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Risk Factors Associated with Severe Injuries in Inland Aquaculture Farms

Amah Martin
University of Kentucky

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Amah Martin, Student

Steven Browning, PhD, MSPH, Committee Chair

Corrine Williams, ScD, MS, Director of Graduate Studies

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Capstone Project Paper

A paper submitted in partial fulfillment of the requirements for the degree of Master of Public Health in the College of Public Health at the University of Kentucky

By Amah Martin, BA

Louisville, Kentucky

Steve, Browning, Ph.D, MSPH, Chair

Lorie Chesnut, DrPH, MPH

Glyn Caldwell, MD

Abstract

Objective: The main objective of this study was to analyze risk factors associated with severe occupational injuries among inland aquaculture farms.

Methods: Survey results were compiled in a data set that consisted of qualitative data from 51 farmers who were interviewed between 2008 and 2011 in 10 states and the Canadian province of British Columbia. Chi-square and Fisher's exact test were used to assess the differences in the dichotomous level of severity among several farm and injury variables. Logistic regression was used to predict the outcome of a severe injury event.

Results: Injury observations that indicated the use of raceway systems made up 42.4% of severe injuries compared to 61.5% of injury observations that indicated use of raceway systems in the less severe category. Injury observations that happened on farms that use of pond had higher percentage of severe injuries (63.8%) compared to less severe injuries (51.9%). Injury observations that happened on farms that use raceway systems indicated an adjusted odds ratio of 0.62 [95% CI: 0.26 – 1.48] and observations that happened on farms that use ponds indicated an adjusted odds ratio of 1.33 [95% CI: 0.54 – 3.27].

Conclusion: Farms that use more advanced technology are less likely to have a severe injury event occur. This study suggest that workers may be have a higher odds of a severe injury when working on farms that are less automated and have less technology.

Introduction

The following review of the literature summarizes the key concepts essential to understanding the background of aquaculture including common occupational injuries related to aquaculture and the proposed and applied interventions to reduce and prevent those injuries. The works cited were collected from peer-reviewed journal articles, federal and international reports from organizations such as the Food and Agriculture Organization, and the United States Bureau of Labor Statistics. The following databases and sources that were used to conduct this literature research include Google Scholar search engine, University of Kentucky InfoKat Catalog, PubMed, and ProQuest. The key words and phrases used to conduct this literature review included aquaculture, occupational injury, fish farming, occupational hazards, epidemiology, cross-sectional study, and cohort study.

The first section of paper will summarize the literature published since 1990 related to aquaculture and will identify the common occupational hazards. This paper will also identify solutions that have been proposed to eliminate or mitigate potential work-related hazards beyond musculoskeletal disorders seen in agriculture and construction.

Overview of Aquaculture Farms

The Food and Agriculture Organization (FAO) defines aquaculture as the farming of aquatic organisms such as fish, mollusks, crustaceans, aquatic plants, crocodiles, alligators, turtles, and amphibians (FAO, 1990-2016). Farming of aquaculture organisms involves the use of one or more intervention methods in order to harvest aquaculture products. For statistical purposes, the FAO also defines aquaculture farming as the process of harvesting of aquaculture products by either an individual or corporate body which has owned them through the rearing period whereas aquatic organisms exploitable by the public are viewed as a common property source (FAO, 1990-2016).

There are three environments in which aquaculture organisms are raised in including freshwater, brackish water, and salt water. Where the final product is cultivated determines the environment in which the aquatic organism is raised. In fresh water environments, aquatic organisms are cultivated where the final product is raised in freshwater such as rivers or reservoirs. Brackish water environments involve the cultivation of aquatic species where the end product is raised in brackish water such as estuaries, coves, bays, lagoons, and fjords. Brackish water environments fluctuate between low and high salinity. It should also be noted that aquatic species can be raised initially in freshwater or marine water environments before being harvested in brackish water environments. Lastly, salt water environments allow aquatic species to be cultivated in fjords, inshore, and open waters where the salinity exceeds 20%. Aquatic species harvested in the salt water environment can be initially raised in freshwater or brackish water environments (FAO, 1990-2016).

