Safety Science 64 (2014) 71–81

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Review

Application of a translational research model to assess the progress of occupational safety research in the international commercial fishing industry

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ARTICLE INFO

Article history:
Received 5 September 2013
Received in revised form 19 November 2013
Accepted 20 November 2013
Available online 14 December 2013

Keywords:
Fishing industry safety
Translational research
Research to practice
Literature review
Occupational safety

ABSTRACT

Translating basic science research into population-level health benefits is a challenge in all areas of public health, including occupational safety in the fishing industry. Translational research is a process for developing evidence-based interventions and implementing them in practice. The purpose of this study was to organize the literature on occupational safety in the fishing industry within the T0–T4 phases of translational research to identify areas of strength and consensus, as well as gaps for future translational research to address. A comprehensive search of the English language literature on the topic of occupational safety in the fishing industry was completed. Scientific investigations of safety problems in the fishing industry first appeared in the literature during the 1950s. The bulk of research has focused on descriptive epidemiology in the T0 phase of translational research. A positive trend in recent studies is the growing emphasis on translational research (i.e. the T1–T4 phases). These types of studies aim to move research-to-practice by investigating potential solutions to safety problems and by developing, implementing and evaluating interventions. Recommendations for future translational research include using consistent methods of injury classification and risk analysis, developing interventions targeted at specific problems in the highest-risk fisheries, and addressing the barriers and facilitators to widespread implementation of interventions. Workplace safety in the fishing industry will improve if future research concentrates on identifying and testing promising safety measures that are effective, practical and scalable. Translational research is the key to making progress toward the prevention of work-related injuries in the fishing industry.

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0925-7535/$ - see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.ssci.2013.11.023

1. Introduction

Fish production is a critical element of global food security, generating a major source of animal protein for billions of people worldwide (FAO, 2010). Global employment in the fishing industry (the capturing of wild fish) is roughly estimated to be 35 million harvesting workers on 4.3 million vessels (FAO, 2010; ILO, 2010). Developing countries employ 97% of the global fish harvesting workforce, approximately 34 million workers (The World Bank, 2010). Fishing vessels vary widely in terms of size and configuration, ranging from small undecked vessels with as few as one person onboard to large decked vessels with dozens of crewmembers who catch and process fish into final products in factories onboard the vessels. Commercial fishing is generally believed to be the most dangerous occupation worldwide, with a rough estimate of 24,000 work-related deaths per year (FAO, 2000). The International Labour Organization has estimated that the fishing industry has a worldwide annual fatality rate of 80 deaths per 100,000 workers (Wagner, 2003). Recognizing the deficiencies in record keeping and fatality reporting in many countries, the true rate of occupational mortality is probably considerably higher (FAO, 2000).

Research on occupational safety in the fishing industry first appeared in the scientific literature during the 1950s. These early case studies and descriptive epidemiologic analyses quantified the injury burden among workers on Polish and United Kingdom (UK) deep sea fishing vessels (Bowdler, 1954; Burns, 1955; Ejsmont, 1958). Since then, research on worker safety in the fishing industry has expanded into a multi-disciplinary, international field (Matheson et al., 2001; Perez-Labajos, 2008; Wagner, 2003). As the volume of research has grown, some authors have observed that the literature lacks cohesion (Perez-Labajos, 2008) and is methodologically inconsistent and narrowly focused (Windle et al., 2008). It has been suggested that research findings and recommendations produced in numerous countries are not efficiently exchanged between academic and governmental researchers, regulatory bodies and the fishing industry. As a result, benefits from interventions do not reach the majority of the world's fishermen (Wagner, 2003), demonstrating a potential deficiency in translating research into practice.

Translating basic science research into population level health benefits is a challenge in all areas of public health (Khoury et al., 2007) including occupational safety in the fishing industry. From a public health perspective, translational research is "a process for developing evidence-based interventions and implementing them in practice" (Khoury et al., 2010). Many models for translational research have been developed (Sussman et al., 2006), including the two-step model defined by the National Institutes of Health (NIH) in launching the Clinical and Translational Science Award (CTSA) program in 2006 (NIH, 2006). The NIH model was later refined by adding a third step (Westfall et al., 2007) and a fourth step (Khoury et al., 2007) to delineate the various types and purposes of research necessary to move from basic science to population impact. This refined NIH process of translational research begins with the description of a health outcome (T0) and proceeds through four translation or "T" phases (T1–T4) of research, with T4 studies showing a measurable improvement in the outcome at a population level. This model of translational research has become widely recognized, and has been adopted as part of the definition of translational research by the current CTSA funding cycle (NIH, 2012).

As described by Khoury et al. (2010), research at the T0 phase contributes to the description of a health problem and discovery of a potential intervention point (e.g., risk factor). T1 research is responsible for assessing the application or intervention potential of a discovery, such as a risk factor or protective factor for a particular health problem. The role of T2 research is to move an intervention from candidacy to evidence of efficacy. After a candidate intervention has been evaluated and found to be efficacious in samples of the population-at-risk, T3 research aims to promote widespread implementation of the intervention. Once the T3 phase research has been completed and the intervention has been disseminated, T4 research seeks to move from widespread

Table 1
Application of the NIH translational research model to occupational safety in the fishing industry[a].

Phase	Details	Role of occupational safety research	Fishing industry safety example
T0	Description of a health outcome and discovery of a potential intervention point (e.g. risk factor)	Describing patterns of injury outcomes by place, time and person (e.g. "descriptive" epidemiology); identifying determinants of injuries (e.g. "analytical" or "risk factor" epidemiology)	Case control study of injuries on fishing vessels in Denmark found foot traffic onboard, especially embarking and disembarking, to be the highest risk work process (Jensen et al., 2006)
T1	From discovery of risk factor to intervention idea	Characterizing discovery and generating potential solutions (e.g. intervention ideas)	Researchers developed safety check-lists as a potential intervention to address specific hazards identified on Spanish fishing vessels (Piniella and Fernandez-Engo, 2009)
T2	From candidate intervention to evidence of efficacy	Assessing the efficacy of candidate interventions on samples from the population at risk by using observational and experimental studies	Observational study tested an intervention on Swedish fishing vessels. The intervention involved visiting captains at their boats and identifying hazards and solutions. Six month follow-ups found 80% of captains had corrected at least 1 hazard (Torner et al., 2000)
T3	From evidence of efficacy to widespread implementation	Assessing facilitators and barriers for uptake and widespread implementation and adoption	Ethnographic study of Australian fishery workers mapped their safety-decision making process to identify barriers and enabling factors for safety interventions (Brooks, 2007)
T4	From widespread implementation to population health outcomes	Assessing the effectiveness of widely disseminated interventions on injury outcomes at the population level	Study used population level surveillance data to measure the effect of the 1988 Commercial Fishing Industry Vessel Safety Act on fatal injuries in the Alaska fishing industry (Lincoln et al., 2001)

[a] Adapted from Khoury et al., 2010.

implementation to population health outcomes. See Table 1 for examples of the phases identified in the fishing industry safety literature.

The NIH translational research model is one way to conceptualize the process of moving from basic research to practice. Other models include the *research to practice* (r2p) initiative created by the National Institute for Occupational Safety and Health (NIOSH) and the *Knowledge Transition* (KT) model developed by the Canadian Institutes for Health Research (CIHR) (Huy et al., 2012). This paper will focus on the NIH translational research model and show how it can be used to analyze the existing body of research in a given field to identify the gaps and provide direction for future work. The purpose of this study was to organize the literature on occupational safety in the fishing industry within the T0–T4 phases of translational research to identify areas of strength and consensus, as well as gaps for future translational research to address.

2. Methods

2.1. Definitions

For the purpose of this study, fishing was defined as the commercial catching or taking of finfish, shellfish, or other marine animals from a natural habitat (OMB, 2007). Occupational safety was defined as protection from work-related traumatic injuries, using criteria for an injury at work as specified by the Operational Guidelines for Determination of Injury at Work, (NIOSH, 2001). Because of the unique setting in which commercial fishing takes place (i.e., workers are exposed to work-related hazards even when off duty), workers in the fishing industry were considered "at work" for the entire time they were at sea. The outcome of interest for occupational safety is traumatic injury, defined in this study as damage to cells and organs from the transfer of energy in amounts above or below the tolerance of human tissue that has sudden, discernible effects (Robertson, 2007).

2.2. Inclusion/exclusion criteria

Only peer-reviewed articles appearing in scientific journals were included. Conference proceedings, presentations, unpublished reports, government documents, commentaries and letters to the editor were excluded. Articles in English from all years and all countries were included. All study designs were included, including qualitative designs. Non-English language articles were excluded, as resources to translate articles into English were not available. Studies of aquaculture workers and non-commercial fishing activities such as sport fishing and subsistence fishing were excluded. Articles on occupational health outcomes (e.g., illnesses and chronic conditions) were excluded. Musculoskeletal disorders (of a cumulative nature) and noise induced hearing loss were categorized as health outcomes rather than acute traumatic injuries, and were excluded from this study. Some articles included research on both occupational safety and health, which were included in this analysis in order to extract the relevant findings on safety outcomes.

2.3. Literature search process

The literature search covered all publication years through the end of 2012 in an attempt to include the earliest articles. The search used a two-step process to identify articles published on the multi-disciplinary topic of occupational safety in the fishing industry. The first step was a keyword search of relevant terms in four major databases (PubMed, Web of Science, PsychInfo, and Google Scholar) that index journals which publish papers in the fields of epidemiology, public health, occupational safety and health, sociology, psychology, anthropology, engineering, and risk. The search procedure used Boolean logic and wildcards to search combinations of terms including: fish, fishing, fishery, fisheries, safety, health, injury, injuries, fatal, fatality, fatalities, mortality, morbidity, drown, drowning, accident, disaster, casualties, occupation, occupational, work, vessel, industry, and industrial. The lists of article titles generated from each search were reviewed, and the titles were selected if they appeared to be related to occupational safety in the fishing industry. The abstracts of the selected titles were then examined to identity those meeting the inclusion criteria. The second step of the literature search was a review of the reference lists of the selected articles to identify additional papers that were not found through the database searches. This two-step approach to searching the literature increased the probability of identifying all relevant articles on the subject of interest.

2.4. Analysis

Articles meeting the inclusion criteria were entered and organized in EndNote X5 software (Thomson-Reuters, 2011). Included articles were then classified according to major research themes such as descriptive epidemiology of fatal and non-fatal injuries, analysis of risk factors of injuries, analysis of the determinants of vessel disasters (sinking, capsizing, fire, etc.) and other injurious events, studies of risk perceptions, safety attitudes, safety culture, and other barriers and enabling factors to injury prevention, and the development, implementation and evaluation of safety interventions. These research themes emerged and grew from the literature as each study was reviewed. Information was extracted from each study on its publication year, country of study population, year(s) of study period, originally calculated fatal and non-fatal injury rates, study design, and key findings. The translational research phase that each study contributed to was coded (T0–T4) using the definitions outlined in Table 1. In some instances a single study contributed to more than one translational research phase, resulting in classification into more than one phase of translational research.

3. Results and discussion

The literature search yielded 169 peer-reviewed articles (for complete list refer to online supplementary file) on occupational safety in the fishing industry published in 65 scientific journals. Each article reported the results of a single study. The earliest study was published in 1954 and research was slow to gain momentum. During the 1950s–1980s there was an average of just one article published per year. During the 2000s the pace of publication had increased to almost eight per year and 80% of the total research was published after 1990 (Table 2).

The body of literature was concentrated on the fishing industries of 19 countries, with most research on workers in the United States (54, 32%), United Kingdom (30, 18%) and Denmark (13, 8%). Only 11

Table 2
Studies on occupational safety in the fishing industry by decade of publication.

Decade	No. articles	Percent	Avg/yr
1950s	3	2	0.3
1960s	4	2	0.4
1970s	15	9	1.5
1980s	12	7	1.2
1990s	33	20	3.3
2000s	76	45	7.6
2010s (3 yrs)	26	15	8.7
Total	169	100	2.7

Table 3
Studies on occupational safety in the fishing industry by country of study population.

Country	No. articles	Percent
United States	54	32
United Kingdom	30	18
Denmark	13	8
Canada	11	7
Poland	11	7
International	8	5
Norway	7	4
Spain	7	4
Australia	6	4
France	6	4
Sweden	6	4
New Zealand	2	1
Egypt	1	1
Greece	1	1
Iceland	1	1
Indonesia	1	1
Italy	1	1
Papua New Guinea	1	1
Portugal	1	1
Turkey	1	1
Total	169	100

Table 4
Studies on occupational safety in the fishing industry by translational research phase.

TR phase	Count[a]	Percent[b]
T0	118	70
T1	31	18
T2	11	7
T3	29	17
T4	8	5

[a] Total count exceeds 169 because a single article may contribute to more than one TR phase.
[b] Percent of total articles (n = 169).

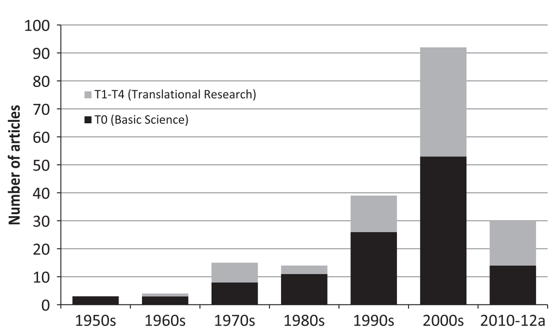

Fig. 1. Number of articles published on fishing industry safety by decade and translational research phase. [a]Three-year period.

articles (7%) involved populations outside of North America and Europe (Table 3). A broad range of themes were addressed in the literature, originating from a host of disciplines including epidemiology, medicine, engineering, health promotion, psychology, sociology, anthropology, and marine policy. The theme of most studies (69%) was the description of patterns and determinants of occupational injuries. Seventy percent of the articles (118 studies) contributed to the T0 phase, while the lowest percentage (5%) contributed to the T4 phase (Table 4). Detailed descriptions of the literature in each translational research phase follows.

3.1. T0 research: description of injuries, hazards and risk factors

Research at the T0 phase contributes to the description of a health problem and discovery of a potential intervention point (e.g., risk factor). In the context of epidemiology, T0 research involves describing patterns of health problems by place, time and person (e.g., "descriptive" epidemiology), and identifying determinants of health outcomes (e.g., "analytical" or "risk factor" epidemiology). These T0 studies are not translational research (T1–T4), but are crucial as a foundation for subsequent research. In the fishing safety literature, T0 studies described patterns of fatal and nonfatal occupational injuries, identified hazards (exposures) that may lead to injuries, and measured risk factors for injuries and injurious events such as vessel disasters.

Although the majority of published research on fishing industry safety has contributed to the T0 phase of description and discovery (Table 4), the proportion of studies that are T0 research has been decreasing (Fig. 1). During the 1980s, 79% of studies were T0 research, decreasing to 67% in the 1990s, 58% in the 2000s, and 47% in the first three years of the 2010s. This trend suggests that translational research (T1–T4) has an increasing share, growing out of the foundation of knowledge set by decades of T0 research.

3.1.1. Fatal injuries

This review identified 36 studies that calculated 63 fatality rates in nine countries (Table 5). The reported rates ranged from 0 to 600 fatalities per 100,000 workers, person-years, or full-time equivalents. Direct comparisons of published fatality rates were not possible because denominator definitions and inclusion criteria for cases varied among studies, even in the same country, and often the published methods were not clear enough to group methodologically similar studies. The earliest study to calculate a fatality rate for workers in the fishing industry was published in 1966 in the UK, and the latest was published in 2010 in the US. Fatality rates in developing nations were not found in the English language literature.

In most country-level analyses of fishing fatalities (in which all fisheries of the country were aggregated), vessel disasters were the leading cause of fatalities (Driscoll et al., 1994; Jaremin and Kotulak, 2004; Schilling, 1966). The highest contribution of vessel disasters to worker fatalities was in Alaska fisheries during 1978–1981 where 85% of fatalities were caused by vessel disasters (Gleason, 1983). Studies of fatalities in other regions of the US found that vessel disasters were also a high contributor to death (71–74% of fatalities) (Lincoln and Conway, 1999; Lincoln et al., 2001; Lincoln and Lucas, 2008).

Although overall fishing industry fatalities in most countries were the result of vessel disasters, studies that analyzed individual fisheries rather than combined fisheries have found exceptions. A fishery is generally defined by the type of fish being targeted and the type of fishing gear being used, as well as the geographic location of fishing activities. Vessels operating in a specific fishery are a more homogenous group than an aggregate of vessels from many or all fisheries in a country. Two studies of fatalities in the Polish deep-sea trawl fishery during 1977–1986 and 1985–1994 reported no deaths related to vessel disasters (Jaremin et al., 1997; Tomaszunas, 1992b). Instead, fatalities in that fishery were most commonly caused by falling overboard or being caught in machinery. A study of fatalities on UK deep-sea trawlers in 1963 reported six deaths due to falls overboard and contact with machinery, with none related to vessel disasters (Moore, 1969). Fatalities in the Maine sea urchin fishery during 1993 also did not involve vessel disasters but rather injuries sustained while diving to gather the urchins (Shannon et al., 1994). These studies demonstrate the importance of conducting T0 research at the fishery-level rather than the country-level. The risk of fatal injuries varied widely by

Table 5
Work-related fatality rates in the fishing industry (ordered by country and time period).

Lead author (year)	Country	Fishery	Time period	No. deaths	No. exposed	Rate per 100,000	Exposure type
Driscoll, T. (1994)	Australia	All Australian Fisheries	1982–1984	47	32944	143	Person-Yrs
Mitchell, R. (2001)	Australia	All Australian Fisheries	1989–1992	55	61639	89.2	Number of Workers
O'Connor, P. (2006)	Australia	All Australian Fisheries	1992–1998	46	82143	56	Number of Workers
Hasselback, P. (1990)	Canada	Atlantic Provence Fisheries	1975–1983	98	183378	53.4	Person-Yrs
Neutel, C. (1989)	Canada	Atlantic Provence Fisheries	1975–1983	95	183378	51.8	Person-Yrs
Laursen, L. (2008)	Denmark	All Danish Fisheries	1995–2005	Unk	Unk	100	Number of Workers
Norrish, A. (1990)	New Zealand	All New Zealand Fisheries	1975–1984	79	30385	260	Number of Workers
Aasjord, H. (2006)	Norway	Deep Sea Fishery, >28 m	1998–2006	15	68493	21.9	Person-Yrs
Aasjord, H. (2006)	Norway	Medium Coastal, >13, <27.9 m	1998–2006	23	37643	61.1	Person-Yrs
Aasjord, H. (2006)	Norway	All Norway Fisheries	1998–2006	85	125000	68	Person-Yrs
Aasjord, H. (2006)	Norway	Small Coastal <12.9 m	1998–2006	47	18952	248	Person-Yrs
Jaremin, B. (2004)	Poland	Inshore Boat & Cutter	1960–1999	177	198920	89	Number of Workers
Tomaszunas, S. (1992)	Poland	Baltic Sea Small Boat Fleet	1977–1985	0	1033	0	Number of Workers
Tomaszunas, S. (1992)	Poland	Baltic Sea Trawl Firm S	1977–1985	5	4706	107	Number of Workers
Tomaszunas, S. (1992)	Poland	Baltic Sea Trawl Firm B	1977–1985	9	3270	275	Number of Workers
Tomaszunas, S. (1992)	Poland	Atlantic Factory Trawl	1977–1986	33	10475	32	Number of Workers
Jaremin, B. (1997)	Poland	3 Global Trawl Fisheries	1985–1994	11	64044	17.2	Number of Workers
Kotulak, E. (2000)	Poland	Inshore Boat & Cutter Fleets	1985–1994	32	48113	66.5	Number of Workers
Torner, M. (2000)	Sweden	All Swedish Fisheries	1983–1995	24	34286	70	Number of Workers
Schilling, R. (1966)	United Kingdom	All UK Fisheries	1948–1964	757	700926	108	Full Time Equivalent
Schilling, R. (1971)	United Kingdom	Near and Middle Water Side Trawlers	1958–1967	Unk	Unk	180	Person-Yrs
Schilling, R. (1971)	United Kingdom	Distant water side trawlers	1958–1967	Unk	Unk	230	Person-Yrs
Reilly, M. (1985)	United Kingdom	All UK Fisheries	1961–1980	711	420710	169	Full Time Equivalent
Moore, S. (1969)	United Kingdom	Grimsby Deep Sea Trawl	1963	6	2460	240	Number of Workers
Richardson, W. (1975)	United Kingdom	Port of Hull Trawlers	1973	7	3354	200	Number of Workers
Roberts, S. (2004)	United Kingdom	All UK Fisheries	1976–1995	454	440355	103	Person-Yrs
Mayhew, C. (2003)	United Kingdom	All UK Fisheries	1989–1992	58	54717	106	Number of Workers
Roberts, S. (2010)	United Kingdom	All UK Fisheries	1996–2005	160	156863	102	Person-Yrs
Gleason, R. (1983)	United States	All Alaska Fisheries	1978–1981	146	161191	90.6	Number of Workers
Schnitzer, P. (1993)	United States	All Alaska Fisheries	1980–1984	Unk	Unk	414.6	Avg Monthly Employ
Conway, G. (1998)	United States	All Alaska Fisheries	1990–1994	117	85000	140	Full Time Equivalent
Lincoln, J. (2001)	United States	Alaska Halibut	1990–1999	Unk	Unk	119	Full Time Equivalent
Lincoln, J. (2001)	United States	All Alaska Fisheries	1990–1999	217	175000	124	Full Time Equivalent
Lincoln, J. (2001)	United States	Alaska Herring	1990–1999	Unk	Unk	204	Full Time Equivalent
Lincoln, J. (2001)	United States	Alaska Shellfish	1990–1999	Unk	Unk	407	Full Time Equivalent
Kennedy, R. (1993)	United States	Alaska Herring	1991–1992	0	1000	0	Full Time Equivalent
Kennedy, R. (1993)	United States	Alaska Groundfish	1991–1992	8	9200	90	Full Time Equivalent
Kennedy, R. (1993)	United States	Alaska Salmon	1991–1992	14	15000	90	Full Time Equivalent
Kennedy, R. (1993)	United States	All Alaska Fisheries	1991–1992	70	34800	200	Full Time Equivalent
Kennedy, R. (1993)	United States	Alaska Halibut	1991–1992	9	3000	300	Full Time Equivalent
Kennedy, R. (1993)	United States	Alaska Shellfish	1991–1992	32	6000	530	Full Time Equivalent
Lincoln, J. (1999)	United States	Alaska Halibut	1991–1998	Unk	Unk	92	Full Time Equivalent
Lincoln, J. (1999)	United States	All Alaska Fisheries	1991–1998	162	139200	116	Full Time Equivalent
Lincoln, J. (1999)	United States	Alaska Herring	1991–1998	Unk	Unk	250	Full Time Equivalent
Lincoln, J. (1999)	United States	Alaska Shellfish	1991–1998	Unk	Unk	275	Full Time Equivalent
Thomas, T. (2001)	United States	All Alaska Fisheries	1991–1998	167	388372	43	Number of Workers
Thomas, T. (2001)	United States	All Alaska Fisheries	1991–1998	167	140336	119	Full Time Equivalent
Drudi, D. (1998)	United States	All U.S. Fisheries	1992–1996	380	271429	140	Number of Workers
Shannon, S. (1994)	United States	Maine Sea Urchin	1993	4	1439	278	Number of Workers
Lincoln, J. (2008)	United States	Westcoast Groundfish	2000–2006	10	13889	72	Full Time Equivalent
Lincoln, J. (2008)	United States	Westcoast Salmon & Other Pelagic	2000–2006	15	11364	132	Full Time Equivalent
Lincoln, J. (2008)	United States	All Westcoast Fisheries	2000–2006	58	24370	238	Full Time Equivalent
Lincoln, J. (2008)	United States	Westcoast Shellfish	2000–2006	23	6354	362	Full Time Equivalent
Lincoln, J. (2008)	United States	Northwest Dungeness Crab	2000–2006	17	3672	463	Full Time Equivalent
Lincoln, J. (2010)	United States	Alaska Salmon	2000–2009	39	34287	115	Full Time Equivalent
Lincoln, J. (2010)	United States	Alaska Cod	2000–2009	26	21327	120	Full Time Equivalent
Lincoln, J. (2010)	United States	Alaska Halibut	2000–2009	10	7519	130	Full Time Equivalent
Lincoln, J. (2010)	United States	Atlantic Snapper/Grouper	2000–2009	6	3622	170	Full Time Equivalent
Lincoln, J. (2010)	United States	Bearing Sea and Aleutian Islands Crab	2000–2009	12	4658	260	Full Time Equivalent
Lincoln, J. (2010)	United States	Westcoast Dungeness Crab	2000–2009	25	8092	310	Full Time Equivalent
Lincoln, J. (2010)	United States	Atlantic Scallop	2000–2009	44	10384	425	Full Time Equivalent
Lincoln, J. (2010)	United States	Northeast Multispecies Groundfish	2000–2009	26	4340	600	Full Time Equivalent
Day, E. (2010)	United States	All New Jersey Fisheries	2001–2007	31	18942	164	Full Time Equivalent

fishery, as did the types of incidents responsible for causing fatalities.

