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Occupational traumatic injuries among offshore seafood processors in Alaska, 2010-2015

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Abstract

Introduction: The US Coast Guard and Federal Occupational Safety and Health Administration have identified the Alaskan offshore seafood processing industry as high-risk. This study used Coast Guard injury reports to describe patterns of traumatic injury among offshore seafood processors, as well as identify modifiable hazards.

Methods: From the reports, we manually reviewed and abstracted information on the incident circumstances, injury characteristics and circumstances, and vessel. Traumatic injury cases were coded using the Occupational Injury and Illness Classification System, and a Work Process Classification System. Descriptive statistics characterized worker demographics, injuries, and fleets.

Results: One fatal and 304 nonfatal injuries among processors were reported to the Coast Guard during 2010–2015 across multiple fleets of catcher-processor and mothership vessels. The most frequently occurring injuries were: by nature of injury, sprains/strains/tears (75, 25%), contusions (50, 16%), and fractures (45, 15%); by body part affected, upper extremities (121, 40%) and trunk (75, 25%); by event/exposure resulting in injury, contact with objects and equipment (150, 49%), and overexertion and bodily reaction (76, 25%); and by source of injury, processing equipment and machinery (85, 28%). The work processes most frequently associated with injuries were: processing seafood on the production line (68, 22%); stacking blocks/bags of frozen product (50, 17%); and repairing/maintaining/cleaning factory equipment (28, 9%).

Conclusions: Preventing musculoskeletal injuries, particularly to workers' upper extremities and trunks, is paramount. Some injuries, such as serious back injuries, intracranial injuries, and finger crushing or amputations, had the potential to lead to disability.

Practical Applications: Safety professionals and researchers can use the study findings to inform future intervention efforts in this industry. Hazard control measures should target: (a) overexertion from lifting and lowering objects and equipment; (b) equipment and boxes falling and

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striking workers; (c) workers being caught in running machinery during regular operations; and (d) slips, trips, and falls.

Keywords

Fish processing; Food manufacturing; Worker safety

1. Introduction

Offshore seafood processors work in a demanding environment that combines the occupational safety and health challenges faced in the commercial fishing and food manufacturing industries. The US seafood processing industry comprises onshore establishments and vessels operating at sea that engage in the following activities: eviscerating fresh fish by removing heads, fins, scales, bones, and entrails; shucking and packing fresh shellfish; processing marine fats and oils; smoking, salting, and drying seafood; canning seafood; and freezing seafood (NAICS, 2017). Two types of vessels engage in extensive seafood processing. Catcher-processors have the capacity both to harvest seafood using various types of gear on deck, and then to process, package, and freeze the catch in a factory below deck. Processor vessels – also known as floating factories or "motherships" – receive the catch that is harvested by other vessels and then process, package, and freeze it. Vessels' specific processing and packaging activities, seafood products (e.g., fillets, surimi, roe), and crew sizes vary by fleet. Fleets are groups of vessels that operate in the same geographic region, fish for and/or process the same species, and use the same type of gear (e.g., trawl, longline, pot). Only US-flagged vessels are permitted to participate in fisheries within the US Exclusive Economic Zone, which extends up to 200 nautical miles offshore (NOAA, 2017a). The American Fisheries Act of 1998 (46 CFR Part 356) further limits foreign involvement in US fisheries and stipulates that US citizens must retain 75% ownership and control of these vessels (MARAD, n.d.).

In Alaska, processing seafood is a critical step in the supply chain that brings this valuable natural resource to market. During 2015, Alaskan fishermen harvested the majority of the nation's seafood, at 6 billion pounds, and generated the largest portion of the national revenue, at $1.7 billion, with subsequent processing adding value to the product (NMFS, 2016). That year, Alaska's Division of Environmental Health approved seafood processing permits for 87 vessels that had the capability to process over 5,000 lb of seafood per day (Alaska Division of Environmental Health, 2017). Approximately 3,500 people worked onboard these catcher-processors and motherships, with only 6% being Alaska residents (Alaska Department of Labor, 2017). Working onboard these vessels in Alaska is difficult, requiring physical and mental endurance. When recruiting employees, companies describe how the vessels operate in remote locations, are wet, cold, and noisy environments, and the living conditions at sea are cramped. They explain that processors' work shifts are long, and tasks typically monotonous, with prolonged periods of standing, repetitive movements, and heavy lifting. Their photographs show processors wearing personal protective equipment such as: slip-resistant boots; waterproof pants, overalls, and jackets; gloves of various materials (depending on task); hearing protection; safety glasses; and hard hats (Glacier Fish

Company, 2017; Premier Pacific Seafoods, 2017; Signature Seafoods, 2017; Trident Seafoods, 2017).

The US Coast Guard and Federal Occupational Safety and Health Administration (OSHA) share jurisdiction over regulating worker safety and health onboard catcher-processors and motherships in Alaska, with OSHA's jurisdiction extending to 'uninspected vessels' under 5,000 gross tons when operating within 3 nautical miles from the coastline (OSHA, 2010). Both agencies have identified offshore seafood processing as high-risk. Coast Guard regulations for processing vessels are more stringent than regulations for vessels that only harvest the catch, including classification and load line requirements (USCG, 2009). Factors that increase the safety and operational risks to fleets that engage in extensive processing activities within a factory include: having sizeable crews; utilizing processing and freezing machinery; using hazardous gases in refrigeration systems; and having the ability to freeze and store the catch, allowing crews to operate in remote areas that are far from search and rescue support (USCG, 2006). For all fleets, the Coast Guard's fatality prevention activities focus on emergency preparedness. OSHA determined that offshore seafood processing was a high-hazard industry in Alaska and therefore developed a Local Emphasis Program (LEP), which is an enforcement strategy to address hazards that pose a particular risk to workers (OSHA, 2017a). The LEP has been in effect for over a decade and established policies and procedures for regularly-programmed inspections (OSHA, 2016). OSHA's activities focus on preventing fatal and nonfatal injuries and illnesses among offshore processing workers.

