks are completed.

A comparison of accepted claim rates for aquaculture risk classes and all SF risk classes, and by the two most common injuries, work-related

musculoskeletal disorders and struck by/against injuries, shows the highest claim rates for our aquaculture risk classes of interest (Figure 2). Struck by/against and WMSD claim rates for aquaculture risk classes increased, whereas these injuries for all SF risk classes remained relatively steady and all accepted claims in the SF, regardless of industry, appears to be declining. This further highlights the need for injury prevention efforts in the aquaculture industry.

Quarterly data on the population size, sex, and age of aquaculture workers in Washington are available by NAICS code using the U.S. Census Bureau's QWI Explorer tool. However, because our data is based on WC claims and not individual workers, as well as risk class rather than NAICS codes, we cannot provide injury rate estimates and comparisons by age and gender, a limitation of this study. WC claims data underestimate the true incidence of aquaculture injuries and illnesses due to statutory and regulatory exclusions from mandatory WC coverage e.g. employer arrangements involving self-employed workers or tribal employers. This analysis also excludes aquaculture workers that do not fall under the two aquaculture risk classes, such as those who work in open waters. Underreporting of injuries and illnesses is a well-documented limitation to the WC system and likely underestimates the burden of occupational injuries in Washington State. [22,31] Reasons for not filing WC claims include medical treatment cost paid directly by the employer, concerns of employer retaliation, or lack of knowledge about WC or the filing process. [22,31]

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, and provides greater details about injury risks that have been noted in national data. Identified frequency counts can be used to identify the most commonly reported injury characteristics to target effective prevention efforts within the aquaculture industry. 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. Our study suggests that the industry should devote greater attention to prevention of work-related injuries as aquaculture production grows. Additionally, our study shows aquaculture workers are experiencing higher occupational injury rates than other workers in Washington State, highlighting the need for state-based surveillance to reduce the risk for occupational injuries in aquaculture.

Conclusion

Our analysis identifies 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 WC 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 such as cut resistant gloves and eye protection may prevent commonly reported injuries affecting fingers, hands, and eyes. 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 most commonly seen at worksites.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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