T0 research on fishing industry safety indicates that vessel disasters are a vital area to target prevention efforts. Prevention of vessel disasters has the potential to save many lives, especially since a single disaster can place many workers in danger at the same time. One group of T0 studies characterized the types of vessel disasters in terms of their immediate causes. In a study of fatalities in the UK during 1996–2005, foundering/capsizing caused 68% of disasters, followed by grounding (8%), fires/explosions (8%), and collisions (3%) (Roberts, 2010). A study of work-related fatalities in the US fishing industry conceptualized vessel disasters as occurring in a sequence of events, from an initiating event to a final event (Lincoln and Lucas, 2010). The study found that during 2000–2009, 261 out of 504 fatalities resulted from 148 separate vessel disasters in US fisheries. The most frequent initiating events to vessel disasters were flooding (28%), instability (18%), struck by a large wave (18%), collision (10%), and fire/explosion (5%).

In addition to the studies describing the causes of vessel disasters in the UK and US, several studies were conducted in Poland (Jaremin et al., 1997; Kotulak and Jaremin, 2000), Australia (Driscoll et al., 1994; O'Connor and O'Connor, 2006), and Denmark (Laursen et al., 2008) with similar results. The main limitation of these and other studies describing the characteristics of vessel disasters is the absence of control groups of vessels to enable the measurement of risk factors for vessel disasters. A key part of T0 research is the identification of risk factors for the outcome of interest. In order to identify risk factors for vessel disasters, data must be obtained on the hypothesized exposure, and on the occurrence of the outcome (vessel disasters) among exposed and unexposed vessels. The rates of vessel disasters can be calculated using the exposure and outcome data to estimate the risk of disaster among the exposed and unexposed vessels. For example, in an analysis of British trawler disasters during 1957–1966, Schilling (1971) hypothesized that vessel age was a risk factor for vessel disasters. He obtained data on the age and days-at-sea per year of all British trawlers, and categorized them as older than 21 years (the exposed group) and under 21 years old (the unexposed group). He then calculated the rate of occurrence of vessel disasters (the outcome) per 100 vessel-years in each group. Schilling found that trawlers older than 21 years were at higher risk of vessel disasters (2.55 disasters/100 vessel-years) than trawlers under 21 years old (0.86 disasters/100 vessel-years), a risk-ratio of 2.96. The results supported the hypothesis that vessel age was a risk factor for vessel disasters.

Nine studies from five countries identified risk factors for vessel disasters by estimating risk based on exposure. Collectively, these studies found that the risk of vessel disasters was higher among older vessels, medium sized vessels, trawlers and longliners, in certain geographical areas, in poor weather conditions, and during winter (Jin et al., 2001, 2002; Jin and Thunberg, 2005; Norrish and Cryer, 1990; Perez-Labajos et al., 2006, 2009; Schilling, 1971; Wu et al., 2005, 2009). The scarcity of research on the risk factors for vessel disasters is a clear gap in the literature.

3.1.2. Non-fatal injuries

The risk of non-fatal injuries in the fishing industry was assessed by 16 studies in seven countries. Their methods for identifying cases and measuring exposure varied sufficiently that comparisons of risk between studies were not possible. For example, a prospective cohort study in North Carolina during 1999–2002 found 2.7 self-reported injuries per 1000 work-days (Kucera et al., 2010). A retrospective study of compensated injuries from claims filed in New Zealand during 1987–1988 reported a rate of 104 injuries per 1000 workers per year (Norrish and Cryer, 1990). The rates from these two studies (and others) are not comparable due to differences in the source of data and exposure definition.

Results from studies on non-fatal injuries indicate that the most common types, sources and severities of non-fatal injuries are different depending on the fishery and vessel type. Injuries to workers in the Turkish Aegean small-scale fisheries were most often minor injuries due to falls on board (Percin et al., 2012) whereas workers in North Carolina fisheries commonly experienced penetrating wounds from fish spines (Marshall et al., 2004). Non-fatal injuries among Scottish fishermen were most often described as acute back injuries (Lawrie et al., 2003). The broad range of findings from studies of non-fatal injuries emphasizes the need for T0 research to target specific fisheries to identify their unique injury patterns.

Risk factors for non-fatal injuries were empirically identified by 13 studies. Four studies examined the age of workers as a possible risk factor, and found mixed results. In Norwegian fisheries during 1991–1996, the highest risk of injuries was among younger workers (Bull et al., 2001). Other studies in New Zealand, North Carolina, and Denmark found that age did not increase the risk of injuries (Jensen, 1996; Kucera et al., 2010; Norrish and Cryer, 1990). The differences in these findings may be due to differences in the fisheries or study methods. Two studies in Poland and Denmark found that vessel size was a risk factor for non-fatal injuries. In Poland, workers on small vessels had a higher risk of injuries than those on large vessels (Tomaszunas, 1992a), while in Denmark the risk was highest on large vessels (Jensen, 1996).

3.2. T1 research: intervention ideas for improving safety

T1 research is responsible for assessing the application potential of a discovery, such as a risk factor or protective factor for a particular health or safety problem. These studies aim to characterize the discovery and generate potential solutions such as intervention ideas. The potential interventions are designed to mitigate risk factors or promote protective factors. T1 research may generate and develop potential interventions through qualitative methods such as case studies, focus groups or Delphi studies, or through examination of existing theoretical frameworks. In the literature on fishing industry safety, 18% of research (31 studies) contributed to the T1 phase of translational research (Table 4). Only 11 studies were solely T1 research. Most often T1 research was completed in conjunction with T0 research (11 studies) or T2 research (6 studies).

The earliest T1 studies were published in the 1970s and focused on designing safer work clothing for fishermen in the UK. The researchers described the work clothing that was available to fishermen at that time and the features that would be required to make the clothing safer. Prototypes were designed that incorporated all the required features, including flotation and thermal protection (Constable, 1970; Crockford, 1970, 1973; Newhouse, 1970).

The majority of T1 research (65%) was published during 2000–2012. A wide range of intervention ideas were conceived and explored in these studies, such as safety check-lists (Piniella and Fernandez-Engo, 2009), collision avoidance systems (Morel and Chauvin, 2006), safety guidebooks (Jezewska et al., 2011), emergency-stop systems (Lincoln et al., 2008), fisheries management policies (Kaplan and Kite-Powell, 2000), safety legislation (Lincoln et al., 2001; Wagner, 2003), personal protective equipment (Storholmen et al., 2012), and marine safety training (Levin et al., 2012).

The importance of T1 research in the field of fishing safety is that it generates potential solutions to problems described in T0 studies. Research at the T1 phase sets the stage for testing the efficacy of interventions at the subsequent T2 phase. The quality of T1 research is dependent on the availability and use of validated T0 research.

3.3. T2 research: evidence of intervention efficacy in samples

The role of T2 research is to move an intervention from candidacy to evidence of efficacy. This is done by assessing the efficacy of candidate interventions on samples from the population-at-risk by using observational and experimental studies. Ideally, samples should be representative of the larger population so that the findings are more likely to be valid and generalizable. Only seven percent of the literature (11 articles) was T2 research (Table 4). None of the T2 studies were published prior to 2000, making T2 research in fishing industry safety a relatively new undertaking. These studies used the findings of T0 and T1 research to test the efficacy of proposed interventions on improving safety. Out of 12 interventions tested (one study tested two interventions), five were worker education programs, three were firm or government policies, and

Table 6
Studies on the efficacy of interventions to prevent work-related injuries in the fishing industry (T2 research).

Lead author (year)	Country (state)	Study design	Intervention	Intervention category	Outcome(s)	Findings
Chauvin, C. (2008)	France	Pre/post intervention evaluation	Vessel design for safety	Firm or govt policies	Hazard reduction	On a large vessel, hazards were designed out. On 3 small vessels, designing out hazards failed
Morel, G. (2009)	France	Firm risk comparison	Firm management policies	Firm or govt policies	Vessel disasters, injury rates	High performance firms had lower rates of vessel disasters but higher rates of injuries than low performance firms
Davis, M. (2011)	United States (Maine)	Cross-sectional survey & vessel examination	Safety legislation	Firm or govt policies	Compliance with safety laws	40% Of vessels were not in compliance with 1988 legislation for safety equipment
Geving, I. (2006)	Norway	Safety product design and testing process	Comfortable, buoyant work clothing	Safety product	Work clothing preferences	Improved work clothing was found to be comfortable and acceptable to workers
Lincoln, J. (2008)	United States (Alaska)	Safety product design and testing process	Emergency-stop button for deck winches	Safety product	Worker approval of system	E-stop system was found to be unobtrusive and acceptable to workers on test vessels
Morel, G. (2009)	France	Product field testing	Collision avoidance system	Safety product	Use of product	Workers misused the collision system to improve productivity, which interfered with the safety features of the system
Jensen, O. (2011)	Denmark	Case control	Anti-slip boots	Safety product	Slips, trips and falls	The incidence of slips, trips and falls was lower with the anti-slip boots than the old boots
Torner, M. (2000)	Sweden	Pre/post intervention evaluation	Interactive vessel safety inspections	Worker education	Hazard reduction	Follow-up found 80% of captains had corrected at least 1 hazard. Most common safety corrections were higher use of safety glasses, hearing protection, and ergonomic improvements
Eklof, M. (2005)	Sweden	Pre/post intervention evaluation	Participatory accident analysis	Worker education	Risk perceptions, safety practices	Modest increase in safety practices observed post intervention
Murray, M. (2006)	Canada	Community based participatory research	Community arts events on safety theme	Worker education	Safety awareness	Participation and enthusiasm for program was high. Safety awareness was heightened
Dzugan, J. (2010)	United States (Alaska)	Mixed qualitative methods	Marine safety training	Worker education	Survival of vessel disaster	Workers involved with vessel disasters reported that their safety training helped them survive
Levin, J. (2012)	United States (Texas)	Qualitative pilot project	Culturally appropriate marine safety training	Worker education	Safety knowledge/skills	Culturally appropriate safety training materials were found to be effective for educating Vietnamese workers

four were various safety products (Table 6). Only three T2 studies evaluated efficacy in terms of injury reduction. The other studies measured the efficacy of interventions on different intermediate outcomes thought to be associated with injury reduction.

The efficacy of formal safety training (courses with established lesson plans) as an intervention to improve safety was evaluated by two studies (Dzugan, 2010; Levin et al., 2012). One evaluated an Alaska-based safety training program, which was initiated in 1985 and focused on emergency preparedness and marine survival. Evidence was found through interviews with a sample of workers that the formal safety training program helped them survive vessel disasters. The other study used industry partnerships to develop culturally appropriate safety training materials for Vietnamese fishermen. The training was delivered to samples of fishermen and was found to be effective at fostering participation and teaching the safety skills.

Interventions aimed at improving safety through informal education of workers have also been assessed. Torner et al. (2000) evaluated an educational intervention with 101 Swedish fishing vessels. A safety engineer visited each vessel at baseline and inspected the vessel. The engineer then educated the vessel operator on preventive measures for hazards identified. After six months, the authors found that 80% of vessel operators had addressed at least one of the deficiencies identified in the safety inspection.

In another participatory intervention aimed at informally educating workers to improve safety, Eklof and Torner (2005) recruited 11 Swedish fishery workers to participate in a 10-month group-discussion program. The workers met at baseline to take a questionnaire regarding risk perceptions and safety behaviors. The workers then kept incident diaries and met as a group six times during the study time period to discuss and analyze the incidents in which they were involved. The qualitative analysis of the group discussions suggested that experience with incidents did not lead to preventive measures by the workers; however there were some indications that the group discussions increased safe behaviors such as fixing safety-related problems and certain risk perceptions including the manageability of risks.

Safety products such as engineering controls and personal protective equipment (PPE) have been evaluated in four studies for efficacy in reducing injuries onboard fishing vessels. Jensen and Laursen (2011) evaluated an intervention to reduce slips, trips and falls to workers on fishing vessels in Denmark by outfitting workers with anti-slipping boots; self-reported slips, trips and falls decreased after switching to the anti-slip boots. Lincoln et al. (2008) addressed the hazard of winch-related injuries on purse seine fishing vessels in Alaska. An emergency-stop button located strategically on the hydraulically powered winch was determined to be the most practical solution based on three safety engineers' field and lab research. The device was developed, tested, and licensed to a manufacturer for installation on new winches and for retrofitting on existing winches.

Although T2 studies were only a small proportion of the total published research on fishing industry safety, the recent emergence of this type of research is a positive trend. Interventions will be most successful when they are targeted at specific safety problems and have been tested for efficacy in samples of the population-at-risk. T2 research appears to be a growing area of emphasis, but is still rather limited and is a gap that needs to be addressed. Many intervention ideas proposed in T1 studies have yet to be tested for efficacy.

3.4. T3 research: facilitators and barriers to widespread implementation

After a candidate intervention has been evaluated and found to be efficacious in samples of the population at risk (typically in ideal situations), T3 research aims to move the intervention from evidenced to widespread implementation. These types of studies assess facilitators and barriers for uptake and widespread implementation and adoption. The findings can be used to design the dissemination plan, utilizing the facilitators and overcoming the barriers. T3 research is crucial for making widespread adoption of an intervention successful, because it uncovers problems and concerns prior to implementation. In the literature on fishing industry safety, 17% of studies (29 articles) contributed to T3 research (Table 4). Like T1 and T2 studies, the bulk of T3 studies were published recently, with 72% of the work appearing during 2000–2012.

T3 studies took two main approaches. The first approach, which included all of the studies published prior to the late 1990s, analyzed barriers and facilitators to safety interventions in general. These 15 studies were not linked to a specific intervention, but examined how certain factors like risk perceptions, risk preferences, and worker culture hinder the adoption of all safety initiatives. The second approach analyzed barriers and facilitators to specific safety interventions such as marine safety training and use of PPE. These 14 studies have appeared more recently in the literature and were often directly related to published T1 and T2 studies.

Studies on risk preferences and risk perceptions of fishing industry workers have found mixed results. A study in Maine concluded that workers were risk loving (Davis, 2012), while studies in California and Sweden found that workers were risk neutral or risk averse (Eggert and Martinsson, 2004; Smith and Wilen, 2005). Studies on risk perceptions found that workers' perceived risk was either low (Bye and Lamvik, 2007; Davis, 2012; Eklof and Torner, 2002) or high (Brooks, 2005; Pollnac et al., 1998). These studies involved workers in many different fisheries in various parts of the world. The inconsistent findings suggest that workers in different fisheries do not share the same risk characteristics, indicating that solutions to safety problems must be tailored to specific fisheries to address the particular barriers of the workers within those fisheries.

Out of five T3 studies on barriers and facilitators to using PPE, four focused on personal flotation devices (PFDs). Geving et al. (2006) incorporated the concerns of workers in the design of safer work clothing with inherent buoyancy. Storholmen et al. (2012) found that workers in northern regions of Europe gave flotation high priority in their preferences for work clothing, while Mediterranean workers resisted the incorporation of flotation. Lucas et al. (2012) measured workers' satisfaction with PFDs to identify the preferred ergonomic features of the devices. Workers in each fishery found PFDs that were acceptable to work in. A study on the decision to wear a PFD was examined among workers in an Australian fishery (Brooks, 2007). Decisions were made by integrating information, social contact, cultural assumptions and folk heuristics. The study concluded that understanding the workers' decision making process can make interventions more successful.

Successful implementation of marine safety training was explored by four T3 studies. Two studies identified barriers, enabling factors, and cultural influences on receptivity to safety education interventions among Vietnamese shrimp fishermen in Texas (Carruth et al., 2010; Levin et al., 2010). The studies found that culturally appropriate training materials and instruction methods were critical to educating workers in that particular fishery. Another study found that participation in safety training increased dramatically following a high-profile fatal vessel sinking (Hall-Arber and Mrakovcich, 2008), suggesting that elevating awareness and perceptions of risk may motivate workers to seek out safety training.

T3 research is an important step in the translational research model for improving safety in the fishing industry. Once an intervention has gained evidence of efficacy in T2 studies on samples of workers, the findings of T3 research help to guide the widespread implementation of the intervention to the relevant population. The recent surge of T3 research in the literature suggests that the value of T3 research has been recognized. During the first three years of the 2010s, 30% of studies (9 articles) were contributing to the T3 phase of translational research, and all but two focused on defined interventions rather than broad applicability.

3.5. T4 research: population level improvement in safety outcomes

Once the T3 phase research has been completed and the intervention has been disseminated, T4 research seeks to move from evaluating widespread implementation to population health outcomes. This involves assessing the effectiveness of a widely disseminated intervention on health or safety outcomes at the population level. After an intervention has been shown to be effective in samples of the population, the decisive evidence of its value is demonstrated by measuring a change in the health or safety problem at the population level once widespread adoption has occurred. T4 studies are scarce in the literature on fishing industry safety, likely due to the many challenges of demonstrating effects at the population level. Only five percent (8 articles) of studies contributed to T4 research (Table 4). The eight T4 studies investigated improvements in safety at the population-level for three types of interventions: safety legislation (5 studies); fisheries management (2 studies); and safety training (1 study).

The two earliest T4 studies examined the effect of the Committee of Inquiry into Trawler Safety (CITS) on population risk among workers onboard UK trawlers (Reilly, 1985, 1984). CITS was a government mandated program set up in 1968 that studied trawler safety and issued guidelines and recommendations based on the findings. Rates of total vessel loss and work-related deaths during 1961–1980 were analyzed for trends pre- and post-intervention. Rates of total vessel loss and fatalities increased over the study time period. Post-CITS deaths rates were 39% higher than pre-CITS death rates. The two studies concluded that CITS did not have any effect on safety in the UK fishing industry.

Three other studies tested the effect of safety legislation on population-level outcomes. These studies evaluated the effect of the US Commercial Fishing Industry Vessel Safety Act (CFIVSA) of 1988 on work-related fatalities by calculating case-fatality rates of vessel disasters in Alaska during 1991–1994 (Conway et al., 1998). The requirements of the CFIVSA included carriage of survival equipment such as life rafts, immersion suits and emergency position beacons; which were phased in during 1990–1993. The authors found that while the frequency of vessel disasters remained constant during the study period, the case-fatality rate experienced a linear decline from 24% in 1991 to 2% in 1994. Two follow-up studies found that fatality rates in the Alaska fishing industry decreased during 1991–1998, but only for fatalities due to vessels sinking (Lincoln and Conway, 1999; Lincoln et al., 2001). The decrease in the risk of death was attributed to the implementation of the CFIVSA which improved the survivability of vessel disasters.

Fisheries management regulations are sets of rules that govern the volume of fish harvested in order to preserve the resource and have sustainable fisheries. How each fishery is managed is hypothesized to indirectly influence the safety of the fleet (Hughes and Woodley, 2007; Windle et al., 2008). Hughes and Woodley (2007) analyzed the effect of changes to three fishery management regimes in Alaska on the safety of the respective fleets. All three fishery management regimes changed at different times during 1995–2005 from open access “derby” style regimes promoting a competitive race for fish to quota-based regimes that allocated predetermined catch amounts to vessels. Since each vessel has a set quota, there should be less pressure to take risks such as operating in hazardous weather conditions. The study found that in the Alaska halibut/sablefish fishery, after the management regime changed in 1995, vessel disasters and fatalities decreased substantially. The authors also examined changes to the management regimes of the Bering Sea pollock fishery in 1999 and the Bering Sea crab fishery in 2005, but were not able show improvements in safety with the limited data available to them. Windle et al. (2008) reviewed the published literature to identify studies on the association between fisheries management and safety, but found little evidence available to inform conclusions.

One T4 study evaluated an Alaska-based safety training program, which was initiated in 1985 and focused on emergency preparedness and marine survival (Perkins, 1995). The study analyzed fatality and survival data for vessel disasters during 1991–1994, and found that decedents of vessel disasters were less likely than survivors to have received the safety training, supporting the hypothesis that training improves survival. The author concluded that the formal safety training program was effective at reducing fatalities by improving the survivability of vessel disasters.

In the few T4 studies that have been published in the literature on fishing industry safety, there have been mixed results. Three studies found evidence to support the use of legislation as a safety intervention, while two studies found no evidence. One study found evidence to support the changes in fisheries management policies as an intervention to improve safety, while another study did not. There has only been one study which examined the effect of safety training on fatalities at the population level. Unlike other phases of translational research which have been increasing in recent years, T4 research has declined. During the 1980s, 14% of the literature was T4 research (2 studies), decreasing to eight percent during the 1990 s (3 studies), three percent during the 2000 s (3 studies), and none during 2010–2012. The trend in T4 research is a weak point in the literature.

3.6. Limitations

Non-English language articles were excluded from this review, as resources to translate articles into English were not available. As a result, this review may have a bias favoring research in developed nations which have been published in English. A further limitation was the exclusion of publications such as government reports and conference proceedings, and targeting only peer-reviewed journals. Misclassification bias due to single-investigator coding of translational research phases for each article may have affected the validity of the results.

4. Conclusions and recommendations

Scientific investigations of safety problems in the fishing industry first appeared in the literature during the 1950s. Since then, a substantial body of knowledge has emerged describing the burden of injuries, identifying risk factors, and exploring and testing solutions. By far the bulk of work has focused on descriptive epidemiology in the T0 phase of the translational research model. Such descriptive efforts are valuable in characterizing the problems and generating hypotheses, but the progression to analytical epidemiology (still in the T0 phase) to test hypotheses regarding risk factors has been rather limited and represents a gap in the research.

T0 research may be improved by shifting from broad, country-level descriptive studies to detailed, fishery-specific studies. Future research should focus on designing studies to test hypotheses regarding risk factors for vessel disasters and for fatal and non-fatal injuries. The development of effective interventions would be greatly enhanced by having a firm knowledge base regarding the determinants of vessel disasters and risk factors for injuries. Well-designed empirical studies are needed to test hypotheses and identify modifiable risk factors.

