safety

Review

Gulf of Mexico Seafood Harvesters: Part 1. Occupational Injury and Fatigue Risk Factors

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Received: 10 April 2018; Accepted: 19 July 2018; Published: 24 July 2018

Abstract: During 2000–2009, 116 Gulf of Mexico (GoM) fishers were killed (23% of the US total) while working in the shrimp, finfish, oyster, clam, and crab fisheries. The purpose of this literature review is to identify injury-related risk factors to better assess the frequency and severity of injuries experienced by fish harvesters in the GoM. Methods: The method of this study is a comprehensive narrative literature review of findings useful for the prevention of fatal and non-fatal injuries among GoM fish harvesters published since 2005. Search engine terms were used to identify relevant literature that included fatalities, injuries, fatigue, and several other terms in combination (e.g., string search with "fishing"). Results: We reviewed 48 articles; the most common cause of fish harvester deaths in the GoM is falls overboard with scant use of personal flotation devices and vessel disasters in which flooding and collision were the most lethal. The root cause of errors resulting in many disasters may have been operator fatigue, but fatigue is also an adverse health effect resulting from working conditions. Non-fatal injuries arise from multiple sources that include working with gears, slips and trips, struck-by or against objects, machine or line entanglements, and falls. Conclusion: Principal risk factors are a lack of sleep aboard fishing vessels, vessel flooding and collisions, poor weather, slips on deck, contact with gear, not wearing personal flotation devices, poor swimming ability, and fishing alone on a vessel or the deck.

Keywords: safety; injuries; fatalities; fishers; fish harvesters; hazards; fishing; fatigue

1. Introduction

Commercial fishing is one of the most dangerous occupations in the world [1,2]. In the United States, occupational fatalities within fisheries occur at rates much higher than national averages for all occupations. Fisher fatigue is an important job-related outcome as well as a risk factor on fishing vessels as reported by the Food and Agriculture Organization [3].

In the Gulf of Mexico (GoM), hazards faced by fish harvesters include challenges from technology, vessels and gear, the weather, fatigue, and making errors. In 2010, the National Institute for Occupational Safety and Health (NIOSH) at the US Centers for Disease Control and Prevention (CDC) reported 509 commercial fishing deaths in the United States, 2000–2009. The US GoM region (Texas, Louisiana, Mississippi, Alabama, and the west coast of Florida) accounted for 116 (23%) of the fatalities [4]. Another NIOSH study revealed 49 deaths in the GoM for the years 2010–2014 [5]. The GoM makes up 17% of US marine waters comprised of three zones: intercoastal waterways, coastal waters extending to 3 miles (4.8 km) from the coast (state jurisdiction), and waters 3 to 200 miles (4.8 to 321.9 km) from the coast (federal jurisdiction) representing 25%, 15%, and 60%, respectively, of known fatalities by the zones in the GoM during the 1990–1994 period [6]. The National Oceanic and Atmospheric Administration (NOAA) reported in 2014 that little research had been conducted on the characteristics of fatal and non-fatal injuries among GoM commercial fishers even though Florida and Louisiana rank highest for the number of fatalities among all states after Alaska and Massachusetts [7].

To better understand the causes of these injuries as well as fatigue, this literature review aims to identify risk factors (i.e., hazards) that contribute to occupational injuries and fatigue, which exist or may exist among GoM seafood harvesters. The review informs a broader study with an aim to assess the frequency and severity of injuries and illnesses experienced by GoM fishers based on interviews and vessel and task observations.

Injury risk factors are framed in two ways consistent with earlier approaches. This review focuses on three problems: fatalities that are the most serious traumatic injury outcome, non-fatal injuries that are frequent and vary regarding severity, and fatigue as a serious result of occupational stress but also that dates back for decades as a recognized risk factor for human error with disastrous outcomes [8].

This analysis is divided into fatal and non-fatal injuries consistent with earlier reports [9]. Moreover, official databases record fatal and non-fatal injuries separately that includes the US Coast Guard (USCG), the US Departments of Labor and Transportation, and NIOSH. Much injury research is based on these official sources of data. Also addressed, because of its secondary impact on injuries, is fatigue as another adverse occupational outcome among fishers. Further, an epidemiological approach used in related studies [10] based on Haddon's classification of risk factors [11] is described and supported by NIOSH as shown in Table 1 [12].

Table 1. Analysis of risk factors of commercial fishing fatality events in Alaska using the Haddon Matrix, 1997.

Phase	Agent/Vessel/Vector	Environment	Host/Human
Pre-event	Unstable vessel. Unstable work platform. Complex machinery and operations.	High winds. Large waves. Icing. Short daylight. Limited fishing seasons. Vessels far apart.	Captain and crew fatigue, stress. Drugs/alcohol. Inadequate training/exposure.
Event	Listing or capsizing vessel. Delayed abandonment. Emergency circumstance misunderstood. Fall overboard (FOB).	High winds. Large waves. Darkness. Poor radio communication. Cold water.	Captain and crew reaction to emergency. Personal flotation devices unavailable or not working.
Post-event	Vessel sinking. Poor crew response to FOB.	High winds. Large waves. Cold water.	Hypothermia. Drowning. Lost at sea. Poor use of emergency equipment.

Source: National Institute for Occupational Safety and Health [12].

Two companion reviews will follow. One reviews health-related risk factors other than injuries [13], and the other reviews the literature regarding known interventions for the protection of the occupational health and safety of fish harvesters [14].

2. Method and Materials

A study, Occupational Health and Safety of Gulf Seafood Workers, was launched to address the health and safety of workers in five GoM fisheries: shrimp, crab, finfish, oyster, and clam. Other fisheries in the GoM were excluded because of their small size that include the sponge and the emerging jellyfish fisheries. We identified studies that examined safety risks relevant to the study with an interest in two criteria: (1) frequency of the condition and (2) severity in the individual case [15]. Selection was based upon three priorities: (1) relevance to GoM fisher safety and health, (2) recent investigations that built on earlier investigations, and (3) research designs that can inform our study. Sources for this literature review follow: NIOSH bibliography (*n* = 156) [16] and string search results—Google Scholar: "Gulf of Mexico occupational injuries fishing" (*n* = 21); Google: "fishermen stress" (*n* = 19); PubMed: "fishing occupational injury Gulf of Mexico" (*n* = 3), "commercial fishing occupational injury" (*n* = 45), "occupational fatalities fishing" (*n* = 22), "commercial fishing fatigue" (*n* = 4), "commercial fishing stress" (*n* = 20), and "commercial fishing epidemiology" (*n* = 75). Exclusion criteria follow: studies before 2005 except for GoM studies and six studies that add information related to the post-2004 studies, non-traumatic injuries (except for drownings), non-injury studies, non-risk factor studies, studies of sport fishing, studies of subsistence fishing, biological animal stings and bites (to be covered in Part 2 in this series), and studies outside North America and Europe (for technological reasons). We examined 365 studies.