Occupational tasks involved in aquaculture vary depending on the environment in which aquatic organisms are raised in and the process stage in aquaculture. The process of fish and animal aquaculture production involves numerous stages which are based on the growth stage of the aquaculture species. The brooding process is the first stage in raising most aquaculture species such as fish. Brooding is a process performed by selected males and females mate and which allows the females to produce eggs and males to fertilize the eggs. After the eggs have spawned and have been fertilized by the male, they are either looked after by the adult aquatic organism or collected and cultivated in hatcheries. Once the eggs have hatched, they are known as fry and are fed a specific diet until they become fingerlings. These early fish species stages are cultivated in nurseries. The fish to be cultivated are then transferred in a grow-out phase, and finally harvested as end products (Myers, 2013).

Trends in Aquaculture Production

The inland and marine aquaculture industry is continually increasing production worldwide. The State of World Fisheries and Aquaculture report that inland aquaculture production has grown from 29.9 million tons in 2007 to 41.9 million tons in 2012 (FOA, 2014). The United Nations Food and Agriculture Organization reports also found that the number of employees in the aquaculture industry has increased by three fold since 1990. Between 1990 and 2004, the number of employees in the industry has increased from approximately 3.8 million workers to 11.3 million workers worldwide (Watterson, Little, Young, et al., 2008).

In 2012, the United States was one of the top five leading exporters of fish and fishery products. They exported approximately $5.8 billion dollars of fishery products in 2012 compared $3.3 billion in 2002. Aquaculture production has increased from $1.1 billion in 2005 to $1.4 billion of aquaculture products in 2012. The United States was one of the top 15 countries producing farmed food fish with a result of 420,024 tons of product (FAO, 2014). Farmed fish production is increasing and there is potential for industry growth.

In terms of production growth for specific fish species, the most recent sales for catfish growers in the United States was $361 million during 2015 which has increased three percent from 2014. The top four sellers include Mississippi, Alabama, Arkansas, and Texas which account for 96% of sales (USDA, 2016). Trout growers sold $104 million dollars in 2015; a one percent increase from 2014. Idaho, North Carolina, Pennsylvania, and Arkansas are the top four sellers for trout (USDA, 2016).

In 2012, the production of aquaculture products per person in North America was 59.3 percent compared to Asia at 3.2%; North America has the highest production per person compared to other regions of the world. Production per person can reflect the industrialization of aquaculture activities as well as small-scale operations that result in low production per person results (FAO, 2014). Therefore, this observation may suggest that the United States has potential for growth in the industry due to advances in technology and industrialization. According to the United States Department of Agriculture, the National Agricultural Statistics Service reported in 2013 a total number of 1,479 ponds operations, 360 recirculating tanks operations, 291 non-recirculating tanks operations, 71 aquaponic tanks operations, 303 cages & pens operations, 391 raceways operations, 352 cultured aquaculture species at the bottom of water bodies operations, and 36 operations that use other methods in United States.

Hazards Identified in the Aquaculture Industry

With aquaculture production showing an increasing trend, there is also a growing need to address the occupational safety and health issues that pertain to the industry. The Bureau of Labor Statistics reported that employees working in animal aquaculture had a nonfatal injury rate of 16.5 per 100 workers in 2008, the highest rate compared to crop production, livestock production, and all other occupations. The incidence rate of nonfatal occupational injuries for animal aquaculture, North American Industry Classification (NAIC) 1125, in 2013 was 11.5 per 100 full-time workers in all establishments. The nonfatal incidence rate for animal aquaculture was higher than crop production (NAIC 111) (5.5 per 100 full-time workers) and livestock production (NAIC 112) (6.2 per 100 full-time workers) in the same work settings (BLS, 2013). Aquaculture and agriculture have similar occupational hazards that put workers at risk of occupational injury but aquaculture includes several additional factors such as wet conditions, drowning, and off shore operations. A 2013 descriptive study, found 15 hazards specific to aquaculture, including drowning, electrocutions, falls from elevation, slips and trips, falling objects, needle stick injections, roadway collisions, strains and sprains, spine wounds, impalements, equipment overturns, dust inhalations from feed, net entanglements, boat or vehicle battery explosions, and fires (Myers, 2013). Decomposition gases were also noted as a hazard with aquaculture (Nikkanen & Burns, 2004).