There is also a need for T0 studies to use consistent methods of injury classification and risk analysis to help make results clear and comparable across fisheries. Jensen et al. (2006) proposed a novel method for measuring and comparing injury risks onboard fishing vessels in Denmark. The authors recorded the time spent on various working processes on fishing vessels to estimate exposure levels. Injuries were then classified by working process and matched to the time-based exposure for that process. Risks of injury were then calculated and compared across working processes and vessel types. Calculating and comparing risks of injury at the vessel type and working process level will provide the detail to accurately target interventions at the highest-risk jobs.

A positive trend in recent studies is the growing emphasis on translational research. These types of studies aim to move research-to-practice by investigating potential solutions to safety problems and by developing, implementing and evaluating interventions. Future T1 studies should utilize the detailed fishery-specific findings from T0 research to develop targeted interventions to reduce risk factors for injuries.

T2 research is a growing area of emphasis in the literature, but is still limited and is a gap that needs to be filled. Future T2 studies should concentrate on evaluating the efficacy of candidate interventions previously identified in T1 research. T2 studies would be stronger if they measured the efficacy of interventions on reducing actual injuries, rather than on intermediate outcomes such as safety behaviors or hazard reduction. Research in the T3 phase should concentrate on studies addressing the barriers and facilitators to the widespread implementation of specific interventions.

The weakest area in the literature on fishing industry safety appears to be the transition from T3 to T4. This gap is evidenced by the few studies identified at the T4 phase. There are at least two possible explanations for the low volume of T4 research. First, the link between T3 and T4 involves the widespread dissemination of an intervention to the relevant population (i.e., a specific fleet of fishing vessels experiencing similar hazards). If interventions are not being widely disseminated after being tested for efficacy in T2 studies and for barriers to implementation in T3 studies, then there is no need for T4 research because there are no widely disseminated interventions ready to study. The second possible explanation is that interventions are being disseminated to the population, but T4 research has not been conducted yet. Such a situation could be explained in part by the many challenges of demonstrating effects at the population level. There is a clear need for projects to disseminate interventions and evaluate their population-level impact.

In addition to the gaps identified in the translational research framework, another gap is the lack of published literature on fishing industry safety in developing countries. The bulk of the global workforce in fisheries operates in these underserved areas, yet few studies were identified that conducted research on fishing safety in those countries. This review was limited to English language journals, which introduces the possibility that studies on safety in those nations' fisheries do exist, but have been published in non-English language journals. Aside from that explanation, the apparent bias toward research on fisheries in developed countries is a large gap in the literature. It is crucial that future studies investigate the risks of fishing to workers in developing nations.

Workplace safety in the fishing industry will improve if future research concentrates on identifying and testing promising safety measures that are effective, practical and scalable. Translational research is the key to making progress toward the prevention of work-related injuries in the fishing industry. Understanding the phases of translational research and how the existing literature fits within them can help the field follow a methodologically consistent, logical and productive course.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ssci.2013.11.023.

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Citation	Lucas, D. L., Kincl, L. D., Bovbjerg, V. E., Branscum, A. J., & Lincoln, J. M. (2014). Primary prevention of fishing vessel disasters: Evaluation of a United States Coast Guard policy intervention. Marine Policy, 50, 67-73. doi:10.1016/j.marpol.2014.05.017
DOI	10.1016/j.marpol.2014.05.017
Publisher	Elsevier
Version	Version of Record
Terms of Use	http://cdss.library.oregonstate.edu/sa-termsofuse

Marine Policy 50 (2014) 67–73

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Primary prevention of fishing vessel disasters: Evaluation of a United States Coast Guard policy intervention

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ARTICLE INFO

Article history:
Received 12 March 2014
Received in revised form
12 May 2014
Accepted 13 May 2014
Available online 2 June 2014

Keywords:
Fishing vessel disasters
Marine safety
Injury prevention
Occupational epidemiology

ABSTRACT

Primary injury prevention strategies are needed to improve worker safety in the fishing industry by reducing the occurrence of vessel disasters. In 2006, the United States Coast Guard (USCG) implemented a novel safety policy intervention for two fleets of freezer-trawlers and freezer-longliners in Alaska. The *Alternate Compliance and Safety Agreement* (ACSA) set standards for vessel stability, watertight integrity, hull condition, and other critical vessel components. To determine if ACSA has been an effective primary prevention intervention for improving safety in the fishing industry, a longitudinal study was conducted using retrospective data on vessel casualties during 2003–2012. On both types of vessels, reported rates of serious vessel casualties decreased after the vessels reached compliance with ACSA requirements, suggesting that ACSA has had a positive effect on vessel safety in the freezer-trawl and freezer-longline fleets. These results support the premise that primary prevention policies can contribute to worker safety by reducing the occurrence of vessel disasters. Future USCG safety policies should be patterned after ACSA and improved by following the recommendations outlined in this study.

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1. Introduction

Vessel disasters (e.g., vessels capsizing, sinking, grounding, or burning) are the leading contributor to occupational fatalities in the U.S. commercial fishing industry [1], which has consistently been one of the most hazardous industries nationwide [2]. During 2000–2009, 148 separate vessel disasters resulted in 261 fatalities in U.S. fisheries, representing 52% of all fishing industry fatalities [1]. Studies in other nations, including Australia, Poland, Denmark and England have also found that vessel disasters are the cause of the majority of deaths at sea among fishing industry workers [3–6]. In the U.S. fishing industry during 2000–2009, Lincoln and Lucas [1] found that fishing vessel disasters were the end result in a sequence of events that culminated with a final catastrophic event, such as the vessel sinking. The most frequent initiating events (the first problems to arise) for vessel disasters were flooding (28%), instability (18%), struck by a large wave (18%), collision (10%), and fire/explosion (5%).

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http://dx.doi.org/10.1016/j.marpol.2014.05.017
0308-597X/Published by Elsevier Ltd.

In April 2001, the 92 foot (28 m) freezer-trawl (FT) vessel *Arctic Rose* was fishing in the Alaska Bering Sea when it flooded and sank, killing all 15 workers onboard [7]. One year later, the 180 foot (55 m) freezer-longline (FL) vessel *Galaxy* caught fire and sank in the Bering Sea with three worker fatalities out of 26 workers onboard [8]. The FT fleet suffered another vessel disaster in 2008 when the *Alaska Ranger* flooded and sank, killing five of the 47 crewmembers [9]. The *Arctic Rose, Galaxy,* and *Alaska Ranger* were part of two fleets of FT and FL vessels that operate in the Bering Sea/Aleutian Islands and the Gulf of Alaska. The distinction between FT and FL vessels and other trawlers and longliners is that the freezer vessels are outfitted with factories and freezers onboard, which are used to process and freeze the catch, while other trawlers and longliners catch and deliver fish whole to onshore processing plants [10]. FT vessels are also known as non-Pollock catcher-processors, factory-trawlers, and amendment 80 vessels. An FT vessel catches fish by towing a large, bag-shaped net along the ocean floor. As the net fills, fish are pushed to the far end of the net, called the “cod-end,” where they accumulate. When the trawl net is full, it is brought to the surface with winches and the fish are transferred into holds until being moved into the factory for processing [11]. After processing, the fish products are packaged and frozen. The average crew size for FT vessels is 36 workers

[12], with jobs including captain, mate, engineer, deckhand, fish processor, and cook [13]. An FL vessel catches fish by setting a line of baited hooks along the ocean floor. Fish are brought onboard one at a time as the line of hooks is retrieved [11]. Fish are then unhooked and moved to the factory where processing and freezing take place. The average crew size for FL vessels is 20 workers [12], with similar jobs as found in the FT fleet [14].

According to the United States Coast Guard (USCG), the FT and FL fleets operating in Alaska are at high risk for worker injuries:

> [FT and FL] operations require a sizeable crew, processing and freezing machinery, hazardous gases (anhydrous ammonia or Freon), and large amounts of packaging materials on board. Additionally, because of their ability to freeze, package and store frozen catch, these vessels can operate in the most remote areas of the Bering Sea, far from search and rescue support. These factors combine to significantly increase safety and operational risks to this fleet. [15]

An empirical study of work-related injuries onboard FT and FL vessels supported the USCG assessment. Specifically, from 2003 to 2012, the annual risk of fatal injuries in the FT fleet was 130 deaths per 100,000 full-time equivalent workers (FTEs), and the annual risk of non-fatal injuries was 44 per 1000 FTEs [12]. The annual risk of fatal injuries in the FL fleet during the same period was 65 deaths per 100,000 FTEs, and the annual risk of non-fatal injuries was 36 per 1000 FTEs [12].

The first attempts to create safety standards for fishing vessels through federal legislation began in 1930s, but were not successful until the Commercial Fishing Industry Vessel Safety Act of 1988 was signed into law [16]. The law requires most fishing vessels to carry survival equipment, such as personal flotation devices, immersion suits, life-rafts, throwable flotation devices, distress signals, emergency position indicating radio beacons, and fire extinguishers [17]. The safety standards of the 1988 vessel safety act were implemented during the early 1990s and had a measurable positive effect on worker fatalities caused by vessel disasters. The case-survivor rate for vessel disasters in Alaska increased from 78% in 1991–1993, to 92% in 1994–1996, to 94% in 1997–1999 [18] because crewmembers had access to these newly required life-saving devices, which increased their survival prospects after abandoning ship. However, the frequency of vessel disasters did not decrease during that decade because the 1988 vessel safety act focuses almost entirely on secondary prevention of death; that is, keeping workers alive in the water until rescue aid arrives [18].

Primary prevention strategies can contribute to worker safety by reducing the occurrence of vessel disasters. During 2004–2005, the USCG engaged the owners and operators of FT and FL vessels to discuss safety problems and to generate solutions [19]. A new set of safety rules was formed for the FT and FL fleets under a special policy, the *Alternate Compliance and Safety Agreement* (ACSA) (for a detailed account of the development of ACSA, refer to [10,19]). The emphasis of ACSA was placed on the primary prevention of vessel disasters; it included rules for vessel stability, watertight integrity, and the material condition of the hull, tail shaft, rudder, and machinery. Alongside the standards for primary prevention, ACSA also included requirements aimed at secondary prevention of fatalities, such as having life-saving equipment, fire-fighting equipment, emergency communications and navigation equipment, and conducting emergency drills [10].

As the administrator of ACSA, the USCG was responsible for examining and certifying the vessels in the program. After vessels corrected deficiencies and reached full compliance with ACSA standards, they were issued an ACSA compliance letter. The overarching hallmark and objective of ACSA was to work "closely with industry stakeholders in developing elements of this alternate and voluntary program in order to save lives" [10]. ACSA was signed into policy in 2006, with a deadline of January 1, 2008 for vessels to reach full compliance with the new rules [19].

By focusing on primary prevention of vessel disasters, ACSA aimed to improve safety in the FT and FL fleets. However, plans for evaluating the efficacy of the program were not included in its design. Consequently, the impact of ACSA on safety in these fleets has been unknown. The purpose of this research was to evaluate the efficacy of ACSA as a primary prevention intervention for vessel disasters.

2. Material and methods

2.1. Study design

To determine if ACSA has been an effective intervention for improving safety in the fishing industry, a longitudinal study was conducted using historical data on vessel casualties during 2003–2012. The goal was to compare the rate of vessel casualties before and after implementation of ACSA. The year 2003 was chosen as the beginning of the study period because it was the first year that exposure data (vessel-days at sea) were available.

The study group consisted of all FT and FL vessels that operated in the Bering Sea/Aleutian Islands and Gulf of Alaska regions during the study time period and were in full compliance with ACSA standards during 2012. Full compliance with ACSA standards was achieved only for vessels that were (i) enrolled in the ACSA program, (ii) inspected for all deficiencies listed in the ACSA requirements, and (iii) issued an ACSA compliance letter by the USCG or recognized third party, which occurred only after correction of any identified deficiencies. There were 17 FT vessels and 20 FL vessels that met the criteria and were included in the study group.

2.2. Data

The outcome used to assess the efficacy of ACSA was the count of vessel casualties on each vessel during each year in the study period. Vessel casualties were defined as failures of vessel components or systems that resulted in problems such as the loss of electrical power, loss of propulsion, loss of steering, flooding, and fire. This outcome was selected through a process of informal interviews with ACSA stakeholders (USCG & vessel owners), a review of the literature, and application of a theoretical framework (theory of man-made disasters) that is described in Section 4. Five USCG personnel and four fishing industry representatives participated in informal interviews and independently provided their expert opinions on the metrics (quantifiable measures of performance) that should be used to evaluate ACSA. All nine informants listed vessel casualties as the primary and most relevant metric for assessing the efficacy of ACSA.

During the design of this study, some marine safety experts conveyed the opinion that because ACSA was designed to prevent vessel disasters (which are the most severe type of vessel casualty), there may not be an effect of ACSA on reducing minor casualties. To address that issue, two forms of the outcome variable were analyzed. Outcome A was the count of *all* vessel casualties (minor, moderate and serious) and outcome B was the count of *serious* vessel casualties. Casualty severity was determined based on how the casualty was resolved. Casualties were coded as minor if they were resolved permanently by the crew at sea and did not require any outside assistance or a return of the vessel to port for repairs. Moderate casualties were either resolved at sea with outside assistance, or the vessel returned to port without assistance for permanent repairs. Serious casualties required the vessel to be towed or otherwise assisted to port for repairs.

Individual vessels operate at sea for different lengths of time during the year. Vessels that operate for longer periods have more exposure to hazards than vessels that operate less. Therefore, the measure of exposure used in this study to adjust risk estimates was *vessel days at sea*, obtained for each vessel in the study group for each year during 2003–2012.

2.3. Data sources

Vessel casualties were identified through two sources, the USCG Marine Information for Safety and Law Enforcement (MISLE) database and the National Marine Fisheries Service (NMFS) Observer Vessel Survey. Data security and use agreements were established to access data from each agency. MISLE is used to record information reported by fishing companies to the USCG on vessel casualties. Federal law requires companies that operate fishing vessels to report vessel casualties to the USCG [20]. USCG investigators enter data into MISLE from a number of sources depending on the seriousness of the casualty. For instance, some records in MISLE concerning minor casualties may only have a single source of data such as a standard USCG reporting form completed by the company, or standard documentation of a telephone call to the USCG. More serious casualties in MISLE may have additional data sources such as witness statements, damage assessments, and repair logs collected by a USCG investigator.

In an attempt to identify casualties that were not reported by companies to the USCG, the NMFS Observer Vessel Survey was utilized. NMFS is the federal government agency responsible for the management of the nation's fisheries to ensure their sustainability [21]. NMFS places observers on vessels that operate in federal fisheries to monitor catch volume, by catch, and other fishing operations [22]. Fishery observers also record safety related events, such as injuries to workers and vessel casualties that come to their attention while on the vessel. The events are initially recorded by the observers in their logbooks and reported to NMFS staff. When observers finish their assignments on the vessels, they are debriefed and provide additional information into the Observer Vessel Survey. Observer coverage (the amount of time a vessel must carry an observer onboard) depends on several factors, including vessel length, fishing gear, and species targeted. Based on those factors, observer coverage during the study period ranged from approximately 30–100% for FT and FL vessels [23].

2.4. Statistical analysis

Data on vessel casualties were extracted from MISLE and the NMFS Observer Vessel Survey and entered into a dataset. Data were matched to identify and remove duplicate records. An exploratory data analysis was completed to examine the distribution of the outcome variable and covariates. Individual vessels reached compliance with ACSA at different times during the implementation period. The earliest ACSA compliance letter was issued in 2006 and the latest in 2010. To control for this variation in calendar years, a new variable, *ACSA years*, was created to indicate the number of years before and after the ACSA compliance letter issuance for each vessel. Year zero was the year that each vessel received its compliance letter; years before the compliance letter issuance were coded with consecutive negative numbers and years after the compliance letter issuance were coded with consecutive positive numbers. Incidence rates of the outcome were calculated for each *ACSA year* using *vessel days at sea* as the denominator.

The count of casualties on each vessel was repeatedly measured at 10 different times (years 2003–2012), introducing correlation of measurements within the same vessel. A second source of correlation, clustering of vessels within the same company, was also expected. To account for correlated longitudinal measurements and clustering of vessels by company, a mixed-effects model was selected to allow for the inclusion of random effects for vessel and company.

An exploratory data analysis revealed that the variances of both outcomes were larger than the means (i.e., overdispersion in Poisson regression). In addition, the Bayesian information criterion (BIC) supported negative binomial regression over Poisson regression due to its inclusion of a dispersion parameter that allows for greater data variability over a Poisson model. Therefore, a multilevel mixed-effects negative binomial regression model was used for data analysis. The outcome variable, y_{ijk}, was the count of casualties (or serious casualties for outcome B) on vessel i from company j during year k that occurred during M_{ijk} days at sea. The corresponding empirical casualty rate was calculated as y_{ijk}/M_{ijk}.

In addition to the primary predictor variable, which was a binary indicator of ACSA compliance letter issuance, the model contained fixed effects for vessel type (FT or FL), vessel length (feet), vessel age (year built), and a random effect for company with a nested random effect for vessel within company. The offset (exposure) was vessel-days at sea. An interaction term was added to allow the effect of ACSA to vary according to vessel type. The random effects were assumed to be normally distributed.

Rate ratios were calculated to compare rates of vessel casualties before and after ACSA for FT and FL vessels. Specifically, the estimated rate ratio and 95% confidence interval (CI) comparing pre to post ACSA compliance letter issuance for FT vessels of the same age and length was calculated, along with the corresponding rate ratio comparing pre to post ACSA for FL vessels. In addition to comparing casualty rates before and after ACSA, the probability of having no casualties was calculated and compared.

Data analysis was performed using Stata 13 [24]. Descriptive statistics were calculated using means, medians, and standard deviation (SD). Model fit was assessed graphically by plotting the residuals and the predicted versus observed mean casualty rates. In addition, BIC was used for model selection.

3. Results

The study group was comprised of 17 FT vessels owned by six companies and 20 FL vessels owned by eight companies. The FT vessels had a median length of 143 ft (mean = 143; SD = 42), a median age of 32 years in 2012 (mean = 32; SD = 4), and had a median crewsize of 34 workers (mean = 34; SD = 12). The FL vessels had a median length of 117 ft (mean = 126; SD = 23), a median age of 32 years in 2012 (mean = 37; SD = 18), and had a median crewsize of 20 workers (mean = 18; SD = 5). Most FT vessels (11, 65%) reached compliance with ACSA during 2008. The earliest ACSA compliance letter was issued in 2006 and the latest in 2009. Among FL vessels, 13 (65%) reached compliance during 2008 with the earliest in 2007 and latest in 2010.

During 2003–2012, FT vessels in the study group operated 39,888 days at sea, an average of 235 days at sea per vessel per year. The FL vessels logged 44,326 days at sea, an average of 222 days at sea per vessel per year. There were 387 vessel casualties reported to the USCG and/or documented by NMFS observers during the study period; 205 occurred onboard FT vessels and 182 occurred onboard FL vessels (Table 1). Overall, 56% of casualties on FT vessels and 43% of casualties on FL vessels were reported by the companies to the USCG.

The most common types of casualties on FT vessels were loss of electrical power (74, 36%), loss of propulsion (65, 32%), and fire (27, 13%). FL vessels had similar casualties: loss of propulsion (63, 35%),

Table 1
Sources of data on vessel casualties involving FT and FL vessels during 2003–2012.

	Total casualties	Data source			% Reported to USCG	% Observed by NMFS
		USCG only	NMFS only	USCG & NMFS		
FT vessels (n=17)						
2003	12	1	9	2	25.0	91.7
2004	11	1	9	1	18.2	90.9
2005	20	8	8	4	60.0	60.0
2006	16	3	8	5	50.0	81.3
2007	10	5	4	1	60.0	50.0
2008	24	5	12	7	50.0	79.2
2009	26	9	11	6	57.7	65.4
2010	30	8	8	14	73.3	73.3
2011	33	12	12	9	63.6	63.6
2012	23	11	9	3	60.9	52.2
Total	205	63	90	52	56.1	69.3
FL vessels (n=20)						
2003	21	1	15	5	28.6	95.2
2004	33	5	21	7	36.4	84.8
2005	16	0	13	3	18.8	100.0
2006	17	1	11	5	35.3	94.1
2007	18	6	11	1	38.9	66.7
2008	10	3	4	3	60.0	70.0
2009	19	6	9	4	52.6	68.4
2010	16	9	6	1	62.5	43.8
2011	16	4	6	6	62.5	75.0
2012	16	6	8	2	50.0	62.5
Total	182	41	104	37	42.9	77.5

Table 2
Vessel casualty type and severity for FT and FL vessels during 2003–2012.

	Minor		Moderate		Serious		Total[a]
	No.	%	No.	%	No.	%	No.
FT vessels (n=17)							
Loss of electrical power	66	89.2	8	10.8	0	0.0	74
Loss of propulsion	33	50.8	14	21.5	18	27.7	65
Fire	25	92.6	2	7.4	0	0.0	27
Flooding	6	31.6	12	63.2	1	5.3	19
Loss of steering	4	57.1	2	28.6	1	14.3	7
Other[b]	3	30.0	7	70.0	0	0.0	10
Total	137	67.8	45	22.3	20	9.9	202
FL vessels (n=20)							
Loss of electrical power	49	86.0	7	12.3	1	1.8	57
Loss of propulsion	27	45.8	25	42.4	7	11.9	59
Fire	16	76.2	4	19.0	1	4.8	21
Flooding	14	77.8	4	22.2	0	0.0	18
Loss of steering	13	72.2	4	22.2	1	5.6	18
Other[c]	1	25.0	2	50.0	1	25.0	4
Total	120	67.8	46	26.0	11	6.2	177

[a] The grand total in this table is 379 casualties due to missing data on severity for 8 casualties.
[b] Groundings, collisions, hull breaches w/o flooding.
[c] Groundings, bilge pump failures w/o flooding.

loss of electrical power (57, 31%), and fire (21, 12%). For all types of casualties combined, 257 (66%) were minor, 91 (24%) were moderate, and 31 (8%) were serious (Table 2). On FT vessels, 68% of flooding (13/19) and 49% of loss of propulsion (32/65) casualties were greater than minor severity, while only 7% of fires (2/27) and 11% of loss of power (8/74) casualties were greater than minor severity (Table 2). On FL vessels, 54% of loss of propulsion (32/59) and 28% of loss of steering (5/18) casualties were greater than minor (Table 2).

Estimates from multilevel mixed-effects negative binomial regression models for outcome A (the count of all vessel casualties) and outcome B (the count of serious vessel casualties) are presented in Table 3. On FT vessels of average age and length, the estimated rate of all casualties from pre to post ACSA rose 52% from 3.05 to 4.62 per 1000 vessel-days (RR=1.52, 95% CI 1.07, 2.15) (Table 4). The probability of an FT vessel having no casualties during a year decreased 38% from pre to post ACSA (Table 5). However, when restricting the analysis to serious casualties only (outcome B), the rate of serious casualties decreased 8% pre to post ACSA (RR=0.92, 95% CI 0.34, 2.46) and the probability of having no serious casualties remained approximately the same.

On FL vessels of average age and length, the estimated rate of all casualties (outcome A) from pre to post ACSA decreased 11% from 4.25 to 3.80 per 1000 vessel-days (RR=0.89, 95% CI 0.61, 1.31) (Table 4). The probability of an FL vessel having no casualties

Table 3
Multilevel mixed-effects[a] negative binomial regression models for two vessel casualty outcomes involving FT and FL vessels during 2003–2012.