Working offshore presents unique risks, including the potential for vessel disasters and falls overboard. Risks vary by vessel and fleet. In July 2016, the F/V Alaska Juris, an aging freezer-trawler built in the 1970s, sank in the Bering Sea more than 126 miles west of Adak, putting at risk the lives of 46 crewmembers, who successfully abandoned ship and were rescued (NTSB, 2017). Recently, a report assessed vessel disasters and fatalities due to traumatic injury during 2002–2014 in the Bering Sea/Aleutian Islands Pollock fleet (AFA fleet), which includes catcher vessels, catcher-processors, and motherships. Among the processor crewmembers, two fatal falls overboard in Alaskan waters occurred in 2003 and 2007. In terms of fatality and vessel disaster frequency, this fleet was found to be among the safest as compared with other Alaskan fleets. However, the report also found that future research was necessary to identify safety hazards related to nonfatal injuries (Case et al., 2017). Nonfatal injuries and illnesses constitute the vast majority of workplace incidents and can be severe, resulting in lowered productivity, lost worktime and wages, lowered quality of life, and disability.

Working in a factory to manufacture food presents additional risks. Hazards in the onshore seafood processing industry include exposures to: bioaerosols containing allergens, microorganisms, and toxins; bacterial and parasitic infections; excessive noise levels; low temperatures; poor workplace organization; poor ergonomic practices; and contact with machinery and equipment (Jeebhay et al., 2004). Risk factors for musculoskeletal disorders in this industry include: highly repetitive and forceful upper extremity movements; localized mechanic stress; awkward and/or static postures at workstations; prolonged standing; and temperature extremes (Aasmoe et al., 2008; Kim et al., 2004; Nag et al., 2012; Ólafsdóttir & Rafnsson, 2000; Quansah, 2005). Recent studies of onshore seafood processing in

Washington State and Oregon have shown high rates of accepted workers' compensation claims in this industry compared to others (Anderson et al., 2013; Syron et al., 2017).

Few occupational safety and health studies of the Alaskan commercial fishing industry have discussed nonfatal injuries and illnesses among processors (Beaudet et al., 2002; Neitzel, 2006; Lucas et al., 2014; Syron et al., 2016; NIOSH, 2016a). To date, no epidemiologic study has focused solely on offshore processors across the multiple catcher-processor and mothership fleets in Alaska. This study's objectives were to determine patterns of traumatic injury characteristics and circumstances among offshore seafood processors working in Alaskan waters during 2010–2015, as well as identify modifiable hazards. The long-term goal of this research is to inform injury prevention strategies.

2. Methods

2.1. Case Definition

Companies that operate commercial fishing industry vessels are legally required to report to the Coast Guard any "injury that requires professional medical treatment (treatment beyond first aid) and, if the person is engaged or employed on board a vessel in commercial service, that renders the individual unfit to perform his or her routine duties" (Code of Federal Regulations, Title 46, Section 4.05–1). Companies use the "CG-2692 Report of Marine Casualty" form to document the details of incidents, including writing a narrative description of what occurred (USCG, 2016). This study included all cases of fatal and nonfatal traumatic injuries among seafood processors working in Alaskan waters during 20102015 that were reported to the US Coast Guard. A traumatic injury was defined as: "any wound or damage to the body resulting from acute exposure to energy… caused by a specific event or incident within a single workday or shift" (BLS, 2016). Not included in this study were disorders resulting from cumulative trauma (e.g., carpal tunnel syndrome, repetitive motion strains, and noise-induced hearing loss) or illnesses (e.g., infections, heart attacks, and diabetes-related complications). Offshore seafood processors were considered at work and exposed to potential hazards any time while at sea, even if they were off duty. Processors complete tasks in the factory and freezer, as well as offloading the frozen product from the vessel once it returns to shore. Workers onboard catcher-processor vessels sometimes perform a combination of tasks related to both harvesting and processing the catch. For this study, if "combination" workers were injured while performing deckhand duties related to harvesting the catch, then they were not included as cases.

2.2. Data Sources

The National Institute for Occupational Safety and Health (NIOSH) Western States Division manages the Commercial Fishing Safety Research and Design Program. This program's ongoing surveillance activities include collecting data on fatal traumatic injuries and vessel disasters in the US commercial fishing industry. The only circumstance under which nonfatal traumatic injury data are collected as part of the program's routine surveillance is when nonfatal injuries occur during vessel disasters (i.e., not during regular operations). The Commercial Fishing Incident Database (CFID) houses data on these fatalities and vessel disasters. Data on fatal traumatic injuries were obtained from this database (CFID, 2017).

For this study, NIOSH and Oregon State University collaborated on data collection on all reported nonfatal traumatic injuries – including those occurring during regular operations. NIOSH and the Coast Guard have a memorandum of agreement which allows NIOSH to utilize information collected by the Coast Guard for safety and health research (USCG, 2014). For this study, the research team manually reviewed the Coast Guard reports of nonfatal incidents – both brief notifications and full investigations – to identify cases of nonfatal, traumatic injuries in any Alaskan fleet and among all crewmembers (e.g., captains, deckhands, engineers, processors, etc.). The only way to determine the crewmembers' position was to manually review all reports. Relevant information from the reports was abstracted, coded, and manually entered into a study database. Cases that met the study's inclusion criteria (i.e., traumatic injuries among processors) were included for analysis.

The NIOSH Institutional Review Board (IRB) determined that this study did not require review because it involved surveillance (NIOSH IRB no. 17-WSD-04D). Likewise, the Oregon State University IRB reviewed this study and determined it to be exempt from full board review, because data abstraction from existing sources did not include abstracting personally identifying information (study number 6386).