Forty-eight articles were selected for this review (listed in the Appendix A). Research geographically distant from the GoM is relevant to fisher safety and health problems in the GoM, especially regarding cross-regional patterns, technology, and study design.

3. Results

Results are presented in three categories: fatality hazards, non-fatal injury hazards, and fatigue-related hazards. Fatal and non-fatal injury hazards are further divided into studies within the GoM and outside of the GoM. The term "hazard" means an energy, biological, or other source with potential to do damage to people. Fatigue is a special concern because of its potential high prevalence and threat to safety for fishers and vessels.

3.1. Fatality Hazards

For the period 2003–2009, the US Bureau of Labor Statistics reported the fatal injury rate among fishers as 203.6 per 100,000 full-time equivalents (FTE) workers, more than 50 times the all-worker rate of 3.5 per 100,000 FTEs [17]. Below, injury and fatality outcomes are examined that relate directly and indirectly to GoM fisheries.

3.1.1. Gulf of Mexico (GoM)-Related Fatality Studies

An early study by Kennedy and Lincoln for the period 1990–1994 found that commercial fishing deaths in the United States totaled 421 fatalities (an average of 84 deaths per year) that included 189 (45%) deaths in the GoM [6]. In 2010, CDC reported on 504 US commercial fishing fatalities for the years 2000–2009 [18]. The sources of the data included reports from the USCG, enforcement agencies, media, death certificates, and state-based systems. The GoM accounted for 124 (25%) of all fatalities and 83 deaths (16%) from vessel disasters. The shrimp fishery in the GoM was responsible for the highest number of deaths by fishery. Across the nation, of all decedents recovered from a FOB, none wore a personal flotation device (PFD). In addition, 88 fatalities were caused by onboard injuries (51), diving (19), and onshore injuries (18). A vessel disaster is defined as a sinking, capsizing, grounding, fire, or other event that forces the crew to abandon ship [4], and a fatal FOB is defined as "unintentionally entering the water outside the hull of a commercial fishing vessel resulting in a fatality" [19].

The 2010 study also determined the highest cause of FOB was "trips and slips" on the deck followed by "lost balance," as shown in Figure 1. It also found that the two leading causes of vessel disaster in the GoM were flooding and collision, as shown in Figure 2 [18].

FOBs dominated the fatality frequency in the GoM. As described in the Introduction, Lincoln and Lucas reported in July and October of 2010 on 116 commercial fishing fatalities in the GoM for the years 2000–2009 [4,20,21]. Lincoln and Lucas and Syron et al. summarized circumstances for 165 GoM vessel-related fatalities through 2014 as shown in Figure 3 [4,5].

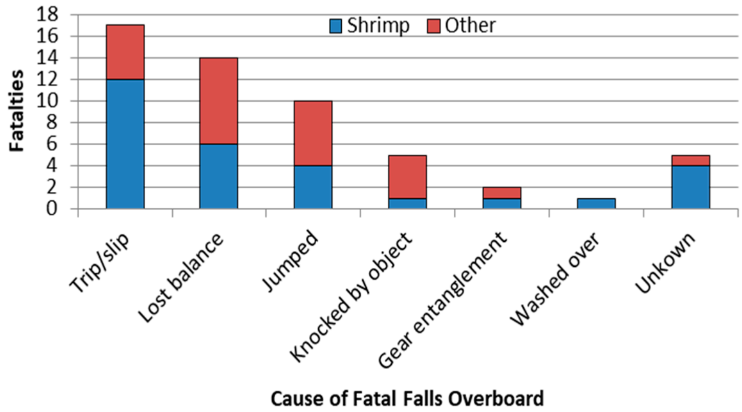

Figure 1. Causes of fatal falls overboard, Gulf of Mexico, 2000–2009, n = 54 deaths [18].

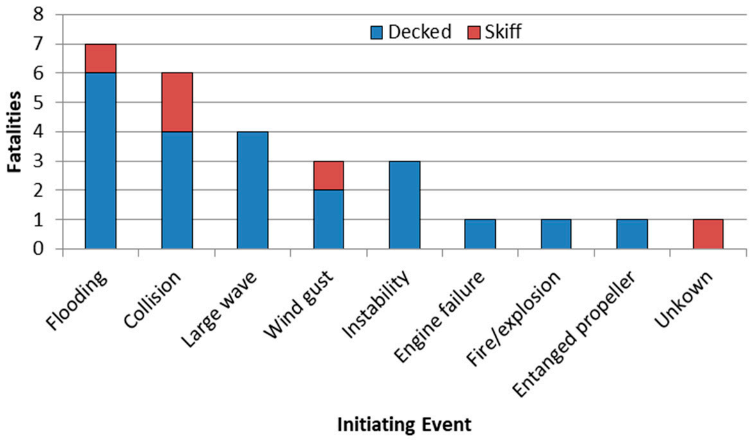

Figure 2. Initiating events contributing to vessel disasters, Gulf of Mexico, 2000–2009 [18].