	Outcome A: all vessel casualties[b]			Outcome B: serious vessel casualties[c]		
	Coeff.	SE	95% CI	Coeff.	SE	95% CI
ACSA time period						
Pre-ACSA (ref)	–	–	–	–	–	–
Post-ACSA	0.42	0.18	0.06, 0.77	−0.09	0.50	−1.07, 0.90
Vessel type						
Freezer-trawler (ref)	–	–	–	–	–	–
Freezer-longliner	0.33	0.42	−0.49,1.16	10.72	0.59	−1.88, 0.43
ACSA × vessel type	−0.53	0.26	−1.04, −0.01	−1.71	1.19	−4.04, 0.62
Vessel length	0.01	0.01	−0.01, 0.02	0.01	0.01	−0.01, 0.01
Vessel year built	0.01	0.01	−0.02, 0.03	−0.03	0.02	−0.07, 0.004
Intercept	−18.53	23.72	−65.03, 27.97	59.97	38.90	−16.28, 136.22

[a] Random effects of vessels nested within companies were included in models, with days at sea serving as an offset.
[b] Sum of counts = 387 total vessel casualties.
[c] Sum of counts = 31 serious vessel casualties.

Table 4
Observed[a] and predicted[b] rates[c] of vessel casualties involving FT and FL vessels during 2003–2012.

Outcome	Observed/predicted	Pre-ACSA rate	Post-ACSA rate	Pre/post RR	95% CI
FT vessels ($n=17$)					
All casualties	Observed	4.40	6.30	1.43	–
All casualties	Predicted	3.05	4.62	1.52	1.07, 2.15
Serious casualties	Observed	0.59	0.51	0.86	–
Serious casualties	Predicted	0.52	0.48	0.92	0.34, 2.46
FL vessels ($n=20$)					
All casualties	Observed	4.71	3.86	0.82	–
All casualties	Predicted	4.25	3.80	0.89	0.61, 1.31
Serious casualties	Observed	0.37	0.05	0.14	–
Serious casualties	Predicted	0.25	0.04	0.17	0.02, 1.37

[a] Empirical rates observed in sample data.
[b] Predicted rates calculated from regression models (Table 3), which were adjusted for covariates and correlated data.
[c] Number of casualties per 1000 vessel days.

Table 5
Predicted probabilities of experiencing zero vessel casualties on FT and FL vessels[a] before and after ACSA compliance.

Outcome	Pre-ACSA	Post-ACSA	% Change
FT vessels ($n=17$)			
All casualties	0.54	0.39	−38.46
Serious casualties	0.90	0.90	0.00
FL vessels ($n=20$)			
All casualties	0.46	0.48	4.17
Serious casualties	0.95	0.99	4.04

[a] For an average length, average age vessel exposed to average days at sea.

during a year improved 4% from pre to post ACSA (Table 5). The decrease in the rate was greater for serious casualties (outcome B), with an 83% decrease in the rate pre to post ACSA (RR = 0.17, 95% CI 0.02, 1.37) and a 4% increase in the probability of having no serious casualties (Table 5).

4. Discussion

This study found indications of a positive effect of ACSA on vessel safety in the FT and FL fleets. On both types of vessels, reported rates of serious vessel casualties decreased after the vessels reached compliance with ACSA requirements. Serious casualties are the most important to prevent since they have the most immediate potential to develop into vessel disasters under certain circumstances (such as severe weather conditions or prolonged time until rescuers arrive) leading to fatal injuries. The negative binomial regression analysis did not identify statistically significant variables, in part because serious casualties were rare events, with only 31 in the study group during 2003–2012. However, the empirical rates and model-based point estimates of rate ratios suggest that the current ACSA policy has had a positive effect on safety for those FT and FL vessels participating in it.

ACSA appears to have been more effective on FL vessels than on FT vessels. The rate of all casualties on FL vessels decreased after ACSA compliance, while on FT vessels the rate increased. Also, the decline in serious casualties was much steeper on FL vessels than on FT vessels. There is not a clear explanation for the difference in ACSA effect on the two vessel types. Apart from fishing gear, the vessels are quite similar, as are the types of casualties that occurred on them. ACSA requirements are the same for both types of vessels. Although the reported rate of all casualties increased substantially on FT vessels after ACSA, there is no reason to think that ACSA was responsible for the increase since there are no provisions of ACSA that would conceivably cause an actual increase in the risk of casualties.

The increase in all casualties on FT vessels is probably not representative of an actual increase in the risk of casualties. Instead, the increase was likely caused by a combination of increased documentation of casualties by NMFS observers, increased reporting of casualties by vessel companies to the USCG, and fluctuations common to trends involving small numbers of rare events. On January 1, 2008 a new fisheries management regulation for FT vessels was implemented, which included a doubling of the number of NMFS observers on FT vessels from one observer to two observers [25]. The implementation of this regulation coincides with the large increase in the number of casualties recorded by NMFS observers in 2008 (Table 1). The increased NMFS observer coverage may have also had an indirect influence on the associated increase in casualty reports by companies to the USCG. The increased documentation and reporting of casualties that occurred in the same year as ACSA implementation may have obscured the effect of ACSA that would have otherwise been identified. The finding that serious casualties on FT vessels decreased even in the face of greater reporting is consistent with this explanation and with ACSA efficacy.

Vessel casualties may be indicators for larger problems with the vessel that could trigger a future vessel disaster. This supposition is supported by the theory of man-made disasters developed by Turner [26], which states that disasters involving complex man-made systems (such as fishing vessels) are not chance events or 'Acts of God' [27]. Instead, a sequence of events, often starting years prior to the disaster, occurs and escalates to the eventual disaster [26]. In the sequence of events, a disaster incubation period exists in which unnoticed or misunderstood events accumulate. Instead of recognizing these precursor events as warning signs of an impending disaster, workers fail to perceive the warning events as such or fail to adequately assess the risk [26].

Vessel casualties may represent misunderstood warning signs of a future vessel disaster. If so, then reducing vessel casualties should in turn reduce vessel disasters and the accompanying loss of life. ACSA standards for the material condition of the hull, internal structure, tail shaft(s), rudder(s), machinery, watertight integrity, safety training and safety equipment attempt to address the causes of vessel casualties and vessel disasters. This study analyzed casualties on each vessel in the study group over time to determine if ACSA has been effective at reducing these events at sea.

A major objective of ACSA was to reduce worker fatalities in the FT and FL fleets through primary prevention of vessel disasters. The decline in serious vessel casualties on both FT and FL vessels in the post-ACSA period is an indication that ACSA is having the desired effect on vessel safety. By employing a primary prevention approach, ACSA represents a shift in conceptualizing vessel safety in the fishing industry. Regulations for fishing vessel safety in the U.S. have historically taken a reactive approach, focusing on saving lives after a vessel disaster has occurred, and omitting requirements that would promote the primary prevention of vessel disasters. ACSA was developed to be a mixed strategy of primary, secondary and tertiary prevention efforts, all of which are needed to make meaningful progress in improving worker safety in the fishing industry.

At the national level, recent U.S. legislation on fishing vessel safety has included components that focus on primary prevention. The "Coast Guard Authorization Act of 2010" was signed into law in October 2010 [28] and contains safety requirements for commercial fishing vessels [29]. In the 2010 Coast Guard Authorization Act, the new safety regulations emphasize primary prevention of vessel disasters, but in the near-term they only apply to newly constructed vessels. After 2020 certain older vessels (> 25 years old) will be required to participate in "alternate safety compliance (ASC) programs" to improve vessel safety. As with the current ACSA program for the FT and FL fleets, these new policies represent a positive shift towards a strategy that includes primary prevention efforts.

Like ACSA, the forthcoming ASC programs will be targeted at specific fleets of fishing vessels. The results of this study suggest that if the new ASC programs are patterned after ACSA, they can be successful at reducing vessel casualties. Two key recommendations from this study may further strengthen the future ASC programs. First, a quantitative risk assessment for each targeted fleet should be carried out prior to drafting the specific provisions of each ASC program. The ASC programs should then be tailored to address the highest risk and most severe types of safety problems experienced by the different fleets. A well-planned, empirical approach to assessing hazards will make the programs more effective at improving safety because they will be focused on resolving the true causes of the worst problems. The data gathered during quantitative risk assessments can also be used as baseline data for evaluating the ASC programs after their implementation.

The second recommendation for future ASC programs is to include an evaluation plan in the design phase. One of the challenges encountered in this study of ACSA effectiveness was the retrospective nature of the data collection, including selecting the outcome within the constraints of existing data. As an ASC program is developed, the metrics for evaluation (such as vessel casualties and crewmember injuries) should be selected during the design of the program, and initial measurements of the metrics should be conducted to establish baseline levels. The selected metrics should encompass the hazards identified in the fleet risk assessment, but may also include other measurable outcomes. Surveillance of the metrics should continue after implementation of the ASC programs to obtain the necessary evaluation data.

5. Limitations

ACSA was initiated many years prior to this study and lacked a plan for evaluating program efficacy, which necessitated using historical data. Because ACSA was applied to almost the entire FT and FL fleets, there were no non-ACSA vessels to form a comparison group. This research used a retrospective longitudinal study design, which did not control for factors outside ACSA that could have affected the outcome measures. Although the study used all available data on ACSA to date, the small sample size of 37 vessels may have decreased the ability of statistical tests to detect significant effects of ACSA.

The selection of an outcome was limited to existing data that had been consistently collected annually by NMFS and USCG staff. Vessel casualties were an appropriate outcome to use for this analysis, however there may have been other types of outcomes that could also be used to evaluate ACSA that were not considered due to the absence of existing data. Vessel casualties were underreported to the Coast Guard (as shown in Table 1), and although the addition of NMFS observer data filled the gap to some extent, there were likely still some casualties that were missed. As a result, the casualty rates measured in this study were likely conservative estimates, meaning that the true risk of casualties was probably higher.

If the amount of underreporting fluctuated during the study period in a way that was correlated with the implementation of ACSA, then those changes in reporting could be responsible for the decreases in casualty rates instead of ACSA. Given the decrease in serious casualties on both types of vessels (which are less likely to be underreported than minor or moderate casualties), even with higher NMFS observer presence on FT vessels after ACSA, it seems unlikely that the effect of ACSA on casualty rates is a spurious relationship.

6. Conclusions

ACSA was designed as a primary prevention intervention for the FT and FL fleets operating in Alaska. Declines in the rates of all casualties on FL vessels and serious casualties on both FT and FL vessels suggest that ACSA has improved safety in those targeted fleets. These results support the premise that primary prevention strategies can contribute to worker safety by reducing the occurrence of vessel disasters. Future ASC programs should be patterned after ACSA and improved by following the recommendations outlined in this study regarding quantitative risk assessment and evaluation planning.

Conflict of interest statement

The authors report no conflicts of interest.

Acknowledgments

The authors express sincere gratitude to personnel at the USCG and in the NMFS observer program who provided access to data for this study. This study did not receive any external funding.

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Assessment of Safety in the Bering Sea/Aleutian Island Crab Fleet

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Suggested Citation
NIOSH (2016). Assessment of Safety in the Bering Sea/Aleutian Island Crab Fleet. By Lucas, D., Case, S., Teske, T., DeLeon, A., Kloczko, D., OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. National Institute for Occupational Safety and Health. DHHS, (NIOSH) Publication No. 2016-112.

DHHS, (NIOSH) Publication No. 2016-112.
April 2016

On the Front Cover: Crewmembers hauling gear onto crab vessel. (Photo courtesy of Alaska Seafood)

On the Back Cover: A crewmember dumps a pot of Opilio crab onto the sorting table of a Bering Sea crab vessel. (Photo courtesy of Mike Fourtner)

Introduction

This report provides a detailed analysis of work-related injuries and vessel safety issues within the Bering Sea/Aleutian Island (BSAI) crab fleet to identify both hazards and opportunities for safety improvements within the fleet. The BSAI crab fleet is comprised of vessels averaging 90–120 feet in length that use pot gear to harvest crab, and either process the catch on board or deliver it to on-shore or floating processors (Woodley & Medlicott, 2001). The fishing seasons for various species of BSAI crab begin in October and typically end by May. The findings and recommendations in this report are especially relevant to the North Pacific Fishery Management Council, United States Coast Guard, and the Bering Sea/Aleutian Island crab fleet.

The BSAI crab fleet was identified as the most hazardous commercial fishery in the United States during the 1990s (Lincoln et al., 2013). During that decade, 73 crewmembers in the fleet died as a result of vessel disasters, falls overboard, or on-board injuries (Lincoln et al., 2013). Although safety regulations in place at that time required vessels to carry lifesaving equipment, such as immersion suits and life rafts, the regulations did not address the problem of overloading vessels with crab pots, a major cause of vessel disasters and deaths. This gap in safety regulations was partially corrected by the Coast Guard in 1999 with the introduction of the "At-the-Dock Stability and Safety Compliance Check" program, in which Coast Guard personnel checked crab vessels in Dutch Harbor prior to departure to ensure that each was loaded in compliance with their stability instructions. Subsequent to the introduction of this program, along with other possible factors such as changes in safety culture, the number and rate of fatalities in the fleet decreased during the period 1999-2012 (Lincoln et al., 2013; Woodley et al., 2009).

In addition to the Coast Guard Compliance Checks, the BSAI crab fishery changed in 2005 from a derby-style race for fish to a quota-based (rationalized) system. This management change contributed to an extended fishing season, smaller pot loads, and allowed for a more experienced and potentially less fatigued crew (Woodley et al., 2009). The change was also associated with a consolidation of the fishing fleet, from an average of 243 vessels during 2001–2004 to 78 vessels during 2005–2010 (North Pacific Fishery Management Council, 2010).

Fatal injuries in the BSAI crab fleet have decreased substantially through the combined and cooperative efforts of the fishing industry, Coast Guard, and National Marine Fisheries Service (NMFS). Further improvements in crewmember safety may be obtained by analyzing the causes of nonfatal injuries and vessel casualties, and developing focused interventions to address hazards. This report summarizes these hazards in the BSAI crab fleet during the 2005/06 – 2012/13 seasons. The results can be used to develop recommendations to improve safety within the fleet by the industry, Coast Guard, and fisheries management.

Data Collection

Vessels that operated (had permits and made landings) in the BSAI crab fishery during the 2005/06 – 2012/13 seasons were identified by NMFS and provided to NIOSH. Researchers at NIOSH reviewed Coast Guard reports of marine casualties that occurred on each identified vessel while it was operating in the crab fishery. Two types of marine casualties, personnel casualties and vessel casualties, were considered safety-related incidents and were included in this assessment.

Personnel casualties were restricted to fatal and nonfatal work-related traumatic injuries sustained by crewmembers in the fleet. Crewmember emergencies involving illnesses such as epileptic seizures or severe hypoglycemia were not included. Variables of interest included incident location, weather conditions, crewmember demographics, injury characteristics (nature, body part, source, mechanism, and severity), job task performed, and vessel characteristics (length and year built).

Vessel casualties were defined in this study as adverse events occurring to vessels that made it difficult or unsafe to continue at sea (e.g., sinking, fire, loss of propulsion, grounding, flooding). Vessel disasters are a subset of vessel casualties and were defined in this study as catastrophic incidents that forced the crews to abandon ship. Variables of interest were casualty type, severity, resolution, incident location, weather conditions, and vessel characteristics.

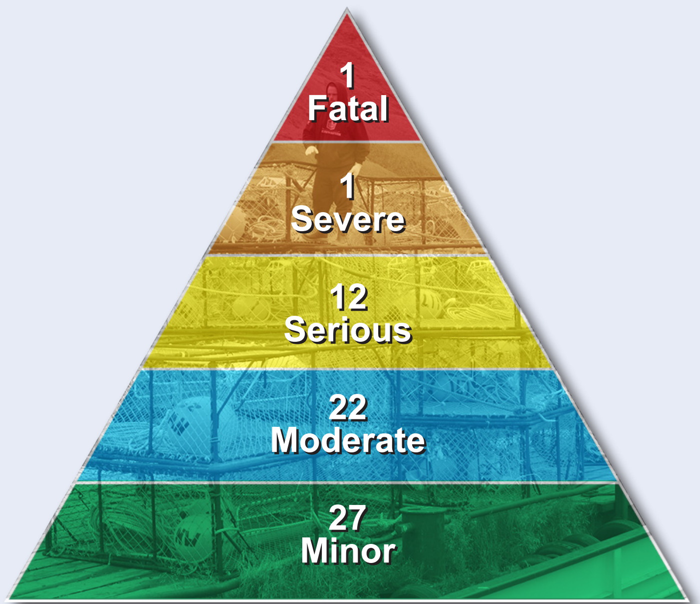
Because fishing vessels vary in terms of days at sea and crew size, they experience differing exposure to hazards that can result in marine casualties. A common denominator is necessary to accurately measure the risk of marine casualties in the BSAI crab fleet and enable comparison to other fishing fleets and industries. The exposure estimate used as the denominator to calculate injury rates in this study was full-time equivalent workers (FTEs), based on a standard 2000 hour work-year. FTEs adjust the worker population to reflect the same amount of exposure to risk as other workers, thereby allowing comparisons of risk between fleets and industries. Risk was expressed as the number of nonfatal injuries that occurred for every 1,000 FTEs. For vessel casualties, the exposure estimate used to measure risk was vessel-days-at-sea, expressed as the number of vessel casualties per 1,000 days at sea.

A statistical analysis was performed to explore and characterize the data. The analysis was complicated by the presence of missing data caused by the varying level of detail contained in the source documents (Coast Guard investigation reports). When calculating percent distributions, missing data were excluded from the denominators. Since each case could have missing data on different variables, the denominator fluctuated for the calculation of each variable's percent distribution. In the following results section, when presenting the percent distribution for each variable, the denominator for that variable is shown for the first calculated percentage and then suppressed for subsequent calculations using the same denominator.

Results: Personnel Casualties

Between 2005/06 and 2012/13, 65 injuries in the BSAI crab fleet were reported to the Coast Guard, of which one was fatal (Figure 1). The remaining 64 injuries were nonfatal, ranging in severity from minor to severe, with severity of two nonfatal cases missing (See Appendix B for injury severity coding rules and examples). Many of these nonfatal injuries were classified as minor (27/62, 44%) or moderate (22, 35%). Twelve injuries (19%) were classified as serious, and one crewmember sustained a severe injury (See Appendix C for descriptions of these 13 serious/severe injuries). No critical injuries were reported during the study period.

Figure 1 - Severity of fatal and nonfatal injuries, BSAI crab fleet, 2005/06 – 2012/13 (n=63, missing data for two cases).



Fatal Injuries

During 2005/06 – 2012/13, one fatality occurred in the fleet. In January 2009, crewmembers were setting pots when a deckhand, who had been throwing a line, inadvertently stepped into a coil of line. The line quickly tightened around his lower leg as a pot was launched and pulled him overboard. Personal flotation devices (PFDs) are not federally mandated to be worn by crewmembers in the fishing industry, and the crewmember in this incident was not wearing a PFD when he was pulled overboard. The crew immediately began man overboard procedures, including maneuvering the vessel to maintain a visual on the entry location, and contacting the Coast Guard for search and rescue assistance. Despite their efforts, the crewmember was never recovered from the water.

Nonfatal Injuries

During 2005/06 – 2012/13, 64 nonfatal injuries were reportedly sustained by BSAI crab crewmembers. The rate of nonfatal injury for this period was 12 injuries per 1,000 FTEs. Most of the injuries occurred to deckhands (39/50, 78%), followed by processors (7, 14%), and engineers (3, 6%). One mate was injured. All injured crewmembers were male, and the median age was 33 years (21-58 years) with a median of four years fishing experience (0–25 years). Most resided in Washington (16/57, 28%), Alaska (12, 21%), and Oregon (11, 19%).

Fractures were the most frequently reported injury (12/57, 21%), of which half (6) occurred while crewmembers were handling gear on deck. Fractures also occurred while crewmembers were setting or hauling gear. Other commonly reported injuries included contusions (11, 19%), lacerations (10, 18%), and sprains, strains, and tears (8, 14%). Most injuries occurred to the upper extremities (24/63, 38%), followed by lower extremities (16, 25%), trunk (15, 24%), and head (8, 13%). Fractures and lacerations were the most common types of injuries affecting upper extremities, and sprains/strains/tears were the most common injuries affecting lower extremities (Figure 2). While most injuries were classified as minor or moderate in severity, fractures, internal injuries, and amputations were more likely to be serious or severe (Figure 3).

Figure 2 - Types of nonfatal injuries, BSAI crab fleet, 2005/06 – 2012/13 (n=56, missing data on either body part or type of injury for 8 cases).