2.3. Measures

The data collected for each case included: incident circumstances (date, geographic location, vessel activity, fishery); worker demographics (age, sex, job title, years of experience); injury characteristics and circumstances (nature, body part, event/exposure, source, work process, severity, injury response); and the vessel characteristics (vessel type, gear type, fleet).

The Occupational Injury and Illness Classification System (OIICS) was used to code the nature of injury, body part affected, and the event/exposure resulting in injury (BLS, 2012). For NIOSH's research on the commercial fishing industry and for this study, the standard OIICS rules for selecting event/exposure codes were slightly modified, so that cases which would typically be coded as "water vehicle incidents" were instead assigned codes that more precisely described the incident that occurred on the vessel. For instance, a crewmember falling onboard the vessel would be coded in the relevant "falls/slips/trips" subcategory, rather than as a "water vehicle incident." Additionally, rather than using the standard OIICS codes for the source of injury, which were developed for use across multiple industries, NIOSH researchers have developed a list of source codes that apply specifically to the commercial fishing industry. Typically, according to OIICS rules, when events are coded as "water vehicle incidents" the corresponding source code must be "commercial fishing vessel." Instead, the NIOSH source codes specify which gear, equipment, structures, environments, etc., were involved. NIOSH researchers expand the list of source codes as data are collected and new sources identified. NIOSH's source codes were utilized in this study.

Injury severity was coded with the severity scale that is utilized by Coast Guard investigators in their reports, which is an adaptation of the Abbreviated Injury Scale (AIS) (USCG, 2012). The Coast Guard severity scale contains the same levels and general definitions as AIS (minor, moderate, serious, severe, critical). However, it has some modifications, and allows

for coding cases that lack clinical diagnosis information, which is typical for the Coast Guard reports on nonfatal incidents (see Appendix A). When sufficient information was available in the reports to code severity, each case was assigned a single severity score. If multiple injuries of different severities were sustained during a single event, then the case was coded with the highest severity score (e.g., an event involving a lacerated hand and fractured arm would be coded with the higher severity corresponding to the fracture).

The work task at the time of injury (i.e., 'work process') was determined by reviewing narrative descriptions of the incident in the Coast Guard reports. When possible, each case was assigned a code from NIOSH's Work Process Classification System (WPCS). The purpose of this classification system is to identify occupational injury causes and specific hazards in each commercial fishing fleet. The WPCS was originally developed and pilot tested in Danish fleets by Jensen et al. (2003, 2005 & 2006) and has been modified for use in US fleets (Lucas et al, 2014.; Case et al., 2015; Syron et al., 2016). During data collection for national surveillance, NIOSH researchers utilize the modified WPCS, and develop codes as needed, when additional work processes associated with traumatic injuries are identified in various US fleets.

Vessel type and fleet were coded using information from Coast Guard reports and publiclyavailable databases. Coast Guard reports included the following information about the vessel: (a) name; (b) official number; (c) length; and (d) type. Vessels of any fleet that had the capability to harvest and process seafood were classified as 'catcher-processors.' Vessels of any fleet that only processed seafood (i.e., 'floating factories') were classified as 'motherships.' The Coast Guard report narrative descriptions oftentimes described the vessel's gear type and/or the seafood species that was being targeted and/or processed onboard the vessel. If the report did not provide sufficient information to code the fleet, then the vessels' name, official number, and length, as well as the date and location, were used to collect additional information from permit databases. These included the State of Alaska's Commercial Fisheries Entry Commission search engine, which provided permit and vessel records (CFEC, 2017), as well as the National Oceanic and Atmospheric Administration's Alaska Regional Office's lists of permits and licenses (NOAA, 2017b). Alaskan fleets were coded using categories from commercial fishing workforce estimates data produced by Natural Resources Consultants Inc. (NRC, 2013).

2.4. Analysis

Descriptive statistics, including frequency, percent distributions, and cross-tabulations, were calculated in Stata version 14.2 (StataCorp, 2015) to determine injury patterns and characteristics. For clarity and concision in reporting the injury characteristic and circumstance in the Results section, detailed OIICS and WPCS code names were oftentimes slightly modified from the original system. This process involved: (a) collapsing multiple detailed codes into a more general main category, (b) creating a new main category for a single detailed code that occurred frequently, or (c) slightly renaming codes to match language that is commonly used in the industry.

3. Results

During 2010–2015, one fatal and 304 nonfatal injuries were reported to the US Coast Guard among offshore seafood processors working in Alaskan waters. No injuries were attributed to vessel disasters or falls overboard. The single fatal injury that met the study's inclusion criteria occurred in 2010 and involved the worker becoming wedged between a conveyor belt and a wall in the freezer hold causing mechanical asphyxia. The 304 nonfatal injuries are described in the following sections.

3.1. Incident Characteristics

During the 6-year study period, an average of 51 nonfatal injuries were reported each year, ranging from a high of 56 injuries in 2010, to a low of 44 injuries in 2012. The vessel's latitude and longitude at the time of injury were reported for 267 cases (88%). The median distance from shore was 33 miles (0–264 miles). Almost all of the injuries occurred onboard the vessel, with only two injuries occurring while workers were at the dock. Vessel activity was reported for 216 cases (71%), with the vessel's activity including fishing (104, 48%), transiting between shore and fishing grounds (44, 20%), being anchored (38, 18%), and being moored (30, 14%). Vessel type could be identified for all cases, with 75% of reported injuries occurring on catcher-processors of any fleet and 25% on motherships.

3.2. Worker Demographics

Gender was reported for almost all nonfatal injury cases, with the vast majority (97%) involving men and only 10 cases involving women. Age was reported for 249 cases (82%), with a median age of 31 years (18–63 years). The amount of work experience in this industry was reported for 225 cases (74%), with the median amount of experience being 2 years (0–29 years). Of those cases reporting years of experience, 32% of the workers had less than a year of experience. Coast Guard reports rarely included information on crewmembers' race or ethnicity.