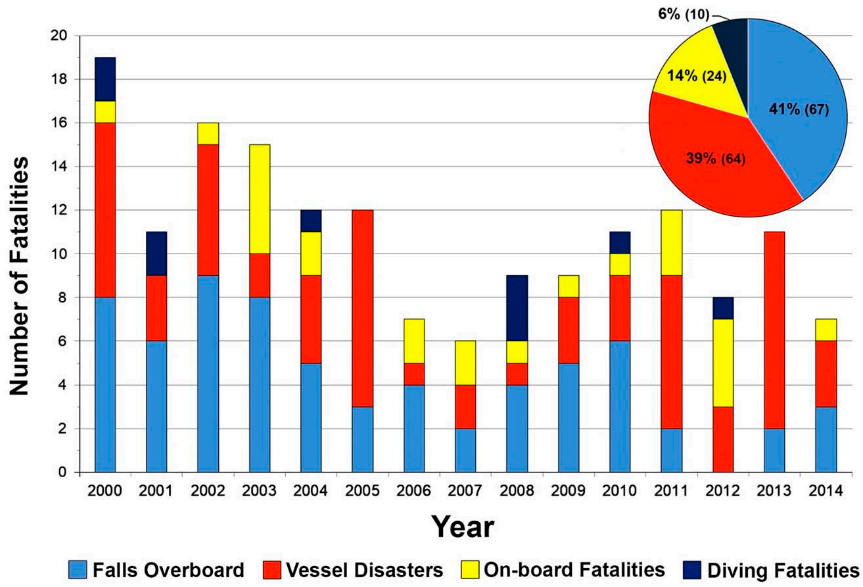

Figure 3. Number of commercial fishing fatalities in the Gulf of Mexico for 2000–2014 (n = 165). Inset chart shows principal cause of death as a percentage of fatalities. Sources: Lincoln and Lucas 2010 [4] and Syron et al. 2017 [5].

Janocha found that Florida had the highest percentage of fatal injuries for the industry in the south-eastern United States based on 2003–2009 national statistics, and Florida placed third for fatalities nationwide after Alaska and Massachusetts [17]. Marvasti [7,22] calculated the rate of commercial fishing fatalities, which placed the finfish (snapper and grouper) harvesters at the highest rate of occupational death and analyzed USCG casualty (fatal and non-fatal injuries and missing persons) data through a Poisson regression model and concluded the following: FOBs are the highest cause of death, older steel-hulled vessels are safer than plastic-hulled vessels, severe weather is the most important environmental risk factor, and larger crews provide increased safety in the event of a rescue response to a crisis. Vessel disasters and injuries have also been related to fatigue among crew members [3].

Across the studies, FOB ranked high as related to death, primarily associated with slips and trips and losing balance. Vessel disasters ranked high as well with flooding as the most significant cause. The most hazardous fishery in terms of frequency of death was shrimping and the reef fishery (snapper and grouper) that had the highest fatality rate based on hours of exposure at sea.

3.1.2. Non-GoM Fatality Studies

In a previous literature review in Great Britain, a study reported of 206 deaths, 92 (47%) resulted from vessel disaster and 116 (56%) from a fatal injury including drowning. The death rate was 20 times greater than for coal miners. Fatigue was a contributing factor to vessel disaster and fatalities. Another study in that review found that of 909 deaths at sea, 78% were caused by vessel disaster or fatal injury, 19% from disease, and 3% from homicide or suicide. Of non-UK studies, one reported on 47 deaths, 68% died from drowning, and 13% from trauma. Overall the review concluded that following a population at risk is difficult because of self-employment and the variation in the number and duration of fishing trips [9]. This conclusion is a concern for research in the GoM as well, and fatality circumstances are similar to those reported in the GoM.

Six other studies of fish harvester fatalities outside of the GoM were reviewed that identified risk factors that potentially indicate hazards to GoM fish harvesters. One study found that 71 fatal FOBs in Alaskan waters for the period, 1990–2005, were associated with fishers washed overboard by waves, loss of balance, pushed or pulled overboard by gear, not wearing PFDs, and unobserved, thus negating rescue [19].

Based on USCG data, Day et al. identified 31 fatal injuries in New Jersey for the period 2001–2007 on commercial fishing vessels, 16% of which were FOBs. Other causes included crushed between objects (39%), non-contact injuries (32%), asphyxiation (13%), diving (10%) and exposure (10%) [23]. Case et al. investigated 28 fatalities based on USCG data in a study of fatal and non-fatal injuries among Dungeness crab fishers in California, Oregon, and Washington, 20 of whom lacked time to don survival equipment, and eight recovered bodies lacked PFDs [24]. Both of these studies used USCG data, which can as a method inform GoM research.

In Australia, Byard cited vessel flooding, propeller entanglement, and strikes by large waves causing the vessel to sink with no time to don survival equipment, launch life rafts, or send distress signals [25]. In the above studies, recovered FOB decedents lacked PFDs, and other significant factors for fatal events included weather conditions, contact by gear including entanglements, slips and trips, and lack of time to don survival equipment during a vessel disaster.

Holen et al. reviewed 34 occupational fatalities in Norwegian mariculture over the years 1982–2015. Juvenile trout and salmon are produced in smolt tubs with fresh water on land (with 1 death at this stage), and the grow-out occurs in sea-based net cages suspended from circular plastic collars (with 33 deaths at this stage): 15 of which involved vessel loss at sea, 6 resulted from contact with an object on the vessel, 5 from FOB, and 4 from diving (one of which occurred onshore when the diver was trapped in a drain pipe) [26]. These results are appropriate for onshore GoM operations but differ regarding current shell fish operations in the GoM. However, as mariculture expands into deeper water in the GoM these factors may increasingly become relevant.

A study regarding Atlantic Canadian waters analyzed relationships of weather factors to fishing vessel incidents. Ice concentration, wind speed, sea surface temperature, and darkness were the most significant factors relative to the severity of fishing incidents, but when cyclones were considered, its intensity replaced ice concentration as a significant factor. Another observation was that individual fisheries can be adversely affected by different weather factors [27]. While ice concentrations are not a problem in the GoM, avoiding cyclonic activity in the Gulf deserves attention.

In summary, fatalities are the most severe injury outcome, and the four risks of death reported in the GoM are FOB, vessel disasters, on-board incidents, and diving as shown in Table 2. Onshore fatalities were recognized but risk factors were not identified. To better understand the risk factors also requires examining studies outside of the GoM. Note that the risk factors between GoM and non-GoM studies were similar for fatalities. The main difference in the literature is the lack of the risk factor of waterborne ice concentrations and frigid water in the GoM.

Table 2. Summary of fatality risk factors that potentially affect Gulf of Mexico fish harvesters.