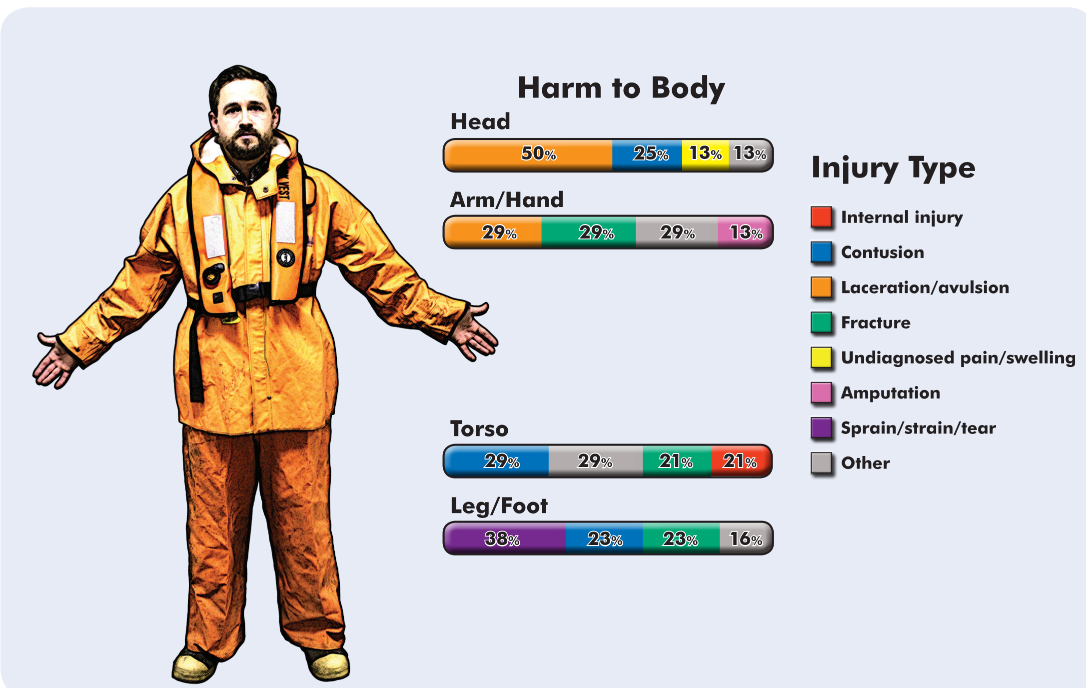
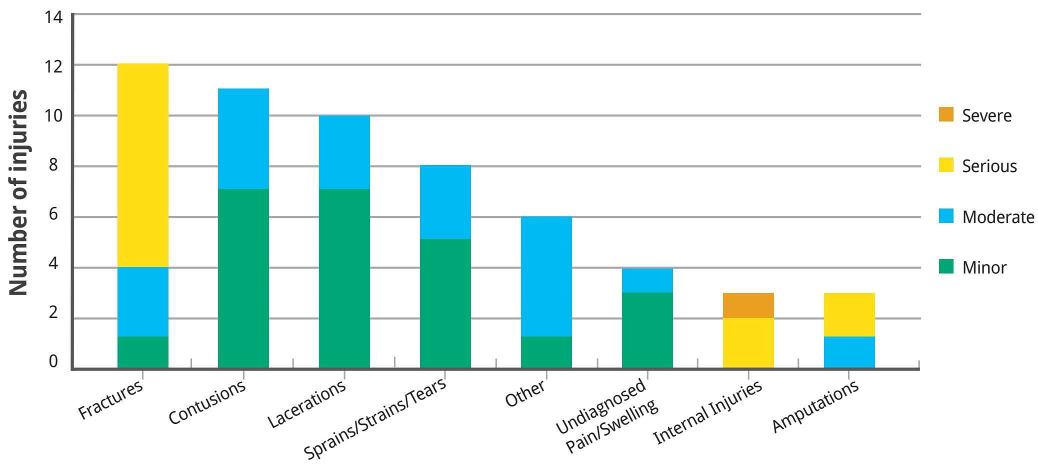
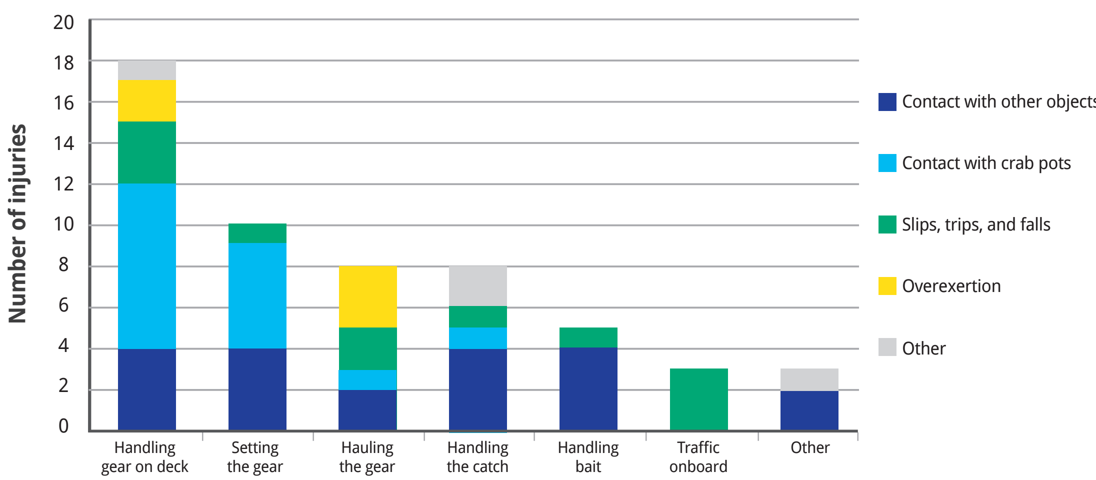


Figure 3 - Types and severity of nonfatal injuries, BSAI crab fleet, 2005/06 – 2012/13 (n=57, missing data on either type of injury or severity for 7 cases).



Injuries most often occurred while crewmembers were handling gear on deck, setting the gear, hauling the gear, and handling the catch (Figure 4). Contact with objects and equipment during these and other job tasks resulted in the most injuries (35/55, 64%). Contact with crab pots in particular made up the largest proportion of those injuries (15/35, 43%), often from crewmembers being struck by moving or falling crab pots, or being struck against pots. The single severe injury in the study period occurred when a pot fell onto a crewmember while he was untying pots. Slips, trips, and falls were the next leading cause of nonfatal injuries, resulting in 11 injuries (20%). Slips, trips, and falls occurred during almost all of the job tasks (Figure 4).

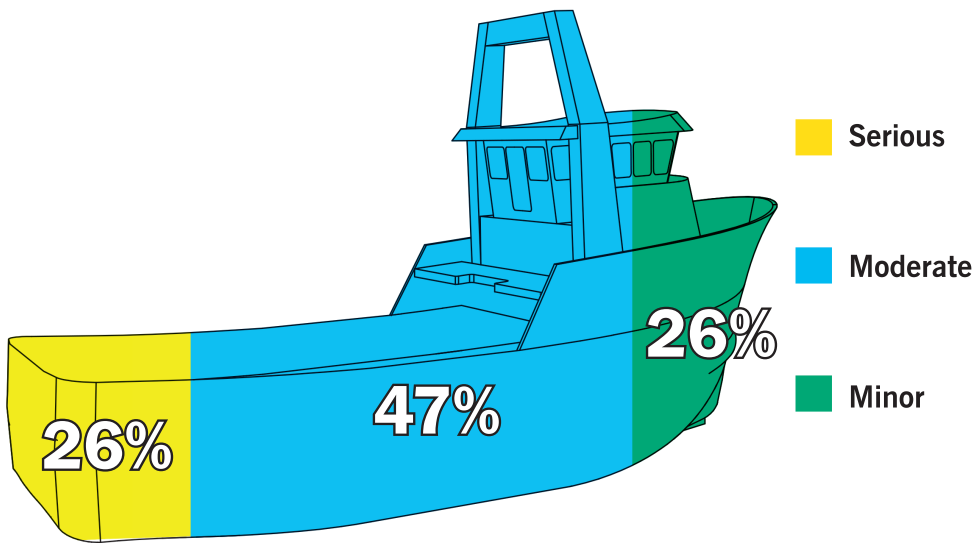
Figure 4 - Job tasks and events causing nonfatal injuries, BSAI crab fleet, 2005/06-2012/13 (n=55, missing data on either job task or event for 9 cases).



Results: Vessel Casualties

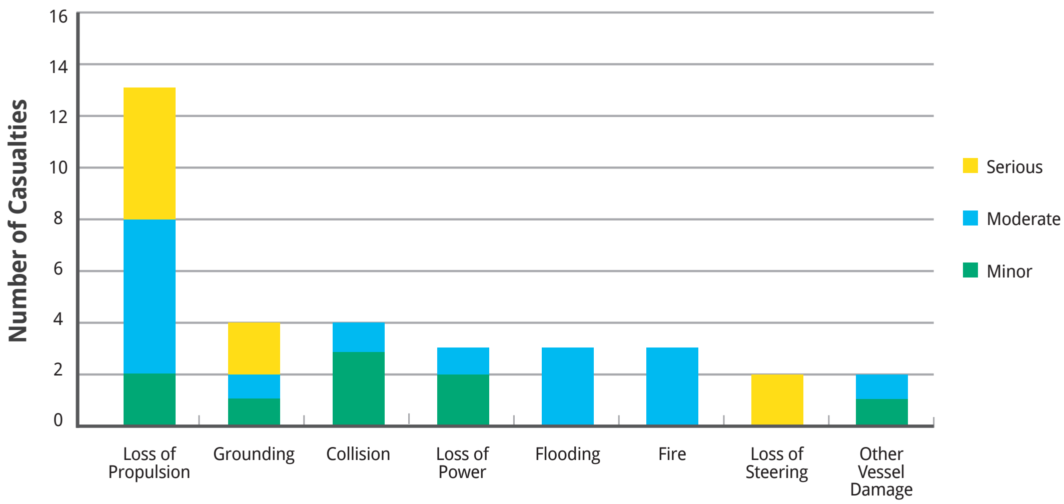
During 2005/06 – 2012/13, 34 vessel casualties were reported in the BSAI crab fleet, resulting in a rate of 7.9 casualties per 1,000 days at sea. Minor vessel casualties, defined as those completely resolved at sea by the crew, accounted for 26% (9) of all casualties. Nearly half of the vessel casualties were classified as moderate (16, 47%), meaning that the problem was either resolved at sea with outside assistance, or the vessel returned to port under its own power for repairs. Nine incidents (26%) were classified as serious casualties, meaning the vessel had to be rescued at sea and towed to port for repairs (See Appendix D for descriptions of these nine serious vessel casualties). There were no vessel disasters (e.g., sinking, capsizing) during the study period.

Figure 5 - Illustration of vessel casualty severity, BSAI crab fleet, 2005/06 – 2012/13 (n=34).



The most frequently reported casualties involved loss of propulsion (13, 38%), followed by groundings (6, 18%) and collisions (4, 12%). The majority of incidents in which the vessel lost propulsion were classified as moderate (6) or serious (5) (Figure 6). While collisions and groundings were similar in frequency, the severity of the casualty differed between the two types. Collisions were mostly minor, while groundings were mostly serious. Flooding and fire events were all classified as moderate in severity, but the two loss of steering incidents were classified as serious.

Figure 6 - Type and severity of vessel casualties, BSAI crab fleet, 2005/06 – 2012/13 (n=34).




Crab vessel Fierce Allegiance setting out from Dutch Harbor, Alaska. Photo credit - NIOSH.

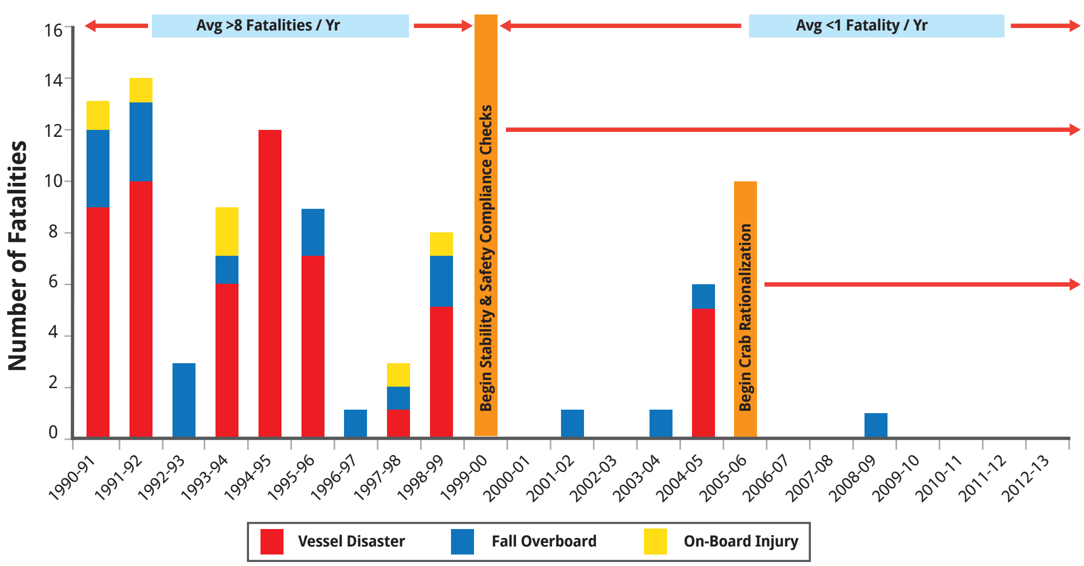
Safety Trends and Recommendations

Fatalities

In the 1990s, the BSAI crab fleet averaged eight fatalities per year; since 2000 after the implementation of the "At-the-Dock Stability and Safety Compliance Check" program and crab rationalization, there has been less than one fatality per year on average (Figure 7). Taking into account reductions in the number of vessels and crewmembers, this represents more than a 60% decline in the risk of fatal injuries (Lincoln & Lucas, 2010). The stability safety program should continue to be administered by the Coast Guard prior to each crab season. In addition, vessel owners and operators should periodically consult a naval architect to refresh knowledge of safe loading limits and adhere to stability instructions (USCG, 2010).

The single fatality in the fleet during the study time period (2005/06 – 2012/13) was due to a fall overboard. This loss of life is a tragic reminder that deadly hazards still exist in the fishery, even as the overall risk of fatalities in the fleet has declined significantly (Woodley et al., 2009). To prevent further deaths from falls overboard, all crewmembers should wear a PFD at all times on deck, as well as a readily accessible knife to cut lines in an emergency (NIOSH, 2010). Effective man-overboard training and drills should be conducted every month (USCG, 2015). As a supplement to the currently required life ring, vessel operators should add more effective recovery devices and utilize the devices during monthly man overboard drills (USCG, 2015).

Figure 7 - Fatalities by season and incident type, BSAI crab fleet, 1991/92 – 2012/13 (n=82). Data sources: for 1990-2009 (Lincoln et al., 2013); for 2010-2013 (NIOSH Commercial Fishing Incident Database, 2014).



Nonfatal Injuries

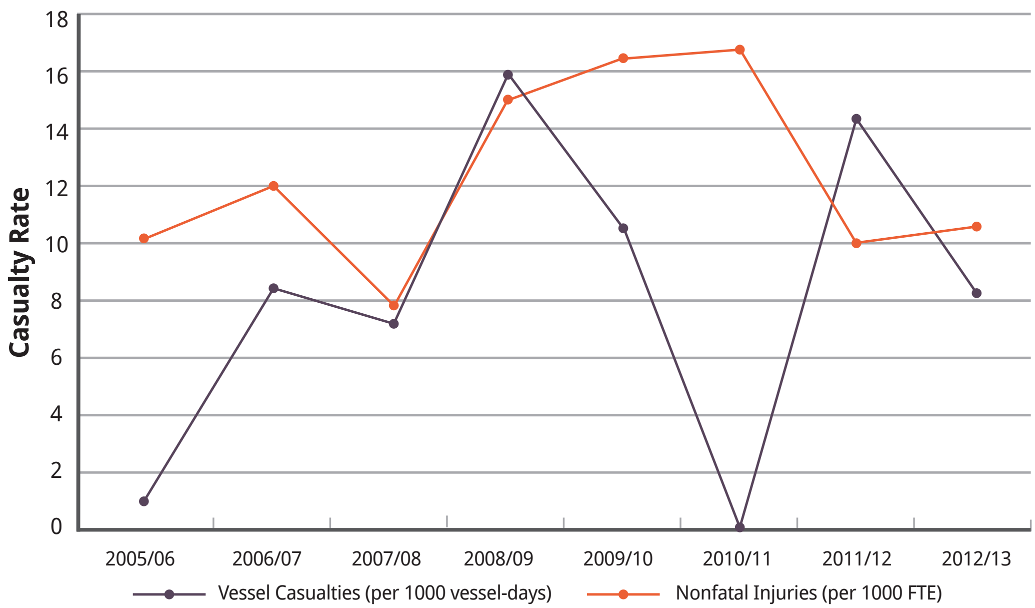
An average of eight nonfatal injuries among crewmembers were reported to the Coast Guard annually during the study period. The number of nonfatal injuries is too small to perform a statistical analysis of the trend over time, but a visual examination of the trend indicates that aside from small yearly fluctuations, the annual number of injuries remained relatively unchanged during the study period (Figure 8). It is unclear how accurately the number of reported injuries represents the true injury burden in the fleet. Underreporting of injuries is likely a problem, but the extent has not been determined. Companies that operate fishing vessels are 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). Enhanced reporting by fishermen and thorough documentation by the Coast Guard would improve data quality. Measures to improve reporting of injuries should be considered by vessel owners and the Coast Guard.

The annual risk of nonfatal injuries in the BSAI crab fleet was 12 per 1,000 FTEs. There are very few studies in the literature that have similarly estimated the risk of nonfatal injuries in fishing fleets, hampering the comparison of risk between fleets. One recent study of nonfatal injuries in the BSAI freezer-longline and freezer-trawl fleets found rates of 35 and 43 injuries per 1,000 FTEs, respectively (Lucas et al., 2014). In 2014, the risk of nonfatal injuries in all U.S. private industries was estimated at 32 per 1,000 FTEs (BLS, 2015). The most likely explanation for the seemingly low risk of nonfatal injuries in the BSAI crab fleet is underreporting of injuries, thereby artificially deflating the true risk.

The large proportion of nonfatal injuries caused by crab pots highlights the hazard of unrestrained and moving pots. Vessel motion can cause unsecured pots to move abruptly, striking crewmembers on deck. Ensuring that pots are secured when not in use can help to prevent this from occurring. Normal operations with pots (e.g., stacking or launching pots) can also be hazardous. Because of their size and weight, even minor mistakes while handling or working near pots can lead to fractures, amputations, and other serious injuries. Procedures for securing and moving pots should be reviewed and adjusted by skippers and crewmembers to decrease the risk of crewmembers being struck by pots. All crewmembers should receive training on safe work practices and be vigilant and aware of their surroundings while working on deck.

To prevent injuries caused by slips, trips, and falls, inspect the deck and other walking surfaces periodically to identify and eliminate slippery areas. Non-skid gratings, fiber mats, and nonslip coatings can be used to reduce slip hazards. Serious injuries were reported that involved unguarded or inadequately guarded machinery. Vessel operators should inspect guards on machinery, including bait choppers, cranes, and winches, and repair or replace deficient or missing guards. Keep all vessel equipment maintained regularly per manufacturers' guidelines.

Figure 8 - Rates of vessel casualties and nonfatal injuries by season, BSAI crab fleet, 2005/06 – 2012/13



Vessel Casualties

Although there were no vessel disasters during 2005/06 – 2012/13, vessels should continue to carry functional lifesaving equipment on board at all times and to regularly conduct emergency drills such as vessel abandonment, to familiarize crewmembers with the equipment. All crewmembers should take an 8-hour marine safety class at least every five years to maintain the skills needed in an emergency (USCG, 2015).

The frequency of vessel casualties that were reported to the Coast Guard was highly variable during the study period, with a high of eight casualties during one season, and a low of zero during another season. There was no discernable trend in the rate of reported vessel casualties (Figure 8). Similar to nonfatal injuries, vessel casualties were likely underreported, especially those that did not involve assistance from the Coast Guard. Measures to improve reporting of vessel casualties should be considered by vessel owners and the Coast Guard.

Vessel casualties such as loss of propulsion can result in delayed or shortened fishing trips, which decrease productivity and profits. They may also lead to more serious events, including vessel disasters. Ensuring regular maintenance, particularly on propulsion systems, may help to reduce the risk of vessel casualties or disasters at sea. Vessel owners and operators should consider reviewing and updating their maintenance procedures for propulsion and other critical systems to improve the reliability of those systems at sea (USCG, 2015).

Conclusion

Coast Guard programs, industry initiatives, and fishery management changes have improved crewmember safety in the BSAI crab fleet. Although fewer fatalities have occurred, these fisheries do take place in a harsh environment, in the winter, in remote locations on uninspected vessels, sometimes transiting through ice. Efforts to prevent nonfatal injuries, fatalities, and vessel casualties should be continued by considering the recommendations in this report. In addition, during the development of an Alternate Safety Compliance Program for the BSAI crab fleet, industry representatives should review the findings in this report with the U.S. Coast Guard to determine if other good marine practices outlined in the *Alternate Safety Compliance Program Draft Matrix of Possible Requirements* (USCG, 2015) should be adopted.

Crewmembers conduct survival training in Dutch Harbor, Alaska. Photo credit - NIOSH.

Appendix A: Recommendations for Reducing Hazards* in the BSAI Crab Fleet (NIOSH, 1997; NIOSH, 2010; USCG, 2010; USCG, 2015)**	
Vessel Casualties	**To prevent vessel disasters and other serious vessel casualties:** 1. Participate in the USCG "At-the-Dock Stability and Safety Compliance Check" program prior to each crab season. 2. Periodically consult a naval architect to refresh knowledge of safe loading limits and adhere to stability instructions. 3. Update and formalize maintenance procedures for propulsion, power, steering, and other critical systems, and closely follow the established schedule. 4. All crewmembers should take an 8-hour marine safety class at least every five years to maintain the skills needed in an emergency. 5. Review the findings in this report with the U.S. Coast Guard to determine if other good marine practices outlined in the *Alternate Safety Compliance Program Draft Matrix of Possible Requirements* should be adopted to prevent vessel casualties.
Falls Overboard	**To prevent fatal falls overboard:** 1. Create or update PFD policies to require all crewmembers to wear PFDs at all times while on deck. 2. Increase the effectiveness of man overboard training and drills.. 3. Add effective recovery devices and utilize the devices during monthly man overboard drills. 4. Review the findings in this report with the U.S. Coast Guard to determine if other good marine practices outlined in the *Alternate Safety Compliance Program Draft Matrix of Possible Requirements* should be adopted to prevent falls overboard.
Onboard Injuries	**To prevent injuries sustained onboard the vessel:** 1. Review and adjust procedures for securing and moving pots. 2. Conduct periodic training with crewmembers on deck safety. 3. Inspect the deck and other walking surfaces to identify and eliminate slippery areas. 4. Inspect guards on machinery including bait choppers, cranes, and winches; and repair or replace deficient or missing guards. 5. Keep all vessel equipment maintained regularly per manufacturers' guidelines.

*In addition to existing fishing industry safety regulations.

**Recommendations are based on a review of specific hazards for the BSAI crab fleet during the study period, and reflect previously published NIOSH recommendations for other commercial fishing fleets.

Appendix B. Injury Severity Scale (USCG, 2012)		
Minor	The injury is minor or superficial. No medical treatment was required.	Examples: Minor /superficial scrapes (abrasions); minor bruises; minor cuts; digit sprain; first degree burn; minor head trauma with headache or dizziness; minor sprain/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 for more than 48 hours within 5 days of the injury.	Examples: broken fingers, toes, or nose, amputated fingers or toes; degloving 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.	Examples: broken bones (other than fingers, toes, or nose); partial loss of limb (amputation below elbow/knee); degloving 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.	Examples: 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).

Appendix C. Descriptions of Serious/Severe Injuries, BSAI Crab Fleet, 2005/06 – 2012/13	
Year of Incident	**Description of Injury Event (13 Serious/Severe Injuries)**
Setting the Gear	
2009	A crewmember sustained internal injuries when he was struck by a falling crab pot he had just untied.
2009	A crewmember was untying a crab pot when it fell on him after the vessel rolled, resulting in a broken back.
2013	A crewmember sustained a fractured lower leg while setting gear.
Hauling the Gear	
2013	A crewmember was pulling crab pots from the water when he slipped and fell, breaking his collar bone.
Handling Gear on Deck	
2005	A mate was holding onto a pot when the crane operator winched up. As the pot swung to the side, the crewmember fell, injuring his left shoulder.
2005	A crewmember operating the crane to offload crab lowered the crane boom down on his hand, resulting in an amputation of his right hand at the wrist.
2009	A crewmember was struck by a wave and thrown into pots, resulting in fractured ribs and abrasions.
2010	A crewmember's hand was jammed against a crab pot while stacking pots resulting in a fracture, after the vessel rolled to the side.
2010	A crewmember was repairing a crab pot on deck while lying on his back. The vessel rolled and he slid across the deck, striking the right side of his body against the vessel.
2010	An engineer was attempting to repair a pot when he became pinched between pots and sustained cracked ribs and punctured lungs.
Handling the Catch	
2005	A crewmember slipped and fell off of the sorting table while sorting crab, breaking his ankle.
2013	A crewmember was struck by an unsecured crab pot after the vessel rolled, resulting in a fractured leg.
Handling Bait	
2005	A crewmember was cleaning the bait chopper when he inadvertently turned on the equipment. His left hand became caught in the chopper, resulting in an amputation below his wrist.