Potential Risk Factors for Injury in the Aquaculture Industry

Several potential risk factors identified in aquaculture include the use of cranes, aerators, tractors and sprayer-equipped all-terrain vehicles, lifting heavy loads, boat propellers, high pressure sprayers, slippery surfaces, production of hydrogen sulfide from rotting waste, overturns due to eroding levees, storm-related rushing water, diving conditions, night-time conditions, working alone, lack of training, no personal floatation devices, and all-terrain vehicle use (Myers, 2010). Along with these risk factors, several studies have identified additional exposures that potentially lead to injury among aquaculture workers. These exposures are categorized based on five types of generalized hazards which include physiological, physical, chemical, biological, and psychological hazards (Moreau & Neis, 2009). Exposures identified in physiological hazards include heavy lifting, prolonged standing, awkward postures, repetitive motion, and overexertion. This can lead to common injuries such as low back pain, neck and shoulder pain, bursitis, tendonitis, and carpal tunnel syndrome.

Physical hazards include slips and falls, falls from height, transport and trucking accidents, machinery, electricity, fire, heat and cold, diving, noise, vibration, confined spaces, entanglements, underwater entrapment, lack of visibility, and solar radiation. Potential injuries include cuts, burns, broken bones, amputation hypothermia, hyperthermia, drowning, electrocution, as well as sprains and strains.

Chemical hazards include disinfectants, antibiotics, hydrogen sulfide, carbon monoxide, dust, self-injections from needle sticks, flammabilities, and battery explosions. Common injuries seen with chemical hazards include respiratory illness, burns, cancer, lung, eye, and skin irritations, reproductive effects, birth defects, and poisonings.

Biological hazards include sharp teeth, bacteria, parasites, skin contact with shell fish and finfish tissue and fluids, enzymes, airborne proteins and endotoxins, and fish feed dust. Common injuries seen with biological hazards include bites, cuts, or punctures from aquatic species, allergies, asthma, hives, chapped skin, and itching.

Lastly, psychological hazards include high demand and low control situations, remote locations away from home, potential for large fish kills, and abusive social environment. The most common injury observed with psychological hazards is work-related stress (Moreau & Neis, 2009; Myers, 2010; Durborow 1997; Erondu & Anyanwu, 2005).

Proposed Interventions in Preventing Aquaculture Injuries

When reviewing interventions in aquaculture, a 2013 study focused on prevention by identifying fish farming hazards and solutions to avoid those injuries (Myers, 2013). Individuals from over 50 fish farms provided hazard assessments for three circumstances: close call injuries, injuries, or knowledge of an eminent hazard. Their assessment involved a multi-step design process. These steps include problem recognition and formulation, an analysis of the problem was used to search for solutions, finding alternative solutions on passive interventions since original solutions were active interventions, making the decision based on cost-effectiveness and complexity, and specification of the solution with focus on implementation of solution. Passive interventions require no human control at the work interface. Active interventions rely on human behavior at the work interface and are considered a less safe approach. The results of the study showed that most farmers are aware of existing hazards but less informed about the controls that other farmers use to prevent injury from those hazards.

There were a total of 17 hazards identified at these fish farms and solutions that farmers have come up with developed to prevent those injuries. This study concluded that safer technologies for the protection of workers can be evaluated through use of the hierarchal order of precedence which is following an order to implement safety measures. If the first level of the safety technology does not work then the next solution is applied. The order includes: elimination of the hazard, guarding against the hazard, and warning about the hazard (Myers, 2013). This section concludes with a summary of the implications of research for risk factors associated with aquaculture occupational injury.

Gaps in Aquaculture Industry Research

A limited number of studies have been published assessing aquaculture related hazards from an epidemiological perspective (Marshall, 2004; Erondu & Anyanwu, 2005; NLS, 2001). The gaps in the current literature include the limited number of epidemiological studies of occupational injuries that occurred in inland aquaculture practices as well as analyzing the general risk factors that are associated with the likelihood of an occupational injury. Along with the limited epidemiological studies, there is also limited research in analyzing risk factors associated with occupational injuries in the inland aquaculture industry compared to off-shore operations. Therefore, the primary research objective for this study was to analyze the risk factors associated with severe occupational injuries among inland aquaculture farms.

The implication of this study indicates a need for addressing the occupational safety and health issues that pertain to the inland aquaculture industry. This study will be useful in conducting a quantitative analysis on the link between the risk factors associated with inland aquaculture and a severe injury event. Several studies have identified the common hazards related to aquaculture and how specific interventions have reduced the risk of injury, but few have analyzed the key risk factors that are related to occupational injury in the inland aquaculture setting. By identifying these risk factors, appropriate interventions, recommendations, and solutions can be applied to help employers and employees to ensure better safety practices and protect themselves from occupational injury. Therefore, the primary research objective for this study will involve analyzing the risk factors related to occupational injuries among inland aquaculture farms.