Risks	Technology	Environment	Fish Harvesters
Gulf of Mexico Studies (*n* = 7)			
Fall overboard (FOB)	Trip or slip, knocked by object, gear entanglement	Washed overboard	Lost balance, jumped, not wearing personal flotation devices (PFDs)
Disasters	Flooding, collision, instability, engine failure, fire or explosion, entangled propeller, plastic or wood hulls	Large wave, severe weather	Small crew size, fatigue
On-board	Winch entanglement *		
Diving	Not addressed		
Non-Gulf of Mexico Studies (*n* = 6)			
FOB	Pulled or knocked overboard by gear, slips,	Washed overboard by wave, heavy weather, wind speed, poor visibility (rain)	Loss of balance, not wearing PFDs, alcohol consumption, falls into water, poor swimming ability
Disasters	Flooding, propeller entanglement, vessel size	Strikes by large waves, wind speed, poor visibility, sea surface temperature, darkness, cyclone activity	Fatigue; lack of time to don survival equipment, launch rafts, and send maydays
On-board	Working with gear, gear entanglement, crushed between objects		Exposure
Diving **	Repair vessel hulls and piers		Shellfish harvesting

* Both for fatal and non-fatal injuries, ** Mariculture: stuck in drain pipe onshore, possible net entanglement.

3.2. Non-Fatal Traumatic Injury Hazards

> "Less is known of the variables related to occupational morbidity and non-fatal injuries in commercial fishing both in quantity and severity."
>
> —Jeffery L. Levin, Karen Gilmore, Amanda Wickman, Sara Shepard, Eva Shipp, Mathew Nonnenmann, and Ann Carruth [28]

While fatalities are threshold events for many investigations, less attention had been given to non-fatal injuries. However, the USCG classifies injuries by severity based on the Abbreviated Injury Scale (AIS). This scale covers a range of injuries as follows: 1 (minor), 2 (moderate), 3 (serious), 4 (severe), 5 (critical) and 6 (maximal, untreatable), based on the risk of death [29]. Some researchers in the United States used USCG AIS classifications in studies of fisher non-fatal injuries. Below, we review two studies in the GoM followed by 13 other studies of non-fatal injuries outside of the GoM.

3.2.1. GoM Non-Fatal Injury Studies

A study in the US Southern Shrimping Fleet (the GoM, Florida east coast, and North Carolina) focused on winch-related injuries and identified risk factors for both fatal and non-fatal injuries of fish harvesters. Both try-net (used to sample catch size) and main winches have caused injuries and are depicted in Figure 4 on a drawing of a trawler vessel. Lucas et al. studied winch-related entanglements among fishers in the GoM that involved both fatal ($n = 8$) and non-fatal injuries ($n = 27$). Half of the incidents occurred during nighttime hours. Clothing was entangled in 14 cases (39%), and the deaths were from asphyxiation and multiple injuries [30]. Double rig side trawlers in the GoM as shown in Figure 5 pose a significant hazard of non-fatal as well as fatal injuries among shrimpers; many of which were associated with winches, mostly with clothing entanglement.

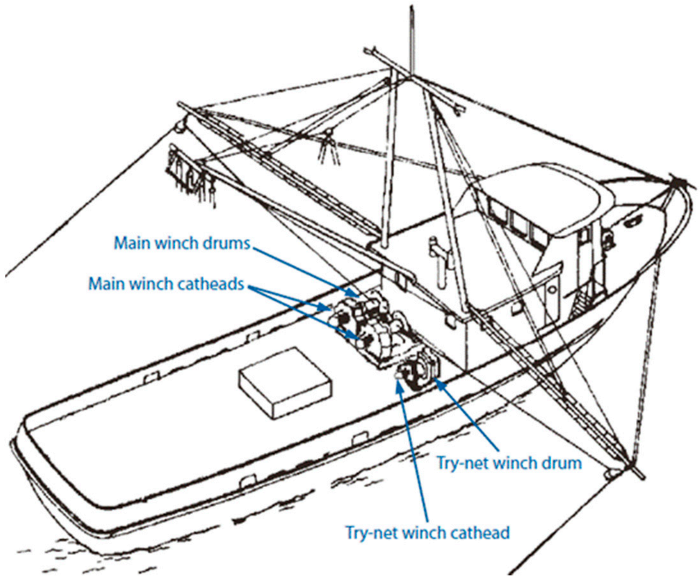

Figure 4. Main and try-net winches shown on a drawing of a double rig shrimp trawling vessel, Courtesy NIOSH [30].

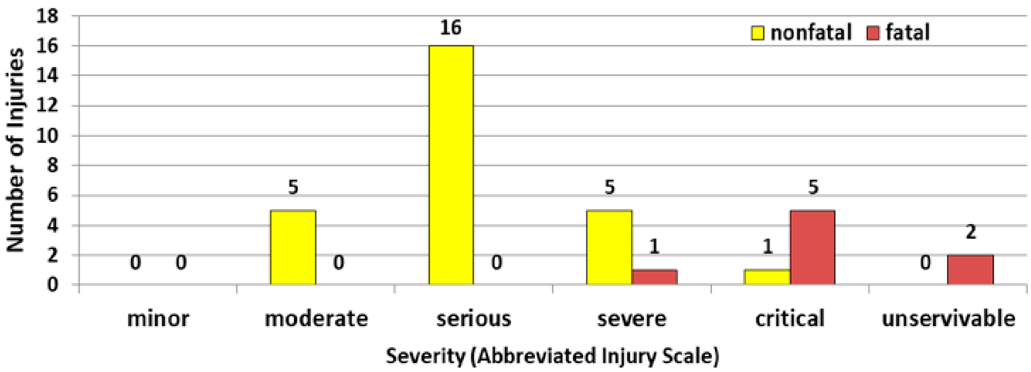

Figure 5. Number of winch-related fatal (n = 8) and non-fatal (n = 27) injuries in the Gulf of Mexico, Florida Eastern Seaboard, and North Carolina, 2000–2011 on the US Southern shrimp fleet. Source: NIOSH [30].

A study of fatal and non-fatal injuries identified the following factors that affect fisher safety along the Texas coast. The vessel-related factors included machinery and the work environment (e.g., slippery and unstable work surfaces); the environmental factors were the conditions at sea that include temperature extremes and weather; and the human factors were fatigue, inexperience, and failure to use safety practices and equipment. The aim of the study was to identify risk factors so as to guide culturally appropriate safety training [2].