Appendix D. Descriptions of Serious Vessel Casualties, BSAI Crab Fleet, 2005/06 – 2012/13

Year of Incident	Description of Event (9 Serious Vessel Casualties)
2008	A vessel experienced steering failure after the weld between the rudder and flange broke. The vessel was towed to port by another fishing vessel for repairs.
2008	A vessel's oil cooler ruptured, prompting a shutdown of the engines. The crew attempted to change the oil cooler at sea but were unsuccessful. The vessel was towed to port by an unspecified vessel.
2009	A vessel experienced a partial loss of propulsion and proceeded to return to port. While en route, the vessel lost all propulsion. The vessel was towed to port by another fishing vessel.
2009	A vessel's engine died after the fuel pressure dropped. The vessel was towed to port for repairs by an unspecified vessel.
2010	A vessel ran aground during transit and was unable to back off the rocks. A tug assisted the vessel and towed it back to port.
2011	A vessel, having just completed routine maintenance, was in transit away from port when the engine died. The vessel was towed back to port by a nearby unspecified vessel.
2012	A vessel ran aground after experiencing radar software errors and low visibility. The vessel was towed to port by a tug.
2012	A vessel's rudder post broke due to metal fatigue, resulting in a loss of steering. The vessel was towed to port for repairs by another fishing vessel.
2013	A vessel experienced loss of propulsion due to water in the fuel, prompting a shutdown of the engines. The vessel was towed to port by another fishing vessel.

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Accepted: 28 July 2017
DOI: 10.1002/ajim.22761

RESEARCH ARTICLE

WILEY AMERICAN JOURNAL OF INDUSTRIAL MEDICINE

Work-related mortality in the US fishing industry during 2000-2014: New findings based on improved workforce exposure estimates

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Background: Commercial fishing is a global industry that has been frequently classified as high-risk. The use of detailed surveillance data is critical in identifying hazards.
Methods: The purpose of this study was to provide updated statistics for the entire US fishing industry during 2010-2014, generate fleet-specific fatality rates using a revised calculation of full-time equivalent estimates, and examine changes in the patterns of fatalities and in risk over a 15-year period (2000-2014).
Results: During 2010-2014, 188 commercial fishing fatalities occurred in the United States. Vessel disasters and falls overboard remain leading contributors to commercial fishing deaths. The Atlantic scallop fleet stands out for achieving substantial declines in the risk of fatalities over the 15-year study period. However, fatality rates ranged from 21 to 147 deaths per 100 000 FTEs, many times higher than the rate for all US workers.
Conclusions: Although the number of fatalities among commercial fishermen in the United States has generally declined since 2000, commercial fishing continues to have one of the highest occupational fatality rates in the United States. The sustainable seafood movement could assist in improving the health and safety of fishing industry workers if worker well-being was integrated into the definition of sustainable seafood.

KEYWORDS
fishing, mortality, occupational, surveillance

1 | INTRODUCTION

Commercial fishing is a critical industry for global food security, generating a major source of animal protein for billions of people worldwide.[1] Fishing vessels vary widely in terms of size and configuration, ranging from small undecked vessels with as few as one person onboard to large decked vessels with dozens of crewmembers who catch and process fish into final products in factories onboard the vessels. The fishing industry has been frequently classified as exceptionally high-risk, with workplace fatality rates that are often the highest among all industries in many countries.[2] The life-threatening hazards faced by workers in the fishing industry have been measured and described in many epidemiologic studies for decades,[2] yet public concern over the death toll has been mostly lacking, including within social movements such as for sustainable seafood.

Interest in sustainable seafood has been steadily increasing among wholesalers, retailers, restaurants, and consumers.[3] Market research has predicted a growing awareness and preference for seafood that is environmentally, economically, and socially sustainable.[3] Definitions of the term "sustainable seafood" have included specific elements such as locally caught, wild harvested, fresh, whole, and sourced from effectively managed fisheries (eg, low impact on habitat, not overfished).[3,4] Missing from the sustainable seafood movement is the health and safety of fishing industry workers who harvest the fish and initiate the seafood supply chain.

Although several recent studies have examined fatal and nonfatal injuries in specific fishing fleets or regions in the United States,[5–8] the most recent epidemiologic profile of work-related mortality for the entire US fishing industry was published in 2010.[9] The study used surveillance data to describe fishing industry fatalities during the decade of 2000-2009. In that study, 504 worker fatalities were identified, an average of 50 work-related deaths per year. The majority of fatalities were caused by vessel disasters (52%) and falls overboard (31%). The Alaska region had the highest number of fatalities (133, 26%), followed by the Northeast (124, 25%) and Gulf of Mexico (116, 23%) regions. The study noted that the annual number of fatalities in the industry had declined gradually since the previous decade of the 1990s. That modest decline was consistent with an international analysis of trends in fatal incidence rates, which found that overall risk in fishing declined in Europe and North America over a three decade period (1980-2010).[10]

Lincoln and Lucas[9] also reported fatality rates for eight large fishing fleets, ranging from 115 to 600 deaths per 100 000 full-time equivalent (FTE) workers, substantially higher than the rate for all US workers. The methodology used in the study for calculating the FTE denominators in fatality rates had been used in several previous studies.[11–13] However, the FTE calculations in those studies were not based on the standard method widely used by other research institutions,[14] making it difficult to compare the rates with others outside of the particular study.

Given the limitations of the previously published FTEs and rates, along with the outdated published national fatality data, the purpose of this study was to (1) provide updated statistics for the entire US commercial fishing industry by conducting a descriptive analysis of fatalities, with a particular emphasis on those occurring more recently during 2010-2014; (2) generate fleet-specific fatality rates using a revised calculation of FTE estimates; and (3) examine changes in the patterns of fatalities and in risk over a 15-year period.

2 | METHODS

2.1 | Case definition

Cases of fatal work-related injuries in the US fishing industry during 2000-2014 were identified and extracted from the Commercial Fishing Incident Database (CFID). This surveillance system, maintained by the National Institute for Occupational Safety and Health (NIOSH), is a nationwide database containing information on all fatalities in the US commercial fishing industry. NIOSH developed CFID to collect data on commercial fishing fatalities and to identify high-risk fleets (defined by species targeted, type of fishing gear used, and location of fishing grounds).

For inclusion in CFID, fatalities must be the result of a traumatic injury, 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."[15] This definition includes fatal poisonings as well as intentional injuries such as homicide and suicide. Fatalities due to illnesses or chronic conditions are not included in the database and were, therefore, not in this study. Only cases that met the criteria for an occupational fatality using established guidelines for injury at work were included. The occupation of commercial fisherman was defined by the Standard Occupational Classification (SOC) code 45-3011 "Fishers and Related Fishing Workers." This definition includes captains, mates, and deckhands. CFID also contains data on fatal injuries involving at-sea fish processors and fishery observers if the event occurred onboard or otherwise involved a fishing vessel.

In 2014, NIOSH entered into a Memorandum of Agreement with the US Coast Guard (USCG) to facilitate information sharing. This formal partnership allows NIOSH researchers access to Coast Guard investigative reports for CFID data collection. Data in CFID are also obtained by NIOSH staff from other sources in each state, including reports from local law enforcement agencies and local media; death certificates; and state-based occupational fatality surveillance programs. Causes of death were coded using the International Classification of Disease version 10 (ICD-10) obtained from death certificates or determined from investigative reports.

Five types of fatal incidents were identified in CFID: vessel disasters, falls overboard, onboard injuries, onshore injuries, and diving injuries. Vessel disasters involved the fishing vessel being capsized, sunk, or damaged to a degree that the crew abandoned the vessel. This includes both decked and open vessels, such as skiffs. A fall overboard was defined as a worker entering the water outside of the vessel, which included all methods for entering the water: struck by gear, washed over, slipped, jumped, entangled, etc. Onboard fatal injuries occurred on or within the fishing vessel (eg, struck by gear, entangled in winch). Onshore injuries occurred while on land, including on a dock or float. Falls into water from a dock were coded as onshore injuries, not falls overboard. If a fall into water occurred while boarding or disembarking a fishing vessel, the fatality was coded as a fall overboard if the decedent was in contact with the vessel, or as an onshore injury if the decedent was in contact with the dock. Diving injuries occurred when the worker was intentionally in the water for the purpose of harvesting or other work-related tasks (eg, diving to untangle a line or net from the propeller).

Fatalities occurred in five fishing regions of the United States: East Coast, Gulf of Mexico, West Coast, Alaska, and Hawaii. Fatal injuries that involved US fishing vessels in Canadian waters while in transit to or from Alaska were included in the Alaska region counts.

2.2 | Workforce data (exposure)

Period fatality rates were calculated for fleets with five or more fatalities during the 5-year periods 2000-2004, 2005-2009, and 2010-2014, where workforce data were available. These fleet-specific fatality rates enabled the comparison of risk between fishing fleets that have different levels of exposure as measured by the number of vessels, workers, and days at sea. The rates adjust the number of fatalities in each fleet based on a common denominator of 100 000 FTE workers. In this study, the method for calculating the FTE denominator was revised from earlier NIOSH publications to enhance the validity of the rates and standardize the calculation with the currently accepted method widely used by other agencies and academic institutions. As a result of these changes, the fishing fatality rates published in this study are not comparable to rates published in previous NIOSH studies, such as Lucas and Lincoln,[11] Lincoln and Lucas,[9] and Thomas et al.[13] However, to enable comparisons during 2000-2014 of fleet-specific fatality rates in this study, the previously published rates from 2000 to 2009 were recalculated using the revised standard method.

The previously published FTEs[9] were calculated by multiplying the number of vessels that made at least one landing in the fishery during the calendar year by the mean operating days for vessels in the fishery, and by the mean crew size for vessels in the fishery. The product, "crew-days," was then divided by 250 standard 8-h workdays in 1 year. Finally, fisheries with short seasons (<15 days duration) were weighted by a factor of three (essentially increasing 8-h days to 24-h days), and medium seasons (15-49 days) were weighted by a factor of two (increasing 8-h days to 16-h days). Seasons lasting longer than 49 days were not weighted.

The methodological justification for weighting the FTEs based on season length was that crewmembers in fisheries with shorter seasons worked longer hours per day than crewmembers in fisheries with longer seasons, and in that way had greater exposure to hazards. This framework implied that workers on fishing vessels were only at risk of injury or death when they were on-duty. However, previous studies of fatalities using that FTE included deaths in the numerator that occurred at any time, including to workers off-duty, creating incongruity between the cases in the numerator and exposure time in the denominator. Because of the unique setting in which commercial fishing takes place (ie, workers are exposed to work-related hazards even when off-duty), in this study, workers in the fishing industry were considered to be "at work" the entire time they were at sea.

A revised FTE formula was used in this study to account for all exposure time of cases in the denominator. The first part of the calculation was the same as the previous method, and used the same data inputs:[16] the number of vessels that made at least one landing in the fishery during the calendar year were multiplied by the mean operating days for vessels in the fishery, and by the mean crew size for vessels in the fishery. The product, "crew-days," was the same for both methods, but diverge at the next step. The revised calculation multiplied crew-days by 24 to create "crew-hours." Crew-hours were divided by 2000 h (the standard number of hours in a full-time work year). There was no weighting of FTEs based on season length as was done in the past. All workers in all fleets were considered at-risk the entire time they were onboard the vessels. Because FTEs were not available for 2013 or 2014, the estimates from 2012 were extended for those years.

2.3 | Analysis

A descriptive analysis was completed to explore the patterns and characteristics of work-related fatalities in the US fishing industry during the 5-year period 2010-2014. The analysis of this 5-year period was completed in a similar style as the previously published analysis of fatalities during 2000-2009.[9] The frequency of fatal injuries was calculated for each year during the study period. Descriptive statistics, including frequency and percent distributions, measures of central tendency and dispersion, and cross-tabulations were calculated for all fatal injuries, both in aggregate for the United States and by specific fishing regions. Fatality rates were calculated for certain fleets in each of three 5-year periods (2000-2004, 2005-2009, 2010-2014) using the revised formula for FTE estimates as previously described. Results from the recent 5-year analysis (2010-2014) were then compared to the prior time periods (2000-2004 and 2005-2009) to evaluate changes in fatalities and fatality rates over time.

Many cases were missing data for one or more variables. Cases with missing data were excluded from analyses that involved the variables with missing data. Consequently, the total number of cases for each statistic (eg, percent distribution, correlation, cross-tabulation) reported in the results may be different depending on the amount of missing data in each variable in that particular analysis. This study received a determination of "non-human subjects research" by the NIOSH IRB. All required safeguards for data security and protection were followed by the study team.

3 | RESULTS

3.1 | Findings from most recent 5-year period

During 2010-2014, 188 commercial fishing fatalities occurred in the United States, a mean of 38 deaths annually. Decedents were on average 44 years old, predominantly male (185, 98%), and most often deckhands (94, 50%). Drowning was the reported cause of death in the majority of fatalities (139, 75%). Vessel disasters (80, 43%) and falls overboard (57, 30%) were the leading types of fatal incidents. Commercial fishing deaths also resulted from onboard injuries (31, 16%), diving injuries (14, 7%), and onshore injuries (6, 3%). The East Coast had the most commercial fishing deaths (60, 32%) compared to other fishing regions, followed by the Gulf of Mexico (49, 26%), Alaska (45, 24%), and the West Coast (30, 16%). The remaining four fatalities occurred near Hawaii, each due to drowning after falling overboard.

Vessel disasters resulted in the most fatalities during 2010-2014 compared to other types of fatal incidents, with 54 vessel disasters causing 80 deaths (Table 1). Severe weather contributed to 37% of fatal vessel disasters. Vessel disasters were most frequently caused by instability (11, 22%), being struck by large waves (10, 20%), and flooding (8, 16%). Overloading was the leading cause of instability in vessel disasters (9, 82%). Flooding events had a variety of causes, with water ingress most commonly the result of hull breaches (3, 38%) or wood rot (2, 25%). The fleets that experienced the highest number of fatal vessel disasters were the Gulf of Mexico shrimp fleet, with six

TABLE 1 Initiating events and causes involved with fatal vessel disaster events, United States, 2000-2014

	2000-2004 (*n* = 75)		2005-2009 (*n* = 75)		2010-2014 (*n* = 54)		Total (*n* = 204)	
Events and causes	*n*[a]	%[b]	*n*	%	*n*	%	*n*	%
Initiating events								
Flooding	20	29.9	17	26.2	8	16.3	45	24.9
Instability	10	14.9	14	21.5	11	22.4	35	19.3
Struck by large wave	13	19.4	11	16.9	10	20.4	34	18.8
Collision/allision	8	11.9	6	9.2	7	14.3	21	11.6
Prop entanglement	4	6.0	2	3.1	3	6.1	9	5.0
Fire/explosion	3	4.5	3	4.6	2	4.1	8	4.4
Struck rocks/bottom	3	4.5	0	0.0	4	8.2	7	3.9
Struck by wind gust	2	3.0	3	4.6	1	2.0	6	3.3
Crossing hazardous bar	0	0.0	3	4.6	2	4.1	5	2.8
Gear caught on bottom	1	1.5	3	4.6	1	2.0	5	2.8
Engine failure	2	3.0	2	3.1	0	0.0	4	2.2
Steering failure	0	0.0	1	1.5	0	0.0	1	0.6
Listing	1	1.5	0	0.0	0	0.0	1	0.6
Unknown events	8	–	10	–	5	–	23	–
Causes of flooding								
Down-flooding (foundering)	7	50.0	7	53.8	1	12.5	15	42.9
Swamping (open skiff)	3	21.4	5	38.5	1	12.5	9	25.7
Through-hull fitting break	4	28.6	0	0.0	0	0.0	4	11.4
Hull breach (unspecified)	0	0.0	0	0.0	3	37.5	3	8.6
Wood rot	0	0.0	0	0.0	2	25.0	2	5.7
Hull corrosion	0	0.0	1	7.7	0	0.0	1	2.9
Hull-seam break	0	0.0	0	0.0	1	12.5	1	2.9
Unknown cause	6	–	4	–	0	–	10	–
Causes of instability								
Overloading	5	50.0	5	38.5	9	81.8	19	55.9
Hauling up heavy net	3	30.0	3	23.1	0	0.0	6	17.6
Shifting load	1	10.0	2	15.4	1	9.1	4	11.8
Icing	0	0.0	2	15.4	0	0.0	2	5.9
Structural modifications	1	10.0	0	0.0	1	9.1	2	5.9
Slack tank (free surface effect)	0	0.0	1	7.7	0	0.0	1	2.9
Unknown	0	–	1	–	0	–	1	–

[a]All numbers in this table are the number of events, not number of deaths. One or more deaths can occur during a single vessel disaster event.
[b]Valid percent.

disasters, and the West Coast non-tribal Dungeness crab fleet, with four disasters.

Drowning after falling overboard was the second leading cause of death among commercial fishermen in the United States during 2010-2014. None of the falls overboard victims were wearing a personal flotation device when they died. Falls overboard were most frequently caused by loss of balance (13, 36%) and becoming entangled in fishing gear (8, 22%) (Table 2). Multiple factors can contribute to a single fatal fall overboard; the most commonly identified factors were working alone (29, 51%) and using alcohol and/or drugs (10, 18%). Among those working alone, 14 were single operators alone on their vessel. The Gulf of Mexico shrimp fleet and the Northeast lobster fleet experienced the highest number of fatal falls overboard, with six and five deaths, respectively.

TABLE 2 Causes and contributing factors of fatal falls overboard, United States, 2000-2014 (*n* = 210)

	2000-2004 (*n* = 85)		2005-2009 (*n* = 68)		2010-2014 (*n* = 57)		Total (*n* = 210)	
Causes and contributing factors	*n*[a]	%[b]	*n*	%	*n*	%	*n*	%
Causes								
Trip/slip	24	30.8	19	37.3	4	11.1	47	28.5
Lost balance	22	28.2	11	21.6	13	36.1	46	27.9
Gear entanglement	14	17.9	7	13.7	8	22.2	29	17.6
Jumped	7	9.0	8	15.7	6	16.7	21	12.7
Knocked by gear/object	6	7.7	4	7.8	4	11.1	14	8.5
Washed over	5	6.4	2	3.9	1	2.8	8	4.8
Unknown	7	–	17	–	21	–	45	–
Contributing factors[c]								
Alone	43	50.6	38	55.9	29	50.9	110	52.4
Alcohol/drugs	24	28.2	13	19.1	10	17.5	47	22.4
Vessel motion	8	9.4	7	10.3	3	5.3	18	8.6
Deck obstacles	12	14.1	4	5.9	1	1.8	17	8.1
Leaning over side	6	7.1	3	4.4	5	8.8	14	6.7
Struck by large wave	6	7.1	3	4.4	2	3.5	11	5.2
Fatigue	4	4.7	1	1.5	4	7.0	9	4.3
Lost balance	1	1.2	1	1.5	6	10.5	8	3.8
Other	0	0.0	0	0.0	4	7.0	4	1.9

[a]All numbers in this table are the number of deaths.
[b]Valid percent.
[c]Not mutually exclusive; percent totals exceed 100%.

Sixteen percent of fatalities in the US fishing industry during 2010-2014 were attributed to injuries sustained onboard vessels. The leading causes of these deaths were becoming entangled in fishing gear (7, 23%), poisoning (6, 19%), and being struck by fishing gear or equipment (5, 16%). Over half of the gear entanglement deaths occurred in the Gulf of Mexico shrimp fleet as four fishermen died when they became entangled in deck winches. All fatal poisonings during this period were unintentional drug overdoses.

On the East Coast, vessel disasters and falls overboard were the leading fatal incident types, each resulting in 22 deaths (Table 3). The Northeast lobster fleet experienced the most fatalities in the region with 10 crewmember deaths, followed by the Atlantic scallop fleet with six fatalities (Table 4).

Over three-quarters of fatalities in the Gulf of Mexico occurred during vessel disasters (25, 51%) or after falls overboard (13, 27%) (Table 3). About half of all fatalities in the region occurred in the shrimp fleet (25, 51%) (Table 4).

Most deaths in Alaska were distributed among vessel disasters (15, 33%), falls overboard (14, 31%) and onboard injuries (12, 27%) (Table 3). Ten of the 15 deaths from vessel disasters in Alaska involved crewmembers working in open skiffs that swamped or capsized. The salmon set gillnet fleet experienced the most fatalities in the region, with seven deaths, followed by pot cod (6) and salmon drift gillnet (5) (Table 4).

Thirty fatalities occurred on the West Coast, with the majority from vessel disasters (18, 60%) (Table 3). Falls overboard and dive-related injuries caused the same number of deaths, each resulting in four fatalities. The Dungeness crab fleet had the most fatalities with eight deaths, of which five were in the non-tribal sector (Table 4).

Fleet-specific fatality rates using the revised, improved FTE calculations are shown for each 5-year period in Table 4, sorted in descending order in each region based on the 15-year total number of fatalities. In the most recent 5-year period 2010-2014, fleet-specific rates were largely not calculated due to small frequencies of fatalities in that period. Among the five fleets that had at least five fatalities during 2010-2014 and FTE data available, rates ranged from 21 fatalities per 100 000 FTEs in the Gulf of Mexico shrimp fleet to 147 deaths per 100 000 FTEs in the Alaska salmon set gillnet fleet.

3.2 | Trends during 2000-2014

Over the 15-year period 2000-2014, there were 693 commercial fishing fatalities, a mean of 46 deaths per year. The annual number

TABLE 3 Types of fatal incidents in fishing regions, United States, 2000-2014 (*n* = 693)

	2000-2004		2005-2009		2010-2014		Total	
Region and incident type	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**
East Coast region								
Vessel disaster fatalities	47	60.3	51	58.6	22	36.7	120	53.3
Falls overboard fatalities	18	23.1	18	20.7	22	36.7	58	25.8
Onboard fatalities	9	11.5	9	10.3	7	11.7	25	11.1
Onshore fatalities	2	2.6	6	6.9	4	6.7	12	5.3
Diving fatalities	2	2.6	3	3.4	5	8.3	10	4.4
Total	78	100.0	87	100.0	60	100.0	225	100.0
Alaska region								
Vessel disaster fatalities (decked)	26	38.8	32	47.8	5	11.1	63	35.2
Vessel disaster fatalities (skiff)	6	9.0	3	4.5	10	22.2	19	10.6
Falls overboard fatalities	23	34.3	19	28.4	14	31.1	56	31.3
Onboard fatalities	7	10.4	5	7.5	12	26.7	24	13.4
Onshore fatalities	2	3.0	7	10.4	1	2.2	10	5.6
Diving fatalities	3	4.5	1	1.5	3	6.7	7	3.9
Total	67	100.0	67	100.0	45	100.0	179	100.0
Gulf of Mexico region								
Vessel disaster fatalities	24	33.3	16	37.2	25	51.0	65	39.6
Falls overboard fatalities	34	47.2	18	41.9	13	26.5	65	39.6
Onboard fatalities	9	12.5	6	14.0	9	18.4	24	14.6
Onshore fatalities	0	0.0	0	0.0	0	0.0	0	0.0
Diving fatalities	5	6.9	3	7.0	2	4.1	10	6.1
Total	72	100.0	43	100.0	49	100.0	164	100.0
West Coast region								
Vessel disaster fatalities	30	69.8	28	66.7	18	60.0	76	66.1
Falls overboard fatalities	10	23.3	11	26.2	4	13.3	25	21.7
Onboard fatalities	2	4.7	1	2.4	3	10.0	6	5.2
Onshore fatalities	0	0.0	1	2.4	1	3.3	2	1.7
Diving fatalities	1	2.3	1	2.4	4	13.3	6	5.2
Total	43	100.0	42	100.0	30	100.0	115	100.0
Hawaii region								
Vessel disaster fatalities	0	0.0	1	33.3	0	0.0	1	10.0
Falls overboard fatalities	0	0.0	2	66.7	4	100.0	6	60.0
Onboard fatalities	2	66.7	0	0.0	0	0.0	2	20.0
Onshore fatalities	0	0.0	0	0.0	0	0.0	0	0.0
Diving fatalities	1	33.3	0	0.0	0	0.0	1	10.0
Total	3	100.0	3	100.0	4	100.0	10	100.0

of deaths varied from a high of 61 in 2001 to a low of 29 in 2014. The mean number of fatalities was highest in the first 5-year period (2000-2004) with 53 deaths per year and has since decreased, with an average of 48 deaths per year during 2005-2009, and finally, an average of 38 deaths per year during 2010-2014.