3.3. Injury Characteristics

The nature of injury and body part injured could be coded for all cases. Table 1 presents the cross-tabulation of the nature of injury and the broad-category body part affected. Of injuries to the upper extremities, the majority were to hands and fingers (85, 70%). Of the injuries to the trunk, most involved the back (51, 68%). Of injuries to the lower extremities, almost half were to the legs (24, 44%). By nature of injury, almost a third of the injuries to the upper extremities involved fractures (35, 29%), followed by lacerations/punctures (26, 21%) and amputations (16, 13%). These upper-extremity amputations mainly involved fingertips and entire fingers; however, two incidents involved workers' hands. Half of the injuries to the trunk involved sprains/strains/tears (38, 51%). Likewise, many of the injuries to the lower extremities involved sprains/strains/tears (22, 41%). Among head injuries, almost half were intracranial injuries (16, 43%). Intracranial injuries were caused primarily by boxes and bags of frozen product falling and striking processors, as well as processors themselves falling and striking their heads. A single incident involving an ammonia line leaking onboard a vessel resulted in the three poisoning cases, with the entire crew being evacuated.

3.4. Injury Circumstances

The event/exposure that resulted in injury and the source of injury could be coded for all cases. Table 2 presents the cross-tabulation of the injury source and the broad-category event/exposure resulting in injury. Of the cases involving contact with objects and equipment, the most frequent events were workers being struck by falling objects or equipment (50, 33%), being caught in running machinery during regular operations (22, 15%), and being compressed or pinched by shifting objects and equipment (17, 11%). Of the cases involving overexertion and bodily reaction, one-third involved overexertion from lifting and lowering (28, 36%). Of the cases involving slips/trips/falls, over half were falls on the same level (35, 54%), followed by falls to a lower level (14, 22%), and slips/trips without falls (12, 18%). By source, freezer pans constituted over half the cases involving processing equipment/machinery (45, 53%). Vessel was coded as the source of injury for slips/trips/falls from vessel surfaces. The majority of slips/trips/falls occurred in the factory (27, 42%) or the freezer (20, 29%), with a few cases occurring on deck (5, 8%) and other locations around the vessel.

Workers' location onboard the vessel at the time of injury could be determined for most of the cases (272, 89%), with over half occurring in the factory (161, 59%), followed by the freezer (98, 36%), holds (7, 3%), and on deck (6, 2%). Rough seas were reported as a contributing factor for seven cases. In four cases, the vessel movement resulted in workers losing their balance in the factory, on deck, and in the fishmeal hold. In three cases, the vessel rolling caused processing equipment and freezer pans in the factory to fall onto workers.

3.5. Work Process Associated with Injury

The work process associated with injury could be coded for the vast majority of cases, with only six cases lacking sufficient information in the narrative description. Table 3 presents the cross-tabulation of the work process by the general-category event/exposure resulting in injury.

Processing the catch (also known as working on the "slime line") accounted for almost a quarter of injuries. Of these cases, roughly half of the narrative descriptions did not specify the exact processing task. For cases in which detailed information was available, the most frequently occurring tasks were "heading the catch" (10), "counting/sorting the catch" (7), "packing fish in pans" (6), and "cleaning the catch" (3). On the slime line, the pieces of equipment most frequently involved were conveyor belts and header blades. Of the seven cases involving exposure to harmful substances while on the slime line, three involved an ammonia leak incident, two involved exposure to boiling water, and two involved fish slime and scales getting into workers' eyes.

Stacking blocks/bags of frozen product was the second-most frequently occurring work process associated with injury. While stacking the frozen product, almost half of workers' injuries resulted from contact with objects and equipment – mainly boxes of frozen fish striking workers. The majority of overexertion/bodily reaction cases associated with this work process involved strains, with a few cases involving twisted knees and ankles.

Repairing, maintaining, and cleaning the factory equipment was the third-most frequently occurring work process associated with injury. During repair, maintenance, and cleaning, workers were frequently caught in or compressed by the processing machinery (9) or conveyors (3). While cleaning factory equipment, facial injuries – particularly to the eyes – resulted from chemical exposures (6).

3.6. Injury Severity

Injury severity could be coded for all but eight cases. Table 4 presents a cross-tabulation of injury severity and work process. The Abbreviated Injury Scale is an anatomical-based coding system and the US Coast Guard's adapted system provided levels of treatment corresponding to the severity categories. Minor severity cases (158, 53%) did not require professional medical treatment (e.g., minor lacerations, bruises, or strains/sprains). Moderate severity cases (116, 39%) might have required professional treatment (e.g., broken or amputated fingers or toes, dislocated joints, or severe strains/sprains). Serious severity cases (22, 8%) might have required significant medical/surgical treatment (e.g., broken or partially amputated limbs). None of the nonfatal injury cases were severe or critical. All of the work processes associated with injury had a range of injury severity scores. The following work processes included cases with serious injury severity scores: processing the catch on the slime line (6); stacking blocks/bags of frozen product (4); repairing/maintaining/cleaning factory equipment (4); removing frozen product from conveyors/slides (2); cleaning up the vessel (2); cracking freezer pans (1); and bagging frozen product (1).

3.7. Injury Response

The crew's response to an injury was reported infrequently, for only 60% of cases. Of these cases, most responses involved the injured worker initially being treated on the vessel, and then either seeking treatment at a clinic later (68, 37%), continuing work (59, 33%), or returning home (9, 5%). In some instances, the vessel was moored and the injured worker could be treated at a clinic right away (21, 12%). Other times, the vessel was out at sea and returned to shore immediately so that the injured worker could receive advanced medical treatment (16, 9%). Eight cases (4%) required Coast Guard medical evacuation.