3.2.2. Non-GoM Non-Fatal Injury Studies

Marshall et al. evaluated a North Carolina cohort of 215 commercial fishers in small and medium-scale operations in which 83 (39%) fishers self-reported injury cases over the previous

12 months. Most injuries occurred on small vessels (54%), and activities prior to the injury included working with gear (72%) and working with a catch onboard (19%). Other injuries occurred when loading, boarding, and debarking the vessel. One-third of the fishers reported inadequate swimming ability [31]. The fisheries addressed in this study are similar to the GoM environmental conditions and could inform GoM research for appropriate risk factors.

Further up the eastern coast in New Jersey waters, Day et al. analyzed 225 commercial fishing-related injuries for the years 2001–2007, of which 96% of non-fatal and 68% of fatal injuries were caused by bodily contact that related to falls onto a surface (55%) and crushed between or by objects (21%) [23]. Fulmer et al. conducted research of non-fatal injuries among 286 license-holding lobster fishers in Maine and Massachusetts over a two-year period and reported that minor injuries were caused by abrasive or sharp objects and a fast work pace [32]. On the US West Coast, Case et al. studied non-fatal injuries among Dungeness crab fishers. They determined that 28% of injuries occurred while handling gear, 69% occurred onboard, and 29% happened while abandoning the vessel. They estimated that non-fatal injuries may be underreported by 300% [24]. They adapted process codes from Jensen et al. [33] and mapped the codes against AIS classifications. Further north, using hospital data from the Alaska Trauma Registry, Husberg and Lincoln identified 648 fishing injuries for the period 1991–1999. The injuries were associated with machinery (32%), falls (25%), and struck-by-object (15%) [34]. This approach was comprehensive regarding hospitalized injuries fishers and could be explored in the GoM.

In their 2000–2011 study, McGuinness et al. cited the predominant cause of injuries among Norwegian commercial fishers as ship motion [35]. In a later study published in 2016, McGuinness et al. observed that the small fishing vessel fleet suffered more fatalities than the large vessel fleet [36]. Ship motion and vessel size are common risk factors to GoM fishing.

Syron, et al. classified non-fatal injuries in the Alaskan fishing fleet by work processes [33], using a Danish Work Process Classification System that included working with gear (27%), traffic onboard (22%), and handling frozen fish (22%) [37]. Jensen conducted a study of 611 non-fatal slip and fall injuries among Danish commercial fishers in 2000, and found that 32% occurred at the same level and 20% involved falls to a different level. Stumbles accounted for 32% and slips for 13% of the falls [38]. A follow-up study was conducted that offered boots with slip-resistant soles to 161 Danish fishers as a replacement for existing boots. Following several tours at sea, the fishers reported reduced slips, trips, or falls from 74% to 52% with the new boot [39]. In another study, Jensen et al. conducted an exposure study and compared time increments spent on the work processes, which resulted in the highest rate of injuries occurring while boarding or disembarking vessels followed by handling gear and nets [40]. In another study, Jensen et al. classified work processes by observing and video recording the tasks on fishing vessels and observed that half of the injuries occurred when preparing, shooting, and hauling gear and nets [33]. These studies used a task analysis approach for targeting interventions, which can prove useful in GoM studies.

Wang et al. conducted a study of 370 fishing vessel incidents in Great Britain for the period 1992–1999 and found that poor maintenance of vessels contributed to 233 (63%) of incidents, 33 lost vessels, and 370 injuries [41]. Kaustell et al. examined 833 injuries among 439 insured Finish fishers during the years 1996–2015 and found that 20% of the injuries occurred during the repair and maintenance of vessels (57% onshore). Half of the injuries were associated with falls [42]. Chauvin et al. investigated 499 injuries among 4653 French fishers during 2012, and determined that a higher injury incidence rate occurred with active gear than passive gear. See Table 3 for the differences between passive and active gear, which describes the variety of vessels and equipment used to harvest fish in the GoM [43].

Table 3. Different fishing techniques used in the Gulf of Mexico.

Active: * dynamic capture
Trawl: Pull nets across the bottom of shrimp beds in order to scoop the catch into the nets (typically at night when shrimp are active).
Seines: Encircle and bag fish for capture with a drag line and net.
Dredge: Drag chain mesh that is open on one end and scrape across a bottom-dwelling shellfish bed to scoop up a catch.
Passive: * stationary capture or culture
Gillnets: Roll out a length of stationary vertical net and wait to entangle the gills of finfish for harvest.
Pots: Set pots (cages) with bait to trap crustaceans (e.g., crabs) for retrieval.
Lines: Traditional hook, bait, and line.
Tongs: Grasp and lift shellfish (e.g., oysters) with wide tongs onto the boat deck.
Polyester mesh grow-out bags: Mariculture involves pea-sized juveniles (clams raised onshore) staked in shallow estuarine or coastal waters where they remain for about a year while they reach harvestable size and are lifted onto boats.

* Chauvin et al. [43].

Myers and Durborow found that mariculture had many hazards akin to hazards associated with shallow water commercial fishing [44]. They cited risk factors from a study of non-fatal injuries regarding mariculture from a 1980–1999 Norwegian study with machinery and slips and falls accounting for a high numbers of injuries [45]. Holen et al. analyzed 761 occupational injuries associated with trout and salmon mariculture work in Norway. Juvenile fish production is located onshore and grow-out is offshore, typically in net pens. In the land-based production of juveniles, falls caused the highest number of injuries, typically from ladders. The number of offshore injuries was led by blows by an object, typically from falling objects from cranes. The second and third highest frequency injuries were related to entanglements or crushes and falls, respectively. A unique risk was voltage-related injuries from exposure to static electricity released from plastic fodder tubes [46]. Mariculture is an emerging practice in the GoM, which involves shellfish farming but has the potential for expanding into deeper waters and different fisheries. Land-based operations are an important focus for GoM mariculture.

Injury studies within the United States can inform potential preventive actions within the GoM. Contact injuries dominated the frequency of injury, and working with gear was a major hazard. Falls onto hard surfaces was another frequent hazard. Fractures were a major injury type, but head injuries and limb amputations were likely the most severe non-fatal injuries. Minor injuries such as cuts, punctures, and bruises to the hands and wrists were considered routine. Injuries occurred when boarding and disembarking the vessel, and loading and unloading gear and catch. Poor swimming ability is a problem for about one-third of the workers as reported in one study.