The most recent 5-year period saw a substantial decrease in the number of deaths that occurred during vessel disasters. Vessel disaster fatalities were at a high during 2000-2004 with 133 deaths, followed by 131 deaths in the next 5-year period, and contributed to about half of all fatalities in both periods. During 2010-2014, the number decreased to 80 deaths (43% of fatalities). While flooding was the

TABLE 4 Commercial fishing fatality frequencies and rates[a] per 100 000 by fleet, US Fishing Industry, 2000-2014

	2000-2004			2005-2009			2010-2014			15-year total		
Fleet	Fatalities	FTE[b]	Rate	Fatalities	FTE	Rate	Fatalities	FTE	Rate	Fatalities	FTE	Rate
East Coast region												
Atlantic scallop	21	12 091	174	23	13 643	169	6	13 907	43	50	39 641	126
Northeast multi-species groundfish trawl	11	5858	188	14	3565	393	4	2496	NC	29	11 919	243
Northeast lobster	8	–	–	11	–	–	10	–	–	29	–	–
Atlantic clam/quahog dredge	6	1449	414	4	1312	NC	2	1325	NC	12	4086	294
Atlantic summer flounder/scup/black sea bass	5	3870	129	4	3357	NC	3	3330	NC	12	10 557	114
Atlantic snapper/grouper	2	3118	NC	4	2682	NC	3	2355	NC	9	8155	110
Atlantic shrimp	3	–	–	3	–	–	2	–	–	8	–	–
Atlantic clam/quahog other gear types	1	–	–	3	–	–	4	–	–	8	–	–
Atlantic blue crab	3	–	–	4	–	–	0	–	–	7	–	–
Atlantic oyster	2	–	–	0	–	–	5	–	–	7	–	–
Atlantic herring trawl	3	430	NC	1	449	NC	3	396	NC	7	1275	549
Atlantic tuna	5	–	–	1	–	–	0	–	–	6	–	–
Atlantic urchin	0	–	–	5	–	–	0	–	–	5	–	–
Atlantic squid	0	2547	NC	2	2366	NC	3	2369	NC	5	7282	69
Atlantic other fleets (w/<5 fatalities 15 years)	8	–	–	8	–	–	15	–	–	31	–	–
Alaska region												
Alaska groundfish freezer trawl (AM80)	15	12 135	124	8	12 571	64	2	12 503	NC	25	37 209	67
Alaska salmon drift gillnet	8	17 412	46	10	17 469	57	5	18 506	27	23	53 387	43
Alaska pot cod	2	–	–	10	–	–	6	–	–	18	–	–
Alaska salmon set gillnet	6	4516	133	4	4603	NC	7	4751	147	17	13 870	123
Alaska halibut/sablefish longline	4	6308	NC	10	6125	163	0	5384	NC	14	17 817	79
Alaska cod freezer longline	6	12 375	48	1	10 822	NC	2	12 054	NC	9	35 251	26
Alaska Bering Sea crab	2	5238	NC	7	3997	175	0	2768	NC	9	12 003	75
Alaska dive harvest	4	589	NC	1	483	NC	3	468	NC	8	1540	519
Alaska salmon tender	2	3840	NC	1	3720	NC	4	3600	NC	7	11 160	63
Alaska salmon troll	3	4267	NC	2	5129	NC	1	4970	NC	6	14 366	42
Alaska salmon seine	2	14 729	NC	0	12 396	NC	3	14 408	NC	5	41 533	12
Alaska other fleets (w/<5 fatalities 15 years)	13	–	–	13	–	–	12	–	–	38	–	–
Gulf of Mexico region												
GOM shrimp	35	–	–	23	129 768	18	25	121 782	21	83	–	–
GOM snapper/grouper	7	–	–	3	–	–	9	–	–	19	–	–
GOM oyster	8	–	–	3	–	–	4	–	–	15	–	–
GOM crab	6	–	–	2	–	–	2	–	–	10	–	–

(Continues)

TABLE 4 (Continued)

Fleet	2000-2004			2005-2009			2010-2014			15-year total		
	Fatalities	FTE[b]	Rate	Fatalities	FTE	Rate	Fatalities	FTE	Rate	Fatalities	FTE	Rate
GOM menhaden	0	–	–	4	–	–	3	–	–	7	–	–
GOM other fleets (w/<5 fatalities 15 years)	16	–	–	8	–	–	6	–	–	30	–	–
West Coast region												
West Coast non-tribal Dungeness crab	9	7097	127	16	10 147	158	5	9042	55	30	26 286	114
West Coast tribal salmon	4	–	–	6	–	–	4	–	–	14	–	–
West Coast multi-species groundfish trawl	6	2928	205	1	2104	NC	4	1517	NC	11	6549	168
West Coast dive harvest	1	–	–	1	–	–	4	–	–	6	–	–
West Coast tribal Dungeness crab	1	–	–	1	–	–	3	–	–	5	–	–
West Coast other fleets (w/<5 fatalities 15 years)	22	–	–	17	–	–	10	–	–	49	–	–
Hawaii region												
Hawaii groundfish	3	–	–	1	–	–	1	–	–	5	–	–
Hawaii other fleets (w/<5 fatalities 15 years)	0	–	–	2	–	–	3	–	–	5	–	–

NC, rate not calculated when frequency is less than 5 fatalities in a 5-year period; –, missing FTE data for fleet.
[a]All rates in this table were calculated using the revised formula for FTEs described in the Methods section.
[b]Full-time equivalent.

leading initiating event in fatal vessel disasters during the first two periods, these events became slightly less common during 2010-2014 (Table 1).

The number of fatalities due to falls overboard steadily decreased in each 5-year period, starting with 85 deaths during 2000-2004, 68 deaths in 2005-2009, and 57 deaths in 2010-2014. Fatal falls overboard represented about the same proportion (30%) of all fishing deaths in each of the 5-year time periods. The causes of these events have also changed over time. While tripping or slipping was the leading cause of falls overboard during 2000-2004, it became less frequent in the periods that followed (Table 2). Of note, alcohol and/or drug use contributing to fatal falls overboard decreased over the 15 years.

No clear trend was observed in the remaining fatal incident types nationally, with onboard, onshore, and diving fatalities each experiencing fluctuations in the number of deaths attributed to them among the three time periods; however, a higher number of onboard and diving fatalities occurred during 2010-2014 compared to the preceding 5-year period.

On the East Coast, the distribution of fatalities among incident types, especially vessel disasters and falls overboard, were fairly consistent between 2000-2004 and 2005-2009 (Table 3). However, in the last 5-year period, the proportion of fatalities due to vessel disasters had decreased and those to falls overboard increased, both representing 37% of fatalities in the region. Over the three 5-year periods, a decline in fatality rate occurred in the scallop fleet, with the most notable decrease observed in 2010-2014 (Table 4).

In Alaska, the number and percentage of deaths due to each incident type were fairly similar between the first two time periods, although an increase in fatal onboard injuries was observed during 2010-2014 (Table 3). Overall, vessel disaster fatalities decreased in the last time period, but the number and proportion of deaths among fishermen working in skiffs increased considerably in 2010-2014 compared to the previous periods. Among Alaska fleets, the fatality rate in the groundfish freezer trawl fleet decreased during 2005-2009 from the preceding period. Although the rate was not calculated for the 2010-2014 period, this trend appears to continue (Table 4). The Bering Sea crab and halibut/sablefish longline fleets experienced no fatalities during 2010-2014, a clear contrast to the previous 5-year time periods.

During 2000-2004 in the Gulf of Mexico, nearly half (47%) of all fatalities in the region were due to falls overboard (Table 3). These fatalities decreased in the following periods, while fatalities attributed to vessel disaster increased, accounting for 51% of all fatalities in the region during 2010-2014. The only fatality rates available for the Gulf of Mexico were for the shrimp fleet in 2005-2009 and 2010-2014, and the rates were not considerably different between the two periods (Table 4).

Vessel disasters have consistently been the leading cause of fatalities on the West Coast, resulting in 60% or more of commercial fishing fatalities in each 5-year period (Table 3). The proportion of deaths due to falls overboard decreased during 2010-2014, while diving fatalities increased in both frequency and proportion in this period. The most recent 5-year period also had a decrease in the non-tribal Dungeness crab fleet fatality rate compared to the preceding periods (Table 4).

4 | DISCUSSION

The analysis of more recent fatality data in this study (2010-2014) revealed that vessel disasters and falls overboard remain leading contributors to commercial fishing deaths. NIOSH has recommended that vessel owners and operators review their vessel's stability and watertight integrity, and take action to improve and maintain those key conditions.[12,17,18] In situations where primary prevention of vessel disasters is not successful, and crewmembers are forced to abandon ship, it is imperative that well-maintained and fully functional safety equipment is onboard, including life-rafts and immersion suits, to protect fishermen from the effects of cold water immersion. Additionally, crewmembers must know how to use the equipment correctly while under extreme psychological stress. Marine safety training and monthly emergency drills are designed to provide crewmembers with the knowledge and skills they need to respond to vessel sinkings and other vessel emergencies.[19] All crewmembers should take marine safety training as recommended by NIOSH[18] and participate in monthly drills as required by federal regulations.[20] Further, personal flotation device use is recommended to those working in skiffs to keep crewmembers afloat in the event of a rapid skiff swamping or capsizing.

Falls overboard have been consistently identified as a major hazard in commercial fishing[9,11,12,17] and remain a leading cause of death among fishermen in the United States. In previous studies on the barriers to personal flotation device use, fishermen have expressed various concerns about personal flotation devices, including discomfort, cost, and possibility for increased chances of entanglement.[21–22] The lack of personal flotation device use in all man overboard fatalities since 2000 highlights the need for more research to understand fleet-specific barriers and develop innovative, wearable personal flotation devices to voluntarily increase use, as there are currently no regulatory mandates for fishermen to wear personal flotation devices. Because of the many fishermen who died after falling overboard as single operators or while working alone on deck, man overboard systems should be considered to alert others of a fall overboard and potentially shut off the engine.[11] The use of re-boarding ladders may also be useful in enabling self-rescue should a fall occur.

Winch entanglements have been associated with both fatal and nonfatal traumatic injuries in the Gulf of Mexico shrimp fleet,[23,9] and the findings from this study show that deaths due to these entanglements continue to occur in the fleet. Expanding on previous engineering solutions to prevent winch entanglements,[24] prototype testing of stationary guards and auxiliary stops is currently underway with fishermen to inform development of devices that would prevent or reduce the severity of entanglements.[25] If proven to be effective and widely adopted, these mechanisms could greatly reduce the incidence of injuries due to entanglement in drum and try-net winches on commercial shrimp vessels.

One issue that this study identified was the prevalence of unintentional drug overdoses onboard commercial fishing vessels, in addition to other types of fatalities where drug or alcohol use may have contributed. While this is generally an issue that requires attention outside of a traditional marine safety solution, vessel owners and operators should consider creating and enforcing policies prohibiting the use of drugs and/or alcohol on board.

The revised FTE formula presented in this study has improved the validity of fatality rates by including all exposure time of cases in the denominator. The new formula also improved the comparability of rates to other industries by using a standard, widely accepted method. The average annual occupational fatality rate for all US workers during 2010-2014 was 3.4 deaths per 100 000 FTEs.[14] Using the same FTE calculation method, this study found period rates in fishing fleets during 2010-2014 ranging from 21 to 147 deaths per 100 000 FTEs, many times higher than the rate for all US workers. The extreme variability in risk among fishing fleets suggests that hazardous conditions differ greatly, and preventive measures have been more successfully applied in certain fleets than in others.

Because the new FTEs were used in this study to calculate revised fatality rates for fleets retrospectively to the year 2000, observations of trends during 2000-2014 were also possible. The fatality rate of the Alaska dive harvest fleet was among the highest nationally over the 15-year period. The continued incidence of fatalities among sea cucumber harvesters in Alaska reinforces the conclusion that adequate training and the use of experienced tenders are necessary to improve dive safety.[26]

There have been several fleet-specific successes in improving commercial fishing safety since 2000. The Alaska groundfish freezer trawl and cod freezer longline fleets experienced a decline in the number and rate of fatalities over 15 years. This is due, at least in part, to their compliance with the Alternate Compliance and Safety Agreement (ACSA). This program was developed to allow certain vessels to continue processing activities as an alternative to meeting class standards, and included provisions related to watertight integrity and material condition of the hull. Previous research[27] demonstrated a significant decrease in the rate of reported serious vessel casualties among vessels in compliance with ACSA requirements.

The Bering Sea and Aleutian Islands crab fleet has also experienced substantial improvements in vessel and crewmember safety. In the 1990s, an average of eight fishermen died in the fleet annually, primarily due to vessels capsizing and sinking or to falls overboard.[28] The US Coast Guard implemented dockside stability checks in 1999 to prevent vessels from going out to sea while overloaded with crab pots. Because of these stability checks, changes in fishery management, and industry initiatives, the number and rate of fatalities has declined substantially in the fleet from the 1990s to 2000-2014.[28]

In the East Coast region, the Atlantic scallop fleet stands out for achieving substantial declines in the risk of fatalities over the 15-year study period. The fatality rate in the fleet during 2010-2014 was approximately four times lower than the rates in the two previous periods (2000-2004 and 2005-2009). Similarly in the West Coast region, the non-tribal Dungeness crab fleet had a fatality rate during 2010-2014 that was more than two times lower than the rates observed during the previous 5-year periods. The factors that have promoted risk reductions in the Atlantic scallop and West Coast

Dungeness crab fleets are unknown. No studies of hazards or interventions in these specific fleets have been published that would explain the declines in fatality rates. Further research is needed to understand the safety improvements in Atlantic scallop and West Coast Dungeness crab fleets, and to monitor the trends moving forward.

The primary limitation of this study relates to the calculation of FTEs and fatality rates. FTE estimates were not available for all fleets with fatalities, particularly for those outside of Alaska. Data needed to calculate FTEs are difficult to obtain, especially for state-managed fisheries. The Northeast inshore lobster fleet, for example, is one fleet that was missing FTE data for this study. However, fatality rates in that fleet were recently calculated by Fulmer et al.[6] Using the same standardized method for calculating FTEs that this study used, the overall fatality rate in the Northeast inshore lobster fleet was 47.7 deaths per 100 000 FTEs during 2000-2009. Future research is needed to assess and compare the risk of fatalities in other fleets.

This study provided an updated epidemiologic profile of work-related fatalities in the US fishing industry during 2010-2014 and a comparison of fatality rates over 15 years. The findings show that while the number of fatalities among commercial fishermen in the United States has generally declined since 2000, commercial fishing continues to have one of the highest occupational fatality rates in the United States. Workers are exposed to fatal hazards related to the marine environment in which they work, as well as work-related hazards associated with fishing gear and deck equipment. The use of detailed surveillance data is critical in identifying priority hazards to be addressed in order to reduce the number and rate of work-related deaths. As noted by the Occupational Safety and Health Administration,[29] "Employers are only sustainable when they ensure the safety, health, and welfare of their workers." The sustainable seafood movement could assist in improving the health and safety of fishing industry workers if the issue was integrated into the definition of sustainable seafood. This market-driven approach, along with updating safety regulations, could be a successful path for reducing hazards and preventing deaths.

AUTHORS' CONTRIBUTIONS

Devin L. Lucas contributed to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work; drafting the work; and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Samantha Case contributed to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work; and drafting the work.

ACKNOWLEDGMENT

None.

FUNDING

The authors report that there was no funding source for the work that resulted in the article or the preparation of the article.

ETHICS APPROVAL AND INFORMED CONSENT

The work was performed at the National Institute for Occupational Safety and Health, Western States Division office in Anchorage, Alaska. This work did not involve human subjects research and was not reviewed by an IRB. Informed consent was not relevant for this work.

DISCLOSURE (AUTHORS)

The authors report no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

Rodney Ehrlich declares that he has no conflict of interest in the review and publication decision regarding this article.

DISCLAIMER

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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How to cite this article: Lucas DL, Case SL. Work-related mortality in the US fishing industry during 2000-2014: New findings based on improved workforce exposure estimates. *Am J Ind Med*. 2017;1–11. https://doi.org/10.1002/ajim.22761

Safety Science 101 (2018) 190–196

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Factors associated with crewmember survival of cold water immersion due to commercial fishing vessel sinkings in Alaska

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ABSTRACT

Occupational fatality surveillance has identified that fishing vessel disasters, such as sinkings and capsizings, continue to contribute to the most deaths among crewmembers in the US fishing industry. When a fishing vessel sinks at sea, crewmembers are at risk of immersion in water and subsequent drowning. This study examined survival factors for crewmembers following cold water immersion after the sinking of decked commercial fishing vessels in Alaskan waters during 2000–2014. Two immersion scenarios were considered separately: immersion for any length of time, and long-term immersion defined as immersion lasting over 30 min. Logistic regression was used to predict the odds of crewmember survival. Of the 617 crewmembers onboard 187 fishing vessels that sank in Alaska during 2000–2014, 557 (90.3%) survived and 60 died. For crewmembers immersed for any length of time, the significant adjusted predictors of survival were: entering a life-raft, sinking within three miles of shore, the sinking not being weather-related, and working as a deckhand. For crewmembers immersed for over 30 min, the significant adjusted predictors of survival were: wearing an immersion suit, entering a life-raft, working as a deckhand, and the sinking not being weather-related. The results of this analysis demonstrate that in situations where cold water immersion becomes inevitable, having access to well-maintained, serviceable lifesaving equipment and the knowledge and skills to use it properly are critical.

1. Introduction

Fishing vessel sinkings present extreme survival challenges to those involved. When a fishing vessel sinks at sea, crewmembers are at risk of immersion in water and subsequent traumatic injuries or death. Cold water immersion can cause hyperventilation, muscle tension, reduced cognitive function, and swimming failure; leading to death from drowning or hypothermia (Golden, 1973; Cooper et al., 1976; Hayward and Eckerson, 1984). Among the challenges of surviving a vessel sinking are psychological stressors, which have been shown to significantly affect decision making and response abilities, impairing chances of survival (Singer, 1982; Leach, 2004). To overcome these extreme environmental and psychological factors, crewmembers must be prepared with effective survival equipment, knowledge, and skills. High levels of emergency preparedness have not always been ubiquitous in the US fishing industry, which may have contributed to the long history of deadly vessel sinkings. During 1982–1987, an average of 108 commercial fishing fatalities occurred annually in the United States, the majority of which were due to vessel sinkings (National Research Council, 1991).

The US fishing industry is not alone in facing cold water survival challenges when vessels sink at sea. Commercial fishing is recognized as an extremely hazardous occupation worldwide (Jensen et al., 2014). In Arctic and Nordic countries, fishermen are regularly exposed to the threat of cold water immersion (Jensen et al., 2014; Kaustell et al., 2016). Reducing the risk of exposure to cold water is relevant to the fishing industries of all northern nations.

Attempts to create safety standards for fishing vessels through federal legislation began in the 1930s, but were not successful until 1988 when the Commercial Fishing Industry Vessel Safety Act of 1988 (CFIVSA) was signed into law (Hiscock, 2002). The law required the US Coast Guard (USCG) to issue and enforce regulations for safety equipment and operating procedures on fishing vessels (USCG, 2009). Compliance with specific requirements of the law depends on the characteristics and activities of the particular vessel, such as the type and length of the vessel, area of operation, seasonal conditions, number of people on board, whether the vessel is federally documented or state registered, and the date the vessel was constructed or converted (USCG, 2009).

While the specific requirements of the CFIVSA vary based on individual vessel characteristics, in general the law requires most fishing vessels to carry survival equipment such as personal flotation devices

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http://dx.doi.org/10.1016/j.ssci.2017.09.009
Received 8 March 2017; Received in revised form 30 August 2017; Accepted 15 September 2017
Available online 22 September 2017
0925-7535/ Published by Elsevier Ltd.

(PFDs), immersion suits, life-rafts, throwable flotation devices, distress signals, emergency position indicating radio beacons (EPIRBs), and fire extinguishers (USCG, 2009). The law also requires certain fishing vessels to be equipped with high water alarms and bilge systems, and to conduct monthly emergency drills (USCG, 2009). The safety standards of the 1988 CFIVSA were implemented during the early 1990s and had a measurable effect on worker fatalities caused by vessel sinkings. The case-survivor rate for vessel sinkings in Alaska increased from 78% in 1991–1993, to 92% in 1994–1996, to 94% in 1997–1999 (NIOSH, 2002).

Worker fatalities due to vessel sinkings decreased during the 1990s because crewmembers had access to and knowledge of the use of the newly required lifesaving equipment, which increased their survival time after abandoning ship. However, the frequency of vessel disasters did not decrease during that decade, nor did fatalities due to falls overboard and onboard injuries (NIOSH, 2002; Lucas and Lincoln, 2007). These are not unexpected findings, since the CFIVSA focuses almost entirely on secondary prevention of death; that is, keeping workers alive in the water until rescue aid arrives.

As the marine safety regulations mandated by the CFIVSA were being developed, marine safety training organizations were also being established. In 1985, the Alaska Marine Safety Education Association in Sitka, Alaska was created with the initial objective of creating a standardized, hands-on, skill-based training curriculum for marine safety trainers throughout Alaska (Dzugan, 2010). At approximately the same time, the North Pacific Fishing Vessel Owners Association funded a safety training program in Seattle, Washington. These two programs continue to offer hands-on training in emergency skills including issuing mayday calls, EPIRB deployment and maintenance, immersion suit/PFD use and care, life-raft use, and use of flares (Dzugan, 2010).

Aside from the 1988 safety legislation affecting the entire US fishing industry, other fleet-specific safety programs have been established by the US Coast Guard to target high-risk fleets and associated hazards. The *At-the-Dock Stability and Safety Compliance Check* program initiated in the Bering Sea and Aleutian Islands crab fleet in 1999 was designed to ensure vessels were loaded in accordance with their stability instructions. This program contributed to a significant decrease in the number and rate of vessel sinkings and fatalities in the fleet (NIOSH, 2016). In another US Coast Guard safety initiative, freezer-longliners and freezer-trawlers operating in Alaska were enrolled in the *Alternate Compliance and Safety Agreement* (ACSA) beginning in 2006. This program addressed a variety of vessel safety issues, including stability and condition of the hull. The rate of serious vessel casualties decreased in both fleets after complying with ACSA requirements (Lucas et al., 2014). One final example involved the Dungeness crab fleet operating off the West Coast of the US, which has been repeatedly identified as a high-risk fleet with a high proportion of fatalities from vessel disasters (Lincoln and Lucas, 2010; Case et al., 2015). A voluntary program called *Operation Safe Crab* was developed in 2000 to address this issue by evaluating stability, watertight integrity, and lifesaving equipment on board (Hardin and Lawrenson, 2010).