3.8. Injury Reporting to US Coast Guard by Vessel and Fleet

During the 6-year study period, 60 vessels reported at least one nonfatal injury to the Coast Guard. The number of reported injuries varied greatly by vessel. Among the 60 vessels, the number of injuries reported during the study period ranged from 1 to 31 injuries, with 10 vessels reporting 10 or more injuries. The reports from these 10 vessels constituted half of all cases in the study. It is unknown if this variation in reporting reflects an actual variation in how many injuries occurred on each vessel (which could be influenced by the crew size), or if reporting practices simply vary by vessel. For example, there could potentially be either (a) under-reporting of actual injuries, or (b) over-reporting of very minor incidents that do not technically meet the Coast Guard's minimum threshold for reporting.

The number of reported injuries varied by fleet as well. Fleet could be determined for all but one case. These vessels were built between the 1930s and 2010s, with the majority being built in the 1970s (13 vessels) and 1980s (20 vessels). Almost half of the cases were reported

in the Bering Sea/Aleutian Islands (BSAI) Pacific Cod and Other Groundfish Freezer-Trawl fleet (132, 43%), followed by the BSAI Pollock Freezer-Trawl fleet (58, 19%), the state-wide Multi-Species Mothership fleet (48, 16%), the BSAI Pacific Cod Freezer-Longline fleet (39, 13%), and the BSAI Pollock Mothership fleet (26, 9%). Natural Resource Consultants Inc. provided estimates of how many vessels operated in each fleet. Based on these estimates, it was possible to determine how many vessels in each fleet reported at least one injury during the study period. All of the vessels in the small Pollock Mothership fleet reported at least one injury, as did almost all of the vessels in the Pollock Freezer-Trawl fleet. Approximately 60% of the vessels operating in the larger Pacific Cod and Other Groundfish Freezer-Trawl fleet and Pacific Cod Freezer-Longline fleet reported at least one injury. One-quarter of the vessels in the Multi-Species Mothership fleet reported at least one injury.

4. Discussion

This is the first epidemiologic study to characterize patterns of traumatic injuries and identify modifiable hazards among offshore seafood processors working across multiple Alaskan fleets. During 2010–2015, one fatal and 304 nonfatal traumatic injuries were reported to the US Coast Guard. The fatal injury due to mechanical asphyxia highlights the potential danger of working in freezer holds around conveyor systems. Among the nonfatal injuries, severity ranged from minor to serious, with many cases resulting in lost work time and requiring advanced medical treatment. The detailed results presented in this study could inform injury prevention strategies and future research efforts in this industry.

4.1. Nonfatal Injury Characteristics

The majority of reported injuries occurred among men, with at least a quarter of all injured processors having less than a year of experience in the industry. Further research is needed to estimate workforce demographics and turn-over rates in this industry, in order to calculate injury rates by gender and work experience, and thereby determine if these characteristics are associated with higher risk of injury.

Sprains, strains, and tears, which frequently occurred in both the trunk and extremities, constituted a quarter of all injuries. Main contributors to these injuries were overexertion from handling boxes of frozen fish and using processing equipment and machinery. Processors' upper extremities – especially hands and fingers – often experienced fractures, lacerations/punctures, crushing, and amputations. Serious back injuries, as well as finger and thumb crushing and amputations, may have resulted in long-term disability. Of special concern were the head injuries, almost half of which were intracranial injuries.

These results, which demonstrate the importance of preventing sprains, strains, and tears, as well as preventing various types of injuries to upper extremities, are consistent with prior research. A recent study of Oregon workers' compensation disabling claims in this industry found that, (a) by nature, incidents most frequently involved traumatic injuries to muscles, tendons, ligaments and joints – primarily to the trunk and upper extremities; and (b) by body part, workers' upper extremities were most frequently injured, including open wounds and musculoskeletal disorders (Syron et al., 2017). Over the past 25 years, musculoskeletal

symptoms and disorders, particularly to the upper extremities, have been described in various studies of onshore seafood processing (Aasmoe et al., 2008; Babski-Reeves & Crumpton-Young, 2003; Chiang et al., 1993; Kim et al., 2004; Nag et al., 2012; Ohlsson et al., 1994; Ólafsdóttir & Rafnsson, 2000; Silverstein et al., 1998). For offshore seafood processing specifically, previous studies of traumatic injuries among all commercial fishermen (deckhands, engineers, captains, processors, etc.) have not specified the patterns of injuries by nature and body part among the injured processors. However, two studies of the Alaskan commercial fishing industry have identified similar types of injuries and hazards as those found here. These include: (a) processing tasks being responsible for most of the lacerations, punctures, avulsions, amputations, and poisonings among all crewmembers, with the most frequent causes including being caught in running processing equipment and slipping knives (Lucas et al., 2014); and (b) tasks involving handling frozen fish resulting in sprains, strains, tears, and fractures, and tasks involving hands-on processing resulting in lacerations, punctures, amputations, and fractures (Syron et al., 2016).

The injury patterns identified in this and other studies of the seafood processing industry are similar to those found in the poultry processing industry. In both industries, facilities are designed for rapid line production and then movement of the packaged product for storage and transport, all of which involves strenuous and repetitive manual labor. Poultry processors are at high-risk for musculoskeletal injuries and disorders, particularly in the upper extremities (Cartwright et al., 2012; NIOSH, 2015; OSHA, 2013; Quandt et al., 2006).

4.2. Practical application: nonfatal injury circumstances and potential prevention strategies

Offshore seafood processors faced hazards while working in factories and freezers, as well as moving throughout the vessel, both on- and off-duty. Injury prevention strategies should target the work processes and events that are associated with the most frequently-occurring and severe injuries. When deciding upon and implementing hazard controls, the hierarchy of controls should be followed, with elimination of hazards and engineering controls favored over administrative controls and personal protective equipment, in order to provide the most effective protection (NIOSH, 2016b).