Methods

The current literature is limited in the field of inland aquaculture practices. More specifically, there are few studies that assess the risk factors that influence the likelihood of an occupational injury (Marshall, 2004; Erondu & Anyanwu, 2005; NLS, 2001). This study will focus on identifying risk factors related to inland aquaculture practices that are associated with occupational injuries by using epidemiological methods. The following section gives a detail summary of the how the data were collected, organized, and analyzed to create a final model interpreting the risk factors related to the occupational injuries among inland aquaculture farms.

Study Population and Design

The primary data source for this study was obtained from the Southeast Center for Agricultural Health and Injury Prevention which was funded by Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health (CDC/NIOSH) Cooperative Agreement U50 007547. The data were collected by a research team led by Mr. Myers who administered a cross-sectional survey between 2008 and 2011 in various states in the United States and British Columbia. Aquaculture farms were recruited by primarily interacting with farmers in professional associations and organizations such as the Mississippi Catfish Association as well as other similar aquaculture associations. Convenience sampling was used to administer the survey, which consisted of 74 items requesting information from aquaculture farmers about (a) what they thought were the most dangerous jobs on their farm, (b) the effect of an injury on their family and farm operation, (c) actual injury and close call injury events, (d) safety practices used to prevent injuries, and (e) simple solutions they have used or could have used to remove hazards and prevent injuries. Along with conducted these interviews with aquaculture farmers and farm managers, the research team took photographs and videos to capture information that would aid in understanding the common hazards workers in the inland aquaculture industry encounter.

Once the field work was completed, a data set was compiled that consisted of qualitative data from 51 farmers who were interviewed between 2008 and 2011 in 10 states (West Virginia, South Carolina, Pennsylvania, North Carolina, Missouri, Mississippi, Kentucky, Idaho, Arkansas, and Alabama) and the Canadian province of British Columbia (Myers 2009 & 2013). The original data contained 257 variables about the 51 farms and 151 injuries. The injuries reported included events that happened between 1971 and 2011. The data was accessible by computer and saved in SPSS file format. A primary analysis was conducted to assess which risk factors were associated with a severe injury that occurred on inland aquaculture farms.

Definition of Variables

The analysis of this dataset investigated the association between aquaculture farm characteristics that are recognized as potential risk factors and the outcome of a severe injury event. The original data set was modified from a list of farms with each injury to a list of injuries and the farm associated with those injuries. The observations were converted from 51 farms to 151 injuries. In this modified dataset, additional categorical variables and variables converted from numerical to categorical were added. The additional categorical variables that were added to the dataset included severity, part of the body injured, mechanism of cause, type of injury, single or multiple species production, number of aquaculture production processes conducted, and whether or not the aquaculture farm was greater than 116 acres or less than/equal to 116 acres. These variables were created using the injury descriptions given by the interviewees, as well as a yes or no indication of each aquaculture species listed, yes or no indication of what technology is used, yes or no indication of production process conducted, and total acre size.

For variables part of the body injured, mechanism of cause, and type of injury, the Occupational Injury and Illness Classification System (OIICS) Manual for 2012 created by the Bureau of Labor and Statistics was used. Classification for these three variables were a key part in conducting in this analysis. Therefore, descriptions for each variable related to the injury is as follows the OIICS Manual for 2012: type of injury or nature of injury identifies the physical characteristics of that work related illness or injury. Body part injured refers to part of the body that has been injured or subject to illness. Lastly, the mechanism of cause refers to the object, substances, equipment, and other factors that are responsible for the illness or injury incurred by worker or which precipitated the event or exposure (BLS, 2012). The following table gives a detail description for type of injury, body part injured, and mechanism of cause:

Table 1. Classifications Groups for Type of Injury, Body Part Injured, and Mechanism of Cause

Variable	Listed Categories	
Type of Injury	Cuts and Punctures Fractures Bruises and Abrasions Sprains, Strains, Tears	Multiple Injuries Other Unclassified
Body Part Injured	Head Upper Extremities Lower Extremities Hands, Wrists, Digits Other	
Mechanism of Cause	Parts and Materials Persons, Plants, Animals Falls, Slips, Trips on Structure or Surface Containers, Furniture, fixtures, and Vehicles	Tools, Instruments, and Equipment Other Unclassified

Table 1. Description of categorical variables related directly to injury observations. The categories that were created are based on the Occupational Injury and Illness Classification System (OIICS) Manual for 2012.