European studies tended to be more comprehensive, addressing onshore as well as offshore risk factors. They also added more detail to the hazard types. While small vessels experienced more fatal events, larger vessels experienced more non-fatal incidents. Principal risk factors were working with gear, mostly with machinery; slips and falls; vessel motion; slippery surfaces; and boarding and disembarking the vessel. The injuries occurred most often on upper and lower extremities. The lack of maintenance was associated with vessel disasters, and higher injury incidence rates occurred with active gear than with passive gear (See Table 3).

To summarize, non-fatal injuries can range in severity from permanent disability such as an amputation or loss of vision to minor injuries that may include cuts, abrasions, or bruising. The reviewed studies did not evaluate severity except for these studies that used the USCG 6-point AIS scale to classify injury severity. One study found that the injury incident rate was higher for active gear than for passive gear, and more generally, handling gear present the major injury hazards. The risk factors identified in the literature are summarized in Table 4. The only GoM-specific studies regarded winch entanglements and identifying and targeting specific risk factors for a safety awareness program. Many similar risk factors were reported in US and European studies, but there is a greater variety in these findings because of the range of types of non-fatal injuries. There was also an emphasis on onshore and dock-related risk factors in the European studies than has not been considered in the United States except in North Carolina and Alaska.

Table 4. Summary of non-fatal injury risk factors that potentially affect Gulf of Mexico fish harvesters.

Risks	Technology	Environment	Fish Harvesters
Gulf of Mexico Studies (*n* = 2)			
GoM winch entanglements	Double rig trawlers, unguarded winch drums.	Shrimp fishery, nighttime work.	Loose clothing.
Non-fatal and fatal injuries (TX)	Machinery, unstable and slippery work surfaces.	Extreme temperatures, weather.	Fatigue, inexperience, failure to use safety practices and equipment.
Non- Gulf of Mexico Studies (*n* = 11)			
Injuries (NC)	Working with catch, loading and boarding vessel, hooks and knife blades, loading boat, small boats, working with nets, pots, and lines.	On the water, dock work, crab, finfish, shrimp, clam, and oyster fisheries.	Fall on hard surface, poor swimming ability.
Injuries (NJ, AK, and US West coast)	Falls on surface, stuck by or between object, caught in lines, handling gear, traffic onboard. Working with catch.	Collision with fixed object.	Falls into water, Injured when abandoning vessel.
Injuries (Europe)	Knives, fish spikes, entanglement, stuck by or against, ladders, vessel loss, boarding and demarking boat, lack of vessel maintenance, working with winches, lines, nets, and machinery.	Onshore work (repairs, fish handling), slippery surfaces.	Slips and falls, non-slip soles on boots.

3.3. Fatigue-Related Hazards

> "Fatigue has been identified as a major root cause of human error in a number of extremely high-profile disasters."
>
> —Angela Baker and Sally Ferguson, 2003 [47]

Fatigue is a common risk factor among fishers whether in the GoM or elsewhere. It is a separate section because of its unique feature as a health effect caused by working conditions (an outcome as are injuries), but it is also a risk factor regarding injuries and disasters. Høvdanum et al. cited the definition of fatigue [48]: "A reduction in physical and/or mental capability as the result of physical, mental, or emotional exertion which may impair nearly all physical abilities including: strength; speed; reaction time; coordination; decision making; or balance." Fishers accept fatigue as normal, and it is associated with long working hours, sleep and sleep rhythm disturbance, night work, harsh working conditions, and ship motions. These researchers conducted a literature review of fatigue in 2014 regarding fisher safety and located five articles on the subject as listed below with our comments.

1. Sąlyga and Kusleilkaite conducted a study in 2007 of 532 seafarers, 301 (57%) of whom were fishers, and 76% of the total experienced fatigue at sea [49]. Fishers' work ranged from 11 to 12 h per day. Fatigue effects included lack of energy (87%), slight mistakes (9%), poor judgement (87%), and poor sleep quality overall.
2. Allen et al. published the results of a study in 2010 on the effects of fatigue on 81 fishers [50]. The longest continued duty was 14 h. Of the respondents, 44% (*n* = 36) reported that the fishers had worked to the point of exhaustion.
3. Gander et al. conducted a detailed study of 20 fishers in 2005 based on sleep diaries, a questionnaire, sleep monitors; and a comparison of sleep between home and work [51]. Split sleep was more likely at sea, and sleepiness was higher at sea than at home. Sleep at sea was <4 h per 24 h period.

4. Ólafsdóttir produced a report in 2004 from Iceland that reviewed shift work among fishers [52] and found that early risers who go to sleep earlier perform less well than late risers who go to sleep later, and activity monitors showed that workers dozed off briefly while on duty.
5. Baker and Ferguson stated in 2006 that Australian fishers routinely work 24 to 96 h or more with little or no sleep [46]. A finding was that fatigue was responsible for 2% of human-related vessel collisions and 4% of groundings.

Allen et al. named four risk factors associated with fatigue [53]: (1) circadian rhythm, (2) working patterns and shift schedules, (3) noise and motion, and (4) sleep. Smith et al. concluded that fatigue at sea was due to exposure to a combination of risk factors associated with operations, organization, and the environment [54].

In their review of injury incidence in fishing, Jensen et al. identified fatigue as a causal factor of injury incidents, observed that a majority of fishers claimed their safety had been at risk because of fatigue, and reported that their fatigue level was related to the length of time at sea. Nearly half of fishers in one study that they reviewed said that they had worked to the point of exhaustion or collapse. The reviewers suggested that more investigation is needed into the relationship of fatigue to navigation errors [55].

Rezaee conducted a literature review regarding weather conditions and commercial vessel incidents with an emphasis on Canada [10]. The review included eight studies of fishing incidents, one of which reviewed human errors, which in its turn referred to two other sources that referred to fatigue as the number one concern of mariners and a USCG survey in which fatigue was the most frequently mentioned problem. Another study reported that fatigue contributed to 16% of vessel casualties and 33% of injuries [9]. Still another study determined that 165 of fishers were involved in a fatigue-related incident, of which 44% had worked to the point of exhaustion, 41% fell asleep at the wheel, and 43% fell asleep on the deck or gangway [56].