As expected, seafood processors most frequently experienced injuries while completing processing tasks on the “slime line” in the factories. By severity, the largest number of serious injuries occurred during this work process as well. Hazards on the slime line ranged from contact with conveyors and header machines, to overexertion, and falls, slips, and trips. Following lockout procedures could potentially prevent injuries due to contact with machinery and conveyors during cleaning and maintenance (Jensen Maritime Consultants, n.d.). Ergonomic solutions that have been successfully utilized in other food manufacturing industries, such as poultry processing, to avoid overexertion and musculoskeletal injuries could potentially be translated to this factory setting, with interventions tailored to the unique work processes. Potential engineering controls could include: (a) adjusting workstations and standing work surfaces to fit the worker height and the angle of the tasks being performed; (b) arranging work stations so that any lifting is done in front of workers without twisting; and (c) utilizing mechanical devices that tilt or invert containers in order to

reduce manual removal of products. Administrative controls could include: (a) performing routine and preventive maintenance to assure that equipment is working properly; (b) allowing employees pauses to rest fatigued muscles, as well as breaks in warmer areas of the vessel; (c) designing job rotation schedules between different tasks to "reduce exposure to any single risk factor and to allow body parts to either rest completely, work at slower rates, use less force, or work in more neutral postures" (OSHA, 2013; OSHA 2017b). The extent to which working long hours over extended periods might contribute to musculoskeletal injury is an area for further research.

While stacking the frozen product, processors were frequently struck by the boxes and bags. This also occurred while removing boxes of frozen product from conveyors/slides, and then offloading them once the vessels returned to shore. To prevent workers from being struck by frozen boxes and bags of product, engineering controls should be utilized in areas in which the product is stored and moved. These work processes were also associated with injuries due to overexertion. Various strategies are available to prevent injuries from manual handling and repetitive motion: (a) reduce the size and weight of the load, by reducing packaging sizes, or by workers sharing the load; (b) when possible, rotate work tasks; and (c) adjust or design work heights to reduce working with the back bent and allow for elbows to stay close to the body (SHARP, 2001). Hiring ergonomists and safety engineers to help redesign factories and holds in order to improve the safety of material handling processes is a more effective control measure than *only* utilizing administrative controls, such as training workers to use safe material handling techniques.

The concept of "prevention through design" involves eliminating hazards as early as possible in the life cycle of equipment and workplaces. Worker safety is incorporated into the design, redesign, and retrofit of new and existing tools, machinery, facilities, and work processes (NIOSH, 2013). This concept is especially relevant as new catcher-processors and motherships are designed and built, and vessels are expected to have long service careers. Historically, modernizing catcher-processor and mothership vessels through major upgrades or new builds has occurred fairly infrequently, at less than one vessel per year. The pace of modernizing, however, has increased since 2000, and this positive trend is projected to continue (McDowell Group, 2016). For example, in 2016, a Seattle company debuted a state-of-the-art freezer-longliner, the F/V Blue North, to operate in the Bering Sea/Aleutian Islands Pacific Cod fleet. The vessel was equipped with cutting-edge technology to enhance production efficiency, reduce environmental impact, and also provide a safe workplace for crewmembers:

> A size-sorting component for headed and washed fish will make packing simpler and more efficient, while automatic horizontal plate freezers increase product throughput and minimize crew needs. A semi-automatic packing line for both H-G and Shatter Pack product will also minimize labor needs in the case up area. The new vessel's factory is also fitted with a system that automatically loads product into the cargo hold elevator, which also saves labor and offers a safer way to handle the product. Finally, a full circle roundabout conveyor system in the cargo hold, with automatic in-feed into the offload elevator, makes the whole offload process easier and safer for the crew (Philips, 2015).

These designs could potentially help prevent the types of injuries identified in this study, many of which occurred while: stacking blocks/bags of frozen product; offloading the product; loading and unloading plate freezers; removing frozen product from the conveyor/slide; and bagging/casing frozen product.

Walking throughout the vessel – including areas such as the factory and freezer, which are often wet or icy – and climbing/descending ladders and stairs resulted in slips, trips, and falls. To prevent slips, trips, and falls, passageways should be kept clear of obstructions and substances/seafood should be cleaned up as frequently as possible. Given the wet nature of this work environment, proper drainage should be maintained, with appropriate gratings, mats, or raised platforms provided, and surfaces designed to increase adhesion (OSHA, 2017b).

Hazards associated with repairing, maintaining, and cleaning the factory equipment included being caught in or compressed by processing machinery and conveyors, as well as exposure to chemicals. Again, following regular maintenance and lockout procedures could potentially prevent injuries due to contact with machinery and conveyors. Cleaning product formulations that present fewer hazards to workers should be utilized when possible, and appropriate personal protective equipment should always be worn to prevent contact with the eyes and skin. A single incident involving an ammonia line leak resulted in the three poisoning cases, with the entire crew being evacuated. This event highlights the importance of following safety requirements and recommended best practices for the repair and maintenance of refrigeration systems that use ammonia and halocarbons, which have been outlined by OSHA (OSHA, 2015).

A hazard unique to the offshore environment is vessel movement caused by rough seas. This study identified cases of processors losing their balance in the factory, on deck, and in the fishmeal hold due to vessel movement, as well as vessel rolling causing processing equipment and freezer pans in the factory to fall onto processors. To the extent possible, engineering solutions should be developed to secure objects and equipment from falling or shifting suddenly. Two other hazards unique to offshore work – vessel disasters and falls overboard – were not identified as contributing to traumatic injuries. However, given that vessel disasters and falls overboard can result in fatalities, companies should require all crewmembers to wear personal flotation devices while on deck and adhere to Coast Guard regulations (NIOSH, 2017). The Coast Guard's regulatory activities cover: vessel stability; navigation; fire protection, electrical, and engineering equipment; communication systems; and emergency instructions, drills, and safety orientations, including using survival craft and cold-water immersion suits (USCG, 2009). In contrast, OSHA's regulatory activities are aimed at fatal and nonfatal injury prevention, and are relevant to many of the nonfatal injuries discussed here. Their activities cover: lockout/tagout; maintenance and repair of factory areas; onboard cranes; onboard powered vehicles; fall protection; chemical and respiratory protection; hazard communication; noise; materials handling and storage; and ergonomics (OSHA, 2010).