The outcome variable for the logistic regression model, severity, is defined as a dichotomous variable. Severity is defined as two different levels including less severe and severe. The severity of each observation was classified based on the description of the injury in terms of, whether or not they needed medical care, time away from work, type of each injury and whether or not the injury was fatal. Severe injuries included loss of a limb, cut or puncture wound, electrocution, fractures, any injury resulting in a fatality, and venomous snake bites. Less severe injuries include sprains, strains, tears, and bruises.

The majority of the observations in the data set were used for analysis with the exclusion of four injury observations that involved a minor, one injury observation that involved a non-worker during non-operational hours, and nine observations that were unclassified in terms of severity. The data set contained observations where variables were missing, including variables selected for analysis. Due to large proportions of missing values for each variable, missing values were included in the analysis as unclassified and analyzed as such.

Data Analysis

After selecting variables that relate to occupational injury based on the literature review and available variables in the dataset, statistical analysis used the Chi-square and Fisher's exact tests to determine whether there were significant associations between each categorical variable and the outcome. The Fisher's exact test was conducted on variables that contained cell values less than five in univariate analysis. Univariate logistic regression models were analyzed to determine the unadjusted associations between predicator variables and the outcome of interest. For variables that resulted in values less than five, exact logistic regression analysis was conducted to determine unadjusted associations between the predicator variable and the outcome of interest. Variables with small values were not assessed further due to issues of reduced statistical significance. Results included odds ratio estimates, 95% confidence intervals, and p-values. Multivariable logistic regression analysis was also conducted to examine the associations between a severe injury event and several appropriate predictor variables related to aquaculture practices as well as predicator variables related to injuries characteristics in the dataset while controlling for confounding variables. The final logistic model included odds ratios, 95% confidence intervals, and p-values Analysis was conducted using SAS v9.3.

Results

Table 2 provides a list of all the variables that were listed in the Methods section along with a list of descriptive statistics for each variable stratified by severity level. Descriptive statistics include frequencies of injuries and column percentages which are given for each categorical variable. The variable, type of aquaculture production, shows a similar distribution between the two levels of severity. However, there are a few notable differences between severity levels when observing the number of aquaculture production processes, production technology, aquaculture farm only, total farm production acres owned/leased, mechanism of cause, and body part injured.

Among severe injuries, 67.8% of injury observations were identified as having occurred on a single fish or aquaculture species production compared to multiple fish production (22.3%) and unclassified production (10.2%). A similar distribution is seen in the less severe injury observations as well. As for aquaculture production processes, 40.7% of severe injury events occurred while working on a farm that managed five or more aquaculture production processes 15.3% of severe injury events occurred while working on a farm that managed three to four aquaculture production processes, 27.1% of severe injury events occurred while working on a farm that conducted one to two production processes, and 17.0% of severe injury events occurred while working on farms that were unclassified in the number of aquaculture production processes. Among production technology, both raceway and tank systems had a notable percentage difference between less severe injury observations and more severe injury observations. Injury observations that indicated the use of raceway systems made up 42.4% of severe injuries compared to 61.5% of injury observations that indicated use of raceway systems in the less severe category. Injury observations that indicated use of ponds had higher percentage of severe injuries compared to less severe injuries.

When comparing the severe injury observations within the mechanism of cause, the most prevalent severe injuries were identified in parts and materials (e.g. heavy metal ramps, galvanized screens, dip nets, etc.) (32.2%), person, animals, plants (18.6%), and falling, slipping, tripping on structure or surface (18.6%). In body part injured the most prevalent severe injuries occurred in lower extremities (32.2%), hands, wrists, and digits (32.2%), and other (17.0%).

Table 2: Frequency characteristics of aquaculture farms in the United States and British Columbia, Canada, stratified by severity level (N= 137)[c]