The only GoM study of fish harvester fatigue addressed stress among shrimp fishers associated with (1) environmental conditions (e.g., storms and waves) that placed demands on individual capabilities; (2) the sea worthiness of older vessels (those made of wood or Plexiglas rather than steel); (3) working at night and around the clock; (4) temperature extremes between heat on the deck and cold in the ice holds for fish; (5) dangerous aquatic animals; and (6) social pressures [57]. The researchers used dockside intercepts of captains debarking after a fishing trip in 34 communities along GoM shores. The acceptance rate was 80%, with 567 captains agreeing to the interview: 26% fished in deep waters, 32% fished in shallow waters, and the remainder fished in both locations. The three primary measures were (1) environmental stressors; (2) job satisfaction given economic and regulatory challenges; and (3) mastery—the sense of control over forces that affect their lives. Regarding mental distress, they found one in three fishers had a diagnosable disorder, which was twice the rate of onshore males. Those with a good sense of mastery were at lower risk. The greatest risk emerged from higher rates of overwork and lack of sleep, low satisfaction with the rewards of the work, and high rates of conflict with and lack of cooperation from the crew. A high rate of alcohol use was expected given the stress, but the captains were likely to abstain given the incompatibility of alcohol use with the work of fishing. One-third of captains abstained at sea but engaged in hard drinking onshore.

Jepsen et al. conducted a comprehensive review of seafarer fatigue in 2017. The review led to a process description of the main determinants of and outcomes of fatigue that followed a sequence: (1) Inadequate or insufficient sleep (sleep deprivation, shift-work, stress) → (2) Sleepiness → (3) Fatigue—a progressive loss of mental and physical alertness that can end in sleep (physical exposures, motion sickness, physical demands, individual factors, disease) → (4) Acute effects (safety effects) → (5) Chronic health effects (sleep dysfunction, metabolic, cardiovascular, and psychological disorders, e.g., depression, anxiety). Physical risk factors regarding fatigue included noise, sleep interruption by noise and vessel movement, and motion sickness (a major cause of fatigue) [58].

Fatigue is a widespread and serious risk factor among fish harvesters. It has been associated with vessel disasters and onboard injuries. Fatigue is also an adverse health effect of working conditions.

The risk factors for fatigue included lack of sleep quality and duration, noise and vessel motion, work exhaustion, long working hours, night work, and circadian rhythm disturbance. Stress may be another risk factor in addition to those listed above and could be associated with storms and waves, vessel seaworthiness, temperature extremes, dangerous aquatic animals, and social conflict onboard. Motion sickness has been identified as a major cause of fatigue. The sleep disturbance problem is of a broader health concern based on the background document for the 2017 Nobel Prize in Physiology or Medicine: "Circadian dysfunction has been linked to sleep disorders as well as depression, bipolar disorders, cognitive function, memory formation, and some neurological diseases."–Carlos Ibáñez, 2017 [59].

4. Discussion

Fish harvesters in the GoM are at a high risk of fatal injury associated with FOBs and vessel disasters. Much less is known about non-fatal injuries in the GoM with the exception of winch entanglements. This review of the literature about both GoM and non-GoM fishing hazards identified articles and documents with an aim of identifying risk factors related to both fatal and non-fatal injuries as well as for fatigue on fishing vessels. Fatigue is a work-related condition that is a widespread risk factor associated with vessel disasters and individual injuries. Identifying these risk factors will provide insight into potential countermeasures to mitigate or eliminate the injuries in the GoM. The results of this review are aimed at informing preventive actions in the GoM, but are likely to be helpful to the broader population of interveners nationally and internationally.

The overall approach to the review was to identify literature that dealt with the severity and frequency of injuries among fish harvesters and identify risk factors faced by them including the problem of fatigue. Fatal and non-fatal injuries were examined separately (although there is an overlap between the two such as with winch entanglements), since the literature typically makes this distinction. Moreover, many of the official databases also report fatal and non-fatal injuries separately, which are used as sources for many injury studies. A second framing concept was the use of Haddon's epidemiological approach to classifying risk factors by agent (e.g., vessel and gear), environment, and personal factors as shown in Table 1. The result of this approach is the recognition that in the fishing environment, three strategies, respectively, can focus the type of intervention on equipment redesign and maintenance, weather condition warnings, and health promotion and job redesign.

The existing literature was valuable for informing prevention efforts in the GoM. While GoM sources were scarce, the broader literature added many insights into the range and importance of different risk factors, fatality research, and investigations in North Carolina and Europe in regard to non-fatal injuries and hazards onshore, including the dock and the moored vessel. The literature also helped to provide a valuable understanding of fatigue causes and effects.

This review's results fit well with the existing literature regarding fatalities, non-fatal injuries, and fatigue. Fatality research literature maintained consistency in results across national and international borders with the exception of cold-related conditions. Research on non-fatal injuries was limited. One discovery of value was a study conducted in the GoM outside of the public health literature regarding stress among fishers as it relates to fatigue.

This is a narrative review and not a systematic review. Thus, the findings are generalized and descriptive and do not necessarily reflect statistically significant results or countermeasures. Another limitation is the recognized serious underreporting of non-fatal injuries regarding small, sometimes single operator fishing vessels. In addition, this review depends on an abundance of literature from outside the GoM but, nonetheless, elements of this literature informs the research plans of GoM fishers with cross-regional patterns and investigation methods. There was a lack of accurate GoM-based denominator data for calculating injury rates on which risk assessments rely, and the US literature generally omitted data regarding onshore fish harvester injuries, likely because USCG data excluded these incidents. The review did not address recreational (sport) or subsistence and artisanal fishing.

While diving is an additional cause of fisher deaths, no study was found that addressed diving hazards in the GoM regarding fish harvesting. Diving hazards is addressed in Part 2 of this review series.

Future directions as informed by this review include the two companion reviews of risk factors associated with non-injury health effects (e.g., musculoskeletal disorders, eye diseases) and known countermeasures for risk reduction. These reviews inform a GoM study to conduct interviews and workplace observations and target interventions. Moreover, the review provides insights to conduct a review of USCG data from the GoM to better understand the circumstances of fishing-related fatalities, missing persons, and serious injuries as well as vessel disasters.