4.3. Limitations

Nonfatal injury rates for offshore seafood processors could not be calculated due to lack of workforce estimates by occupation in the Alaskan commercial fishing industry. Future research is needed to estimate the number of processors in each fleet. Potentially inconsistent injury reporting to the Coast Guard is also problematic when attempting to determine risk. It is likely that some vessels underreport injuries and only notify the Coast Guard of incidents that require assistance such as medical evacuation, while others report injuries that do not meet the severity threshold for what is legally required to be reported (e.g., minor lacerations that do not render the worker unfit for regular duties). In a previous study, when analyzing injury data from both Coast Guard investigative reports and the National Marine Fisheries Service Observer Survey, Lucas et al. (2014) found evidence of underreporting to the Coast Guard, with approximately 25% of injuries in the freezer-trawler fleet and 50% of injuries in the freezer-longliner fleet not having been reported to the Coast Guard. Additionally, it is possible that cumulative trauma might have contributed to some of the injuries that companies and crewmembers described as traumatic sprains, strains, and tears in the Report of Marine Casualty Forms' narrative sections. Based solely on reviewing their narrative descriptions (e.g., 'processor pulled muscle in lower back while picking up frozen cases of fish'), it was not possible for us to determine the extent to which cumulative trauma might have been a factor. In this study, a limitation of using the Coast Guard's injury severity scale (which is based on Abbreviated Injury Scale (AIS) scores that represent an injury's threat to life) is that the scale does not take into account the potential disability associated with severe nonfatal injuries. Finally, the Coast Guard's Report of Marine Casualty Form included a question about the injured crewmember's "time in the industry," but did not provide instructions on how to calculate and report years of experience in this highly-seasonal industry. Therefore, reporting practices between companies and individuals potentially could have varied. For example, a response of '2 years' experience could have signified that the crewmember had either (a) worked for 24 months total in the industry, or (b) worked for only a few months over the span of two calendar years.

4.4. Future Research

While this study investigated only traumatic injuries, musculoskeletal disorders (MSDs) and illnesses are areas of concern for seafood processors. In Alaskan catcher-processor fleets specifically, studies have found that exposure to crab allergens resulted in respiratory symptoms (Beaudet et al., 2002) and that almost all crewmembers were exposed to work shift and 24-h noise levels that exceeded the relevant limits, with the primary noise sources coming from engine room machinery and processing machinery on the factory decks (Neitzel, 2006). Future research is needed to determine the extent of illnesses and MSDs among offshore processors. An additional area for future investigation is how chronic conditions – heart disease, diabetes, etc. – might impact safety and health in this population that works in remote areas, far from advanced medical treatment. The extent to which working long hours for extended periods could contribute to musculoskeletal injuries and disorders is another area for study. Analyzing OSHA reports of injuries and illnesses, as well as collaborating with companies to analyze their insurance claims data, are potential sources of information on safety and health in this worker population.

In the future, our team plans to conduct an epidemiologic study on worker safety and health in the Alaskan commercial fishing industry that could overcome some of the limitations of the current study. As mentioned in the Methods section, the research team manually reviewed the Coast Guard reports of nonfatal incidents – both notifications and investigations – among all crewmembers (captains, deckhands, engineers, processors, etc.). The team plans to utilize these data for all crewmembers during 2012–2016 and link these cases with nonfatal injury and illness cases from the Alaska Trauma Registry and Alaska Fishermen's Fund. By linking data sources and including cases among all crewmembers, this study would capture additional types of incidents that are not typically reported to the Coast Guard (MSDs, health conditions, and illnesses) and determine nonfatal injury and illness rates by industry and fleet. A second study, which utilizes qualitative research methods, will engage members of the Alaskan seafood processing industry – both onshore and offshore – in characterizing their worker safety and health programs. Interviews with corporate-level safety and health managers will identify program challenges and successes, as well as characterize workforce demographics.

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Appendix A.: Injury Severity Scale Adapted from the Abbreviated Injury Severity Scale Utilized by United States Coast Guard Investigators

Injury Severity	Definition	Examples
Minor	The injury is minor or superficial. No medical treatment was required.	Minor/superficial scrapes (abrasions); minor bruises; minor cuts; digit sprain; first degree burn; minor head trauma with headache or dizziness; minor strain.
Moderate	The injury exceeds the minor level, but did not result in broken bones (other than fingers, toes, or nose) loss of limbs, severe hemorrhaging, muscle, nerve, tendon, or internal organ damage. Professional medical treatment may have been required. If so the person was not hospitalized from more than 48 hours within 5 days of the injury.	Broken fingers, toes, or nose, amputated fingers or toes; de-gloving of fingers or toes; dislocated joint; severe strain/sprain; second or third degree burn covering 10% or less of the body (if face is included move up one category); herniated disc.
Serious	The injury exceeds the moderate level and requires significant medical/surgical management. The person was not hospitalized for more than 48 hours within 5 days of the injury.	Broken bones (other than fingers, toes, or nose) partial loss of limb (amputation below elbow/knee); de-gloving of the entire hand/arm or foot/leg; second or third degree burns covering 20–30% of the body (if face included move up one category); bruised organs.
Severe	The injury exceeds the moderate level and requires significant medical/ surgical management. The person was hospitalized for more than 48 hours within 5 days of the injury and, if in intensive care, was in for less than 48 hours.	Internal hemorrhage; punctured organs; severed blood vessels; second/third degree burns covering 30–40% of the body (if face included, move up one category), loss of entire limb (amputation of whole arm/leg).
Critical	The injury exceeds the moderate level and requires significant medical/surgical management. The	

Injury Severity	Definition	Examples
	person was hospitalized and intensive care for more than 48 hours within 5 days of the injury.	
Not survivable	Injuries sustained in accident where the individual would not be able to survive under any circumstances.	Decapitation.