Variables	Less Severe Injury (N=78)		Severe Injury (N= 59)		Total (N=137)		P-value
Type of Aquaculture Production[d]	N	%	N	%	N	%	
Single fish production	55	70.51	40	67.80	95	69.34	0.58
Multiple fish production	19	24.36	13	22.03	32	23.36	
Unclassified	4	5.13	6	10.17	10	7.30	
Number Aquaculture Production Processes							
1 to 2	16	20.51	16	27.12	32	23.36	0.27
3 to 4	19	24.36	9	15.25	28	20.44	
5 or greater	36	46.15	24	40.68	60	43.80	
Unclassified	7	8.97	10	16.95	17	12.41	
Production Technology							
Tank							0.55
No	33	42.31	28	47.46	61	44.53	
Yes	45	57.69	31	52.54	76	55.47	
Pond							
No	37	47.44	22	37.29	59	43.07	0.23
Yes	41	52.56	37	62.71	78	56.93	
Raceway				0.00			
no	30	38.46	34	57.63	64	46.72	0.03
Yes	48	61.54	25	42.37	73	53.28	
Aquaculture Farm Only							
No	12	15.38	17	28.81	29	21.17	0.16
Yes	37	47.44	23	38.98	60	43.80	
Unclassified	29	37.18	19	32.20	48	35.04	
Total Farm Production Acres Owned/Leased							
≤116 acres	31	39.74	18	30.51	49	35.77	0.37
>116 acres	26	33.33	19	32.20	45	32.85	
Unclassified	21	26.92	22	37.29	43	31.39	

Table 2 Continued: Frequency characteristics of aquaculture farms in the United States and British Columbia, Canada, stratified by severity level (N= 137)[c]

Variables	Less Severe Injury (N=78)		Severe Injury (N= 59)		Total (N=137)		P-value
Mechanism of Cause[d]							
Parts and materials	14	17.95	19	32.20	33	24.09	<.0001
Person, animal, plant[a]	4	5.13	11	18.64	15	10.95	
Fell, slip, trip on structure or surface	19	24.36	11	18.64	30	21.90	
Containers, furniture, fixtures, and vehicles	10	12.82	6	10.17	16	11.68	
Tools, Instruments, and equipment	1	1.28	7	11.86	8	5.84	
Other	19	24.36	2	3.39	21	15.33	
Unclassified	11	14.10	3	5.08	14	10.22	
Body Part Affected[d]							
Head	6	7.69	4	6.78	10	7.30	<.0001
Upper extremities	13	16.67	7	11.86	20	14.60	
Lower extremities	11	14.10	19	32.20	30	21.90	
Hands, wrists, digits	8	10.26	19	32.20	27	19.71	
Other	40	51.28	10	16.95	50	36.50	

[a] Person, animal, plant includes injuries caused by an individual, animal such as snakes, and plants such as poison ivy or thorns from plants.
[b] Parts and materials include injuries caused by heavy metal ramps, galvanized screens, dip nets, etc.
[c] Chi-square p-values are present unless stated otherwise
[d] Fisher exact p-values presented

Table 3 presents the results from bivariate logistic regression models, which allow for the assessment of unadjusted associations. The only predictor variable that was found to have statistical significance with the outcome of a severe injury was aquaculture farms that use raceway systems [OR_c= 0.46; 95% CI: 0.23- 0.92]. In other words, injury observations that occurred on farms with raceway systems served as a protective factor against severe injuries and had a 0.46 decrease in the odds ratio of a severe injury compared to injury observations that occurred on farms without a raceway system. Aquaculture farms that were unclassified in terms of type of aquaculture production, conducted five or more processes, conducted three to four processes, unclassified in number of processes, indicated to be an aquaculture farm only, indicated the use of a pond system, and were unclassified in terms of total acres of farm land owned/leased were not statistically significant; multiple fish production, use of a tank system, unclassified in terms of being an aquaculture farm only, and farms that indicated a total farm acres greater than 116 were not statistically significant with the outcome of a severe injury.

Table 3. Bivariate logistic regression analysis of risk factors related to aquaculture farm characteristics

Risk Factor			
Type of Aquaculture Production	**Odds Ratio**	**95% Confidence Interval**	**P-value**
Single Fish Production	Reference	-	-
Multiple Fish Production	0.94	0.41 - 2.13	0.39
Unclassified	2.06	0.55 - 7.79	0.27
Number Aquaculture Production Processes			
5 or greater	Reference	-	-
3 to 4	0.47	0.17 - 1.36	0.11
1 to 2	1.50	0.63 - 3.56	0.53
Unclassified	1.43	0.44 - 4.69	0.12
Production Technology			
Tank			
No	Reference	-	-
Yes	0.81	0.41 - 1.60	0.55
Pond			
No	Reference	-	-
Yes	1.52	0.76 - 3.03	0.24
Raceway			
No	Reference	-	-
yes	0.46	0.23 - 0.92	0.03
Aquaculture Farm Only			
No	Reference	-	-
Yes	0.43	0.18 - 1.08	0.22
Unclassified	0.46	0.18 - 1.18	0.34
Total Farm Production Acres Owned/Leased			
≤116 acres	Reference	-	-
>116 acres	1.23	0.55 - 2.88	0.86
Unclassified	1.80	0.78 - 4.15	0.20