The major impact of this review is an understanding of the broader professional efforts involved in prevention activities worldwide regarding injuries among fish harvesters. Some specific insights are the importance of a focus on reducing hazards when working with gear and the need to identify onshore hazards; to consider dangerous wind and cyclone weather conditions in warnings to avoid going to sea; and personal factors such as overcoming stigmas against wearing PFDs, encourage the wearing slip-resistant footwear, and to regard vessel motion as related to motion sickness that is a principal risk factor for fisher fatigue.

As was done in Denmark and some US studies, mapping injuries against tasks (processes) provides an opportunity to target interventions. Fatigue is also addressed as a serious problem among fish harvesters and needs further analysis regarding its causes, extent, and interventions in future research, especially among small crews.

5. Conclusions

The most significant injury problem for both severity in the individual case and frequency of the condition identified in this review was FOB fatalities in the GoM which, along with non-fatal injuries, are linked to slippery and inherently unstable work platforms. Moreover, working alone in a boat or on deck negates or compromises rescue assistance as does not wearing PFDs when exposed to a FOB. Lack of swimming ability among many fishers is also a problem. FOBs were followed in frequency by fatalities related to vessel casualties for which knowledge of emergency circumstances of the incidents and response time would aid in developing interventions. Much less is known about non-fatal injuries and other health-related problems in the GoM with the exception of targeted problems such as winch entanglements, thus filling this information gap is an important avenue of study. Fatigue is a factor to be considered for further research including the nexus between safety and fishing cultures and a better understanding of work exhaustion. Body sway controls (e.g., sea legs) as well as medication may reduce motion sickness, an important risk factor regarding fatigue. Caffeine use is another potential control of sleepiness that can be considered.

Based on studies outside the GoM, risk of injury was high for (1) working with gear; (2) working on decks particularly regarding slips, sways, and trips; and (3) contact with hard surfaces. When examined against exposure time, boarding and disembarking vessels register as a high risk of injury. More information is needed about onshore injuries among fishers. A survey is needed that fills the gap in unreported injuries along with linking the outcomes with causes. Little research has been done about the isolation from medical care for an injured victim on board a vessel (including health risks such as heart attacks). Two companion articles follow this one and will address health effects other than injuries and potential known interventions to prevent work-related injuries and illnesses among fishers.

Author Contributions: M.L.M. conducted the search and initial composition of the manuscript. R.M.D. and A.S.K. provided ongoing reviews and edits of the manuscript, and A.S.K. directed the project.

Funding: The US National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention funded this research through a grant to the University of Florida South-Eastern Coastal Center for Agricultural Safety and Health, Gainesville, Florida, USA.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Literature Reviewed

Table A1. The geographic origin (area) of the study and topic, the safety problem, and a reference to the literature source, n = 48.

Area and Topic	Problem	Source
	Gulf of Mexico USA, n = 9	
Fishing	Fatalities	Kennedy and Lincoln 1997 [6]
Fishing	Fatigue, stress	Johnson et al. 1998 [57]
Fishing	Fatalities	Lincoln and Lucas 2010 Nov. [4]
Shrimping	Risk factors	Levin et al. 2010 [30]
Fishing	Injuries, illnesses, fatalities	Janocha 2012 [17]
Shrimping	Fatal and non-fatal injuries	Lucas et al. 2013 [30]
Fishing	Fatality rates	Marvasta 2014 [7]
Fishing	Fatal and non-fatal injuries	Syron et al. 2017 [5]
Fishing	Fatality risk factors	Marvasta 2017 [22]
	Atlantic Coast, n = 6	
Fishing (NC)	Non-fatal injuries	Marshall 2004 [31]
Fishing (NJ)	Fatal and non-fatal injuries	Day et al. 2010 [23]
Fishing	Weather	Rezaee 2015 [10]
Lobster (MA, ME)	Non-fatal injuries	Fulmer et al. 2016 [32]
Fishing	Non-fatal injuries	Syron, et al. 2016 [37]
Fishing	Weather	Rezaee et al. 2016 [27]
	Alaska USA, n = 5	
Fishing	Non-fatal injury	Husberg and Lincoln 2006 [34]
Fishing	Falls overboard	Lucas and Lincoln 2007 [19]
Fishing	Fatalities	Lincoln and Lucas 2010 Jul. [18]
Fishing	Fatalities	Lincoln and Lucas 2010 Oct. [21]
Shrimping	Winch injuries	Lucas et al. 2013 [30]
	Australia and New Zealand, n = 3	
Fishing	Fatigue	Baker and Ferguson 2006 [47]
Fishing	Fatigue	Gander et al. 2008 [51]
Fishing	Mortality	Byarb 2013 [25]
	Europe, n = 21	
Fishing	Fall and slip non-fatal injuries	Jensen 2000 [38]
Fishing	Gap analysis	Matheson et al. 2001 [9]
Mariculture	Injuries	Norwegian Labor Inspection Authority 2001 [45]
Fishing	Fatigue	Ólafsdóttir et al. 2004 [52]
Fishing	Injury, work process coding	Jensen 2005 [33]
Fishing	Injury incidents	Wang et al. 2005 [41]
Fishing	Work process exposure	Jensen et al. 2006 [40]
Seafarers	Fatigue	Smith et al. 2006 [54]
Seafarers	Fatigue	Allen et al. 2008 [53]
Fishing	Fatigue	Allen et al. 2010 [50]
Fishing	Footwear	Jensen and Laursen 2010 [39]
Fishing	Fatigue	Sąlyga and Kušleikaitė 2011 [49]
Fishing	Injuries	McGuinness et al. 2013 [36]
Fishing	Fatal injury trends	Jensen et al. 2014 [55]
Fishing	Fatigue	Høvdanum et al. 2014 [48]
Fishing	Injuries, diseases	Kaustell et al. 2016 [42]
Fishing	Fatalities and injuries	McGuinness 2016 [36]
Seafarers	Fatigue	Jepsen et al. 2017 [58]
Fishing	Non-fatal injury	Chauvin et al. 2017 [43]
Mariculture	Injuries	Holen, et al. 2017 [46]
Mariculture	Fatalities	Holen, et al. 2017 [26]
	Other, n = 3	
Marine safety	Human error	Rothblum 2000 [8]
Mariculture	Injuries, diseases	Myers and Durborow 2012 [44]
Crab, US West	Traumatic injuries	Case et al.2015 [24]

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