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Table 1.

Nature and Body Part of Nonfatal Traumatic Injuries among Offshore Seafood Processors, 2010–2015

	Body Part (n=304)							
Nature of Injury (n=304)	**Upper Extremities**	**Trunk**	**Lower Extremities**	**Head**	**Multiple**	**Neck**	**Body System**	**Total (row %)**
Sprain/Strain/Tear	13	38	22	0	0	2	0	75 (25)
Contusion/Abrasion	10	14	14	5	6	1	0	50 (16)
Fracture	35	2	4	4	0	0	0	45 (15)
Laceration/Puncture	26	0	3	6	0	0	0	35 (12)
Amputation	16	0	3	0	0	0	0	19 (6)
Intracranial Injury	0	0	0	16	0	0	0	16 (5)
Pain/Swelling	1	7	2	1	1	0	0	12 (4)
Hernia	0	10	0	0	0	0	0	10 (3)
Burn	1	0	1	5	1	0	0	8 (3)
Crushing	7	0	1	0	0	0	0	8 (3)
Dislocation	5	1	1	0	0	0	0	7 (2)
Poisoning	0	0	0	0	0	0	3	3 (1)
Other	7	3	3	0	3	0	0	16 (5)
Total (column %)	121 (40)	75 (25)	54 (18)	37 (12)	11 (3)	3 (1)	3 (1)	304 (100)

Table 2.

Source of, and Event/Exposure Resulting in, Nonfatal Traumatic Injuries among Offshore Seafood Processors, 2010-2015

	Event/Exposure (n=304)				
Source of Injury (n=304)	**Contact with Objects/Equipment**	**Overexertion & Bodily Reaction**	**Falls/Slips/Trips**	**Exposure to Substance/Environment**	**Total (Row %)**
Processing Equipment/ Machinery	61	23	1	0	85 (28)
Vessel Interior/ Exterior	14	0	48	0	62 (20)
Box Frozen Fish/ Product	37	21	0	0	58 (19)
Bodily Motion	0	28	11	0	39 (13)
Conveyor	21	0	1	0	22 (7)
General Tool/ Equipment	10	2	3	0	15 (5)
Unpackaged Seafood - Fresh or Frozen	7	2	0	2	11 (3)
Chemical	0	0	0	9	9 (3)
Temperature/ Boiling Water	0	0	0	2	2 (1)
Dock	0	0	1	0	1 (1)
Total (Column %)	150 (49)	76 (25)	65 (22)	13 (4)	304 (100)

Table 3.

Work Process Associated with, and Event/Exposure Resulting in, Nonfatal Traumatic Injuries among Offshore Seafood Processors, 2010–2015

	Event/Exposure (n=304)				
Work Process (n=298)	**Contact with Objects/Equipment**	**Overexertion & Bodily Reaction**	**Falls/Slips/Trips**	**Exposure to Substance/Environment**	**Total (Row %[a])**
Process Catch on Slime Line	38	15	8	7	68 (22)
Stack Blocks/Bags Frozen Product	23	17	10	0	50 (17)
Repair/Maintain/Clean Factory Equipment	15	3	4	6	28 (9)
Offload the Product	16	3	3	0	22 (7)
Unload Plate Freezers	10	11	0	0	21 (7)
Crack Freezer Pans	13	5	1	0	19 (6)
Walk: Factory	3	2	10	0	15 (5)
Climb/Descend Ladders/Stairs	1	1	9	0	11 (4)
Walk: Freezer	4	1	5	0	10 (4)
Walk: Deck, Corridors, Dock	1	0	7	0	8 (3)
Load Plate Freezers	3	5	0	0	8 (3)
Remove Frozen Product Conveyor/Slide	8	0	0	0	8 (3)
Clean Up Vessel	3	1	4	0	8 (3)
Bag/Case Frozen Product	3	3	1	0	7 (2)
Off Duty	2	2	1	0	5 (2)
Move Carts of Frozen Product	0	4	0	0	4 (1)
Other	4	1	1	0	6 (2)
Missing	3	2	1	0	6 (−)
Total (Column %)	150 (49)	76 (25)	65 (22)	13 (4)	304 (100)

[a]Valid percentages (which exclude missing values from the denominator) were used for all percent calculations

Table 4.

Work Process and Severity of Nonfatal Injuries among Offshore Seafood Processors, 2010–2015

	Injury severity (n=296)				
Work Process (n=298)	**Minor**	**Moderate**	**Serious**	**Missing**	**Total (Row %)**
Process Catch on Slime Line	33	29	6	0	68 (22)
Stack Blocks/Bags Frozen Product	29	16	4	1	50 (17)
Repair/Maintain/Clean Factory Equipment	13	11	4	0	28 (9)
Offload the Product	8	12	0	2	22 (7)
Unload Plate Freezers	12	8	0	1	21 (7)
Crack Freezer Pans	9	9	1	0	19 (6)
Walk: Factory	8	5	0	2	15 (5)
Climb/Descend Ladders/Stairs	8	2	0	1	11 (4)
Walk: Freezer	8	2	0	0	10 (4)
Walk: Deck, Corridors, Dock	5	3	0	0	8 (3)
Load Plate Freezers	7	1	0	0	8 (3)
Remove Frozen Product Conveyor/Slide	2	4	2	0	8 (3)
Clean Up Vessel	2	4	2	0	8 (3)
Bag/Case Frozen Product	6	0	1	0	7 (2)
Off Duty	3	2	0	0	5 (2)
Move Carts of Frozen Product	1	3	0	0	4 (1)
Other	2	1	2	1	6 (2)
Missing	2	4	0	0	6 (−)
Total (Column %)	158 (53)	116 (39)	22 (8)	8 (–)	304 (100)