The results for the bivariate logistic regression models related to the injury event are presented in Table 4. Due to small cell values, exact logistic regression analysis was performed for both mechanism of cause and body part injured. None of the predictor variables were found to have a statistical significance associated with the outcome of a severe injury in the body part injured. However, there were a few categories that were statistically significant in mechanism of cause. The predictor variables that were statically significant include all categories with exception of injuries caused by falling, slipping, tripping on structure or surface, containers, furniture, fixtures, and vehicles, and unclassified. The magnitude of the odds ratios and 95% confidence interval for several categories in the mechanism of cause variable are quite large due to very small numbers in select categories in this variable as well as small sample size. Risk factors that were significant associated include parts and materials, person, animal, plant, and tools, instruments, and equipment. None of the risk factors among part of body injured were significant.

Table 4. Bivariate analysis for logistic regression related to injury characteristics[a]

Risk Factor	Odds Ratio	P-value	95% Confidence Interval
Mechanism of Cause			
Other	Reference	-	-
Parts and Materials	12.29	0.001	2.35 - 126.01
Person, animal, plant	22.85	<.001	3.31 - 291.78
Fell, Slip, Trip on Structure or Surface	5.33	0.06	0.97 - 55.94
Containers, Furniture, fixtures, and Vehicles	5.42	0.10	0.78 - 64.58
Tools, Instruments, and Equipment	49.98	<.001	3.98 - 999.99
Unclassified	2.52	0.61	0.25 - 34.58
Body Part Injured			
Head	Reference	-	-
Upper Extremities	0.81	1.00	0.13 - 5.33
Lower Extremities	2.53	0.36	0.48 - 15.10
Hands, wrist, digits	3.43	0.19	0.62 - 21.60
Other	0.38	0.34	0.07 - 2.20

[a] Fisher's exact confidence intervals and p-values presented.

The final multiple logistic regression model in Table 5 refers to covariates related to aquaculture farm characteristics. The final model did not have any predictors that were statistically significant; however, adjusting for all other covariates, variables such as three to four production processes [OR_a = 0.85; 95% CI: (0.31 – 2.36)] and an indicator of a raceway system [OR_a = 0.62; 95% CI: (0.26 – 1.48)] approach statistical significance. The adjusted odds ratio estimates of farms that use ponds [OR_a = 1.33; 95% CI: (0.54 - 3.27] and farms that were unclassified in number of processes [OR_a = 1.910; 95% CI: (.489 – 7.455); P=.3537] showed moderately increased adjusted odds ratio estimates.

Table 5. Final logistic regression model of risk factors related to aquaculture farm characteristics

Risk Factor	Adjusted OR	95% Confidence Interval	P-value
Number Aquaculture Production Processes			
5 or greater	Reference	-	-
3 to 4	0.85	0.31 - 2.36	0.32
1 to 2	1.39	0.57 - 3.37	0.71
Unclassified	1.91	0.49 - 7.46	0.35
Production Technology			
Pond			
No	Reference	-	-
Yes	1.33	0.54 - 3.27	0.54
Raceway			
No	Reference	-	-
Yes	0.62	0.26 - 1.48	0.29

Discussion

The purpose of this study was to determine the risk factors in aquaculture farms and injury characteristics that are associated with a severe injury outcome. When reviewing the main findings in this study, farms that use ponds had greater percentage of severe injuries (63.8%) compared to less severe (51.9%) and farms that use one to two aquaculture production processes had a greater percentage of severe injuries (27.1%) compared to less severe injuries (20.5%). The final logistic regression model indicates these aquaculture farm characteristics may be risk factors associated with a severe injury event although are not statistically associated.

Adjusting for additional covariates, the odds ratio of a severe injury among observations that work on farms that conduct three to four production processes have a more protective effect against severe injuries. The adjusted odds ratio of three to four production processes was 0.85 [95% CI: 0.31 – 2.36] compared to observations that occurred on farms that conduct five or greater production processes. Adjusting for additional covariates, the odds ratio of a severe injury among observations that work on farms that use raceway systems also have a more protective effect against severe injuries. The farms that use raceway systems indicated an adjusted odds ratio of 0.62 [95% CI: 0.26 – 1.48] compared to farms that do not use raceway systems. However, adjusting for other covariates, the odds ratio of a severe injury among observations that work on farms that use pond systems have a greater odds ratio for severe injuries. The farms that use pond systems indicated an adjusted odds ratio of 1.33 [95% CI: 0.54 – 3.27] compared to farms that do not use ponds. Perhaps these results indicate that farms that use more advanced technology and are more automated are less likely to have a severe injury event occur. Previous published literature has stated that ponds pose a risk of snake bites, crabs attacks, and bites from fish as potential hazards (Erondu & Anyanwu, 2005). Along with these hazards previous literature has also indicated that the primary cause of pond related fatalities is due to tractor overturns on steep levees or soft pond banks (Myers, 2009). Advanced systems would more likely have built-in control hazards that prevent severe injuries from occurring. The type of hazard can vary based on the type of technology being used on aquaculture farms. Many farms in this dataset use more than one type of technology, the most common systems are raceways and pond systems in the Southeast region of the United States (Myers, 2012).

There were also some notable observations in the prevalence of severe injuries for mechanism of injury and body parts injured. Categories such as parts and materials, person, animals, or plants, tools, instruments, or equipment, injured hands, wrists, or digits, and lower extremities were noted to be higher in comparison to less severe injuries in the same categories. The most common body parts injured were lower extremities (21.9%), hands, wrists, and digits (19.7%), and other (36.5%). The most common mechanism of causes overall included parts and materials (24.1%), falls, slips, trips on structure or surface (21.9%), and other (15.3%). These differences resulted in large odds ratio results but the direction of magnitude and comparison between categories within the mechanism of causes and body part injured by injury does show which categories have a greater or less probability of a severe injury outcome. Previous literature studies have also shown that one of most common body parts injured are hands, wrists, digits in industries that relate commercial fishing (Marshall, 2004). Injuries to hands, wrists, and digits were considered the second most common in this study. The mechanism of cause variable showed similar results to previous literature studies as well. A similar study in Norway showed that the most common mechanism of causes where due to machinery (20%), other (24%), and slips and trips (18%) (NLA, 2001). This study provides insight as to what tasks and operations are more likely to introduce a severe injury event and can suggest targeted interventions towards specific farms that have risk factors that are more likely to introduce a severe injury.

Limitations

The limitations of this study include presence of recall bias since the original survey relies on the accuracy of answers provided by farmers and farm managers. The original survey asked for any injuries that ever occurred on the farms and these observations date back as far as 1971. Some interviewees are less likely to recall pertinent information with regards to the type of injury, mechanism, and body part injured in past years. Recall bias can negatively impact the results of the study in terms of validity. Perhaps limiting responses to injuries that were most severe in the past few years could minimize the effect recall bias.

The original study design is cross-sectional; therefore, no causal relationships can be inferred due to only obtaining prevalent injury cases as opposed to incident cases. Another limitation of this study includes participation bias due to convenience sampling method because there may be a difference between participants and non-participants.

A major issue with evaluating the statistical significance among mechanism of cause and body part injured by injury is the small values in several cells in the stratified analysis, which reduced the statistical significance of associations making interpretation of the impact of these two variables questionable.

There were many variables that were not collected in the original survey that have further aided in analyzing the risk factors associated with severe injury. Age, lost work days, gender, number of employees, and years of experience in aquaculture could have been useful variables to evaluate in this study. There was also the issue of variables containing large proportions of unclassified/missing data. Several risk factors indicated that these unclassified categories showed an impact in the study but are unable to be useful for understanding why these impacts occur. Lastly, misclassification bias is possible due to the limiting amount of information given by each injury case. Misclassification can lead to overestimation or underestimation of the odds ratio. From the description of the injuries, new variables had to be created which may allow for misclassification among the exposure and outcome.

Future Directions

Future research must focus on collecting additional variables that could potentially further explain the outcome of severe or any injury on aquaculture farms. There would need to be more variable and larger variable to improve the analyses. No variables in the model to assess the risk factors associated to severe injury were not statistically significant. The best recommendation for future studies is to design a cross sectional survey to capture information about general aquaculture farm characteristics, employee characteristics, and injury characteristics. Other research topics that could be assessed in this dataset include comparing close call injuries to actual injury events. The research question in this comparison would evaluate potential risk factors that are associated with the outcome of any injury. Lastly, comparing NIOSH recommended fish safety practices with farmers proposed safety practices could provide insight into the gaps in safety interventions being implemented.

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