Another source of potential hazard reductions in the fishing industry has involved modifications to fishery management plans, which are unique to each fleet and are designed primarily to prevent the depletion of the fish stock. Several experts have hypothesized that fisheries management plans may affect worker safety (FAO, 2016). The need for safety improvement is mentioned frequently when there is a proposal to implement quota-based fisheries management plans. Since 1990, several fisheries in Alaska have changed to this type of system. NIOSH has provided safety assessments of two of the most notable, the halibut/sablefish fleet and the Bering Sea and Aleutian Islands crab fleet. However, it is difficult to assess exactly how much the management plan change affected safety vs. other policies and changes the fleet experiences. For instance, NIOSH noted that a combination of Coast Guard programs (mentioned above), industry initiatives, and fishery management changes have improved crewmember safety in the Bering Sea and Aleutian Islands crab fleet which has experienced one fatality since implementation of the quota system (NIOSH, 2016). When NIOSH initially evaluated Individual Fishing Quotas (IFQs) in the halibut/sablefish fleet (Lincoln et al., 2007), the findings revealed a significant decrease in the rate of all fatalities in the fleet. However, a more recent review of the rate of fatalities over a longer study period did not reveal the same decrease. This suggests that while fishery management policies may have influenced safety initially, other factors may be responsible for the persistent hazards observed in the fleet.

While the number and rate of fatalities among workers in the US fishing industry have decreased somewhat over time (Lincoln and Lucas, 2010), commercial fishing remains one of the highest risk occupations in the US (Bureau of Labor Statistics, 2016). Occupational fatality surveillance has identified that vessel disasters, such as sinkings and capsizings, continue to contribute to the most deaths among crewmembers nationwide. During 2000–2009, 52% of deaths in the industry occurred during vessel disasters, and several Alaskan fisheries were identified as having relatively high numbers of fatalities from vessel disaster events (Lincoln and Lucas, 2010).

Previous studies investigating the determinants of vessel sinkings have found several factors influencing the probability of a disaster occurring or the severity of the disaster (in terms of vessel damage or crewmember injury), including the type of disaster, wind speed and other environmental conditions, season, vessel age, and operating distance from shore (Jin et al., 2001; Jin et al., 2002; Jin and Thunberg, 2005; Jin, 2014). However, no studies have examined survival factors of crewmembers immersed after a vessel sinking. Also, the previous studies of determinants of vessel disasters were focused on the northeastern US, and may not be generalizable to fleets in Alaska. The purpose of this paper was to identify survival factors of crewmembers immersed in cold water after vessel sinkings.

2. Methods

2.1. Case definition

This study examined crewmembers who experienced cold water immersion after the sinking of decked commercial fishing vessels in Alaskan waters during 2000–2014. If crewmembers were not at risk of immersion, they were not included in the study. Two immersion scenarios were considered separately: immersion for any length of time, and long-term immersion defined as immersion lasting over 30 min. The 30 min cut-point was chosen based on the results of the exploratory data analysis which showed that mortality increased sharply for immersion lasting more than 30 min. Crewmember survival was categorized as a binary outcome: survived or died. For the purpose of these analyses, crewmembers who were lost at sea (body not recovered) were presumed to have died.

Sinking events of decked commercial fishing vessels were included when the vessel was lost at sea. In addition, a small number of events were included in which the vessels capsized, crews abandoned ship at sea, and the vessels remained afloat or eventually ran aground (unoccupied) instead of actually sinking. Open vessels, such as setnet or seine skiffs, were excluded due to the substantial physical and operational differences between open and decked vessels. For instance, skiffs are typically less than 24 feet and operate very close to shore. Skiff operations are short-term, often limited to a few hours at a time. Skiffs do not typically carry life-rafts, EPIRBs, or immersion suits.

Groundings and fires, where vessels remained afloat, were not included in the analysis because of the decreased risk of crewmember immersion. A fatal sinking was defined as a sinking in which at least one crewmember died. A nonfatal sinking was defined as a sinking in which the entire crew survived.

2.2. Data sources and definitions

Data on sinkings were obtained from the Commercial Fishing Incident Database (CFID), a surveillance system managed by the National Institute for Occupational Safety and Health (NIOSH) that contains extensive information on work-related fatalities and vessel disasters in the US fishing industry (NIOSH, 2015). CFID contains over 100 data fields describing the conditions surrounding the event, vessel characteristics, and crewmember details. The primary data sources for CFID are US Coast Guard investigation reports and related US Coast Guard documentation. Supplementary data sources include law enforcement reports, death certificates, medical examiner documents, news media, the National Marine Fisheries Service, Alaska Department of Fish and Game, the North Pacific Fishing Vessel Owners' Association (NPFVOA) and the Alaska Marine Safety Education Association (AMSEA).

In addition to crewmember survival information, data were extracted from CFID for the following vessel and event characteristics: calendar year in which the event occurred; distance of the vessel from shore at the time of the sinking event ($\leq$3 miles/ > 3 miles); whether the sinking event was identified as weather-related in the US Coast Guard investigation report (yes/no); the region of Alaska where the event occurred (Southwest/Southcentral/Southeast); season (summer [Apr–Sept]/winter[Oct–Mar]); vessel length (< 50′/$\geq$50′); vessel age (< 25 years/$\geq$25 years); vessel hull material (fiberglass/aluminum/steel/wood); vessel activity immediately prior to sinking (anchored, fishing, moored, transiting inbound, transiting outbound); crew size; and fishery. Crewmember characteristics extracted from CFID were: age (years, calculated from date of birth); sex (male/female); job position (officer/deckhand/processor/other); where the crewmember evacuated to when abandoning the sinking vessel (rescue helicopter or vessel/land/water/other); length of time the crewmember was immersed in the water (minutes); whether an immersion suit was worn (yes/no); whether the crew member was able to enter a life-raft (yes/no); whether the crewmember had ever received formal safety training (yes/no); and for decedents only, cause of death.

2.3. Data analysis

The outcome of interest in this study was crewmember survival following cold water immersion resulting from fishing vessel sinkings. Descriptive statistics were calculated to explore characteristics of the sinking incidents, involved vessels, and crewmembers. An exploratory data analysis was completed to examine the distribution of the outcome variable and all potential covariates. Listwise deletion was employed to exclude cases with missing data. Consequently, the number of cases reported in the results varies depending on the variables included in each descriptive statistic and regression model.

Logistic regression was used to predict the odds of crewmember survival. Unadjusted models (single outcome with single predictor) were used as part of the exploratory data analysis to measure associations between each individual factor and the outcome of crewmember survival, first for crewmembers who were immersed in water for any amount of time ($y = survival$), and subsequently for the subset of crewmembers who were immersed in water for over 30 min ($y = long\ term\ survival$). Unadjusted models were specified as:

$$\Pr(survival = 1) = F(\beta_0 + \beta_1 X_1)$$

$$\Pr(survival = 1) = F(\beta_0 + \beta_1 X_2)$$

...

$$\Pr(survival = 1) = F(\beta_0 + \beta_1 X_{11})$$

$$\Pr(long\ term\ survival = 1) = F(\beta_0 + \beta_1 X_1)$$

$$\Pr(long\ term\ survival = 1) = F(\beta_0 + \beta_1 X_2)$$

...

$$\Pr(long\ term\ survival = 1) = F(\beta_0 + \beta_1 X_{11})$$

where X_1 = immersion suit worn; X_2 = life-raft used; X_3 = crewmember marine safety training; X_4 = distance of the vessel from shore; X_5 = weather-related; X_6 = region of Alaska; X_7 = season; X_8 = crewmember job position; X_9 = vessel length; X_{10} = vessel age; and X_{11} = hull material.

Factors were selected for inclusion in the analysis based on a review of the literature and a theoretical framework for surviving a vessel sinking. Expert opinion and current or proposed safety regulations were taken into account in formulating the theoretical framework. Unadjusted odds ratios were calculated for each of the factors. Age of crewmember was not included as a factor because of the high frequency of missing values. Sex of crewmember was also excluded because 96% were male.

Adjusted odds ratios were calculated using a multivariable model that included all of the potential predictive factors listed above except for vessel hull material. Hull material was found to be highly correlated with vessel length, and was therefore not included in the final adjusted models. As with the unadjusted models, the adjusted modeling was completed separately for crewmembers who were immersed in water for any amount of time, and for crewmembers who were immersed in water for over 30 min:

$$\Pr(survival = 1) = F(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots\beta_{10} X_{10})$$

$$\Pr(long\ term\ survival = 1) = F(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots\beta_{10} X_{10})$$

Because multiple crewmembers could be involved in a single vessel disaster, observations could not be assumed to be independent. Therefore, standard errors of odds ratios for both the unadjusted and adjusted models were calculated using a clustered sandwich estimator that allowed for intragroup correlation under the assumption that observations were independent across vessels, but not independent within each vessel. Data analysis was performed using Stata Version 13.1 (StataCorp, 2013).

3. Results

3.1. Characteristics of sinkings

During 2000–2014, 187 sinkings occurred in Alaskan waters (Fig. 1). Of these 187 events, 23 (12.3%) resulted in at least one fatality. A median of 10 vessel sinkings occurred annually, ranging from a low of 6 in 2014 to a high of 23 in 2001. The frequency of sinkings resulting in a fatality ranged from zero (in 2004, 2007, 2009, 2013, and 2014) to five (in 2005 and 2006). The majority of sinkings were not weather-related (133, 71.1%) and occurred within three miles from shore (123, 65.8%) (Table 1).

Most vessels were transiting to port (72, 41.6%) or actively engaged in fishing operations (60, 34.7%) immediately prior to the sinking. For fatal sinkings, the most commonly reported initiating event was instability (9, 47.3%), compared with nonfatal sinkings where the most frequent initiating event was flooding (43, 26.4%). Additional characteristics of both fatal and nonfatal sinkings are shown in Table 1.

The salmon seine fleet experienced the highest number of sinkings overall (32, 18.0%), but none were fatal. This was followed by salmon drift gillnetters (31, 17.4%), halibut and sablefish catchers (30, 16.9%), and salmon tenders and processors (19, 10.7%). All three sinkings that occurred in the factory-trawler and freezer-longliner fleets resulted in at least one fatality. The fleets with the highest number of fatal sinkings were halibut and sablefish catchers (5 sinkings), pot cod catchers and catcher-processors (3 sinkings), Southeast crabbers and shrimpers (3 sinkings), and factory-trawlers and freezer-longliners (3 sinkings).

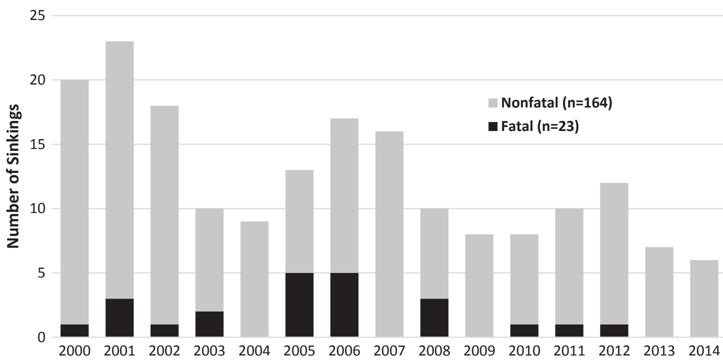

Fig. 1. Frequency of fishing vessel sinkings, Alaska, 2000–2014.

Table 1
Characteristics of fishing vessel sinkings, Alaska, 2000–2014.

	Fatal (n = 23)		Nonfatal (n = 164)		Total (n = 187)	
	n	%[a]	n	%[a]	n	%[a]
Distance from shore						
≤3 miles	6	26.1	117	71.3	123	65.8
> 3 miles	17	73.9	47	28.7	64	34.2
Missing	0	–	0	–	0	–
Weather-related						
No	9	39.1	124	75.6	133	71.1
Yes	14	60.9	40	24.4	54	28.9
Missing	0	–	0	–	0	–
Alaska region						
Southeast	8	34.8	72	43.9	80	42.8
Southcentral	4	17.4	56	34.1	60	32.1
Southwest	11	47.8	36	22.0	47	25.1
Missing	0	–	0	–	0	–
Season						
Summer	10	43.5	112	68.3	122	65.2
Winter	13	56.5	52	31.7	65	34.8
Missing	0	–	0	–	0	–
Vessel length						
< 50 feet	15	65.2	96	58.5	111	59.4
≥50 feet	8	34.8	68	41.5	76	40.6
Missing	0	–	0	–	0	–
Vessel age						
< 25 years	6	26.1	47	29.4	53	29.0
≥25 years	17	73.9	113	70.6	130	71.0
Missing	0	–	4	–	4	–
Hull material						
Fiberglass	4	17.4	63	39.6	67	36.8
Aluminum	3	13.0	13	8.2	16	8.8
Steel	12	52.2	37	23.3	49	26.9
Wood	4	17.4	46	28.9	50	27.5
Missing	0	–	5	–	5	–

[a] Denominator for percentage calculation excludes cases with missing data.

3.2. Characteristics of crewmembers

Of the 617 crewmembers onboard vessels that sank, 557 (90.3%) survived and 60 did not survive. Drowning was the reported cause of death for 52 (88.1%) decedents. Other reported causes of death were hypothermia (6) and asphyxiation (1), with cause of death unknown for one victim. The median crew size was 3 crewmembers (1–47 crewmembers). Among fatal sinkings, a median of 3 fatalities occurred per event (1–15 fatalities). The vast majority of crewmembers were male (534, 95.7%), and ages were normally distributed with a mean of 37 years (8–79 years old). Formal marine safety training was not widely completed by the crewmembers involved in vessel sinkings. Only 15.9% of crewmembers (98) had ever received safety training, and the difference between survivors and decedents was small (Table 2).

Table 2
Characteristics of crewmembers involved in fishing vessel sinkings, Alaska, 2000–2014.

	Deceased (n = 60)		Survived (n = 557)		Total (n = 617)	
	n	%[a]	n	%[a]	n	%[a]
Immersion suit worn						
Yes	23	52.3	144	70.2	167	67.1
No	21	47.7	61	29.8	82	32.9
Missing	16	–	352	–	368	–
Life raft used						
Yes	3	6.7	158	30.2	161	28.3
No	42	93.3	366	69.8	408	71.7
Missing	15	–	33	–	48	–
Marine safety trained						
No	52	86.7	467	83.8	519	84.1
Yes	8	13.3	90	16.2	98	15.9
Missing	0	–	0	–	0	–
Time in water						
0 min	1	1.7	268	55.3	269	49.4
1–30 min	2	3.3	168	34.6	170	31.2
> 30 min	57	95.0	49	10.1	106	19.4
Missing	0	–	72	–	72	–
Job position						
Deckhand	16	26.7	316	57.7	332	54.6
Officer	24	40.0	170	31.0	194	31.9
Processor	13	21.7	36	6.6	49	8.1
Other	7	11.7	26	4.7	33	5.4
Missing	0	–	9	–	9	–
Sex						
Male	60	100.0	474	95.2	534	95.7
Female	0	0.0	24	4.8	24	4.3
Missing	0	–	59	–	59	–
Age						
< 20 yrs	1	1.7	16	7.3	17	6.1
20–29 yrs	14	23.3	61	27.7	75	26.8
30–39 yrs	18	30.0	53	24.1	71	25.4
40–49 yrs	16	26.7	50	22.7	66	23.6
50–59 yrs	10	16.7	29	13.2	39	13.9
60+ yrs	1	1.7	11	5.0	12	4.3
Missing	0	–	337	–	337	–

[a] Denominator for percentage calculation excludes cases with missing data.

During vessel evacuations, 49.4% (269 out of 545 with immersion data) of crewmembers abandoned directly to land or an out-of-water rescue platform (e.g., helicopter, other fishing vessel, skiff, life-raft) without entering the water, and all but one survived. These crewmembers who completely avoided immersion were not included in any further analyses. Of the 60 crewmembers who died, 59 (98.3%) were immersed in water. By comparison, of the crewmembers who survived,

Table 3
Factors associated with crewmember survival of cold water immersion after fishing vessel sinkings, Alaska, 2000–2014.

	Unadjusted Models		Adjusted Model (n = 247)	
	OR	95% CI	OR	95% CI
Immersion suit worn (n = 249)				
Yes	**2.16**	**1.02, 4.57**	2.12	0.95, 4.77
No	–	–	–	–
Life-raft used (n = 261)				
Yes	**9.32**	**1.49, 58.26**	**16.72**	**2.69, 103.87**
No	–	–	–	–
Marine safety trained (n = 276)				
Yes	2.11	0.90, 4.94	3.15	0.58, 16.99
No	–	–	–	–
Distance from shore (n = 276)				
≤3 miles	**7.80**	**2.27, 26.81**	**38.99**	**6.82, 223.00**
> 3 miles	–	–	–	–
Weather-related (n = 276)				
Yes	–	–	–	–
No	1.99	0.57, 6.97	**5.96**	**1.69, 21.03**
Region (n = 276)				
Southeast	1.87	0.55, 6.38	0.21	0.04, 1.08
Southcentral	**5.67**	**1.25, 25.70**	2.29	0.41, 12.98
Southwest	–	–	–	–
Season (n = 276)				
Summer	0.96	0.24, 3.95	2.02	0.69, 5.94
Winter	–	–	–	–
Job position (n = 276)				
Officer	–	–	–	–
Deckhand	**2.93**	**1.42, 6.03**	**12.84**	**2.52, 65.55**
Processor	1.01	0.15, 6.73	16.27	0.96, 275.02
Other	0.88	0.24, 3.25	**9.66**	**2.14, 43.59**
Vessel length (n = 276)				
< 50 feet	1.47	0.49, 4.42	**5.08**	**1.22, 21.18**
≥50 feet	–	–	–	–
Vessel age (n = 275)				
< 25 years	–	–	–	–
≥25 years	2.10	0.52, 8.43	0.93	0.17, 5.10
Hull material (n = 274)				
Fiberglass	3.45	0.74, 16.11	–	–
Aluminum	2.09	0.42, 10.41	–	–
Steel	–	–	–	–
Wood	3.43	0.85, 13.74	–	–

Bold font indicates statistically significant odds ratios based on 95% confidence interval.

Table 4
Factors associated with crewmember survival of long-term[a] cold water immersion after fishing vessel sinkings, Alaska, 2000–2014.

	Unadjusted Models		Adjusted Model (n = 90)	
	OR	95% CI	OR	95% CI
Immersion suit worn (n = 91)				
Yes	**7.27**	**2.27, 23.27**	**5.71**	**1.39, 23.38**
No	–	–	–	–
Life-raft used (n = 91)				
Yes	**3.76**	**1.06, 13.30**	**12.18**	**2.20, 67.36**
No	–	–	–	–
Marine safety trained (n = 106)				
Yes	2.76	0.93, 8.21	2.10	0.23, 19.40
No	–	–	–	–
Distance from shore (n = 106)				
≤3 miles	1.45	0.25, 8.32	3.55	0.16, 80.03
> 3 miles	–	–	–	–
Weather-related (n = 106)				
Yes	–	–	–	–
No	3.58	0.73, 17.47	**25.52**	**6.35, 102.47**
Region (n = 106)				
Southeast	0.66	0.12, 3.51	0.75	0.08, 7.31
Southcentral	2.37	0.34, 16.29	2.82	0.07, 70.18
Southwest	–	–	–	–
Season (n = 106)				
Summer	0.45	0.07, 2.95	1.61	0.20, 12.61
Winter	–	–	–	–
Job position (n = 106)				
Officer	–	–	–	–
Deckhand	**3.28**	**1.15, 9.40**	**26.45**	**1.03, 676.49**
Processor	3.84	0.40, 36.70	22.71	0.81, 633.75
Other	0.75	0.16, 3.62	3.72	0.65, 21.50
Vessel length (n = 106)				
< 50 feet	0.58	0.12, 2.83	8.78	0.62, 123.43
≥50 feet	–	–	–	–
Vessel age (n = 106)				
< 25 years	–	–	–	–
≥25 years	5.03	0.86, 29.31	1.78	0.29, 10.81
Hull material (n = 106)				
Fiberglass	1.21	0.14, 10.26	–	–
Aluminum	0.40	0.03, 5.70	–	–
Wood	2.02	0.23, 17.95	–	–
Steel	–	–	–	–

Bold font indicates statistically significant odds ratios based on 95% confidence interval.
[a] Immersed in cold water for over 30 min.

217 (44.7%) were immersed in water. The majority of crewmembers who entered the water were immersed for 30 min or less (170, 61.6%). Of the remaining 106 crewmembers who were immersed for more than 30 min, 57 died (95% of all decedents) and 49 survived (10% of all survivors). Additional characteristics of crewmembers involved in both fatal and nonfatal sinkings are shown in Table 2.

3.3. Predictors of survival of cold water immersion

In bivariate analyses, statistically significant predictors of survival for crewmembers who were immersed in water for any length of time were: wearing an immersion suit (OR: 2.16 [95% CI: 1.02–4.57]), entering a life-raft (9.32 [1.49–58.26]), sinking within three miles of shore (7.80 [2.27–26.81]), sinking in the southcentral region of Alaska (compared to the southwest region) (5.67 [1.25–25.70]), and being a deckhand (compared to officers) (2.93 [1.42–6.03]) (Table 3). Weather conditions, season, and marine safety training were not significantly associated with survival, nor were the vessel characteristics of length, age, and hull material.

In the adjusted model, the significant predictors of survival were: entering a life-raft (16.72 [2.69–103.87]), sinking within three miles of shore (38.99 [6.82–223.00]), the sinking not being weather-related (5.96 [1.69–21.03]), being a deckhand (12.84 [2.52–65.55]) or 'other' crewmember (9.66 [2.14–43.59]) (compared to officers) and being on a vessel less than 50 feet long (5.08 [1.22–21.18]) (Table 3). Immersion suit use and geographic region were no longer significantly associated with survival when adjusted for other factors.

3.4. Predictors of survival of long-term cold water immersion

Statistically significant predictors of long-term immersion survival in bivariate analyses were: wearing an immersion suit (7.27 [2.27–23.27]), entering a life-raft (3.76 [1.06–13.30]), and being a deckhand (compared to officers) (3.28 [1.15–9.40]) (Table 4).

In the adjusted model, wearing an immersion suit (5.71 [1.39–23.38]), entering a life-raft (12.18 [2.20–67.36]), and being a deckhand (compared to officers) (26.45 [1.03–676.49]) were significantly associated with crewmember survival. The sinking not being related to severe weather conditions was also a significant predictor of survival (25.52 [6.35–102.47]) (Table 4).

4. Discussion

The ideal way to decrease crewmember fatalities following fishing vessel sinkings is to prevent the vessels from sinking in the first place. Such primary prevention efforts should focus on improving vessel stability, watertight integrity, and safety management systems (NIOSH, 2010). As previously described, existing safety regulations and fleet-specific safety initiatives have resulted in reduced risk of crewmember immersion and death. Yet commercial fishing remains a high-risk occupation with many deaths occurring during vessel sinkings. Faced with this ongoing reality in which fishing vessels continue to sink regularly, crewmembers must be prepared to respond to the dangers of cold water immersion.

The findings from the analysis of crewmember survival emphasize the importance of avoiding cold water immersion completely by evacuating a sinking vessel directly to another vessel, helicopter, or life-raft. About half of crewmembers involved in vessel sinkings successfully avoided immersion, and all but one survived (death caused by asphyxiation while trapped inside the capsized vessel). While this study did not examine the specific circumstances that contributed to prompt, direct rescue of crewmembers without immersion, potential factors could have included early recognition of the serious nature of the vessel emergency and proactive communications with other vessels and the US Coast Guard. Both of those skills are taught and practiced in marine safety courses (Dzugan, 2010), which NIOSH has recommended that all crewmembers participate in at least every five years (NIOSH, 2010).

In situations where cold water immersion becomes inevitable, having access to well-maintained, serviceable lifesaving equipment and the knowledge and skills to use it properly are critical. Fishing operations are often conducted in remote areas, and rescue resources may not be immediately available when a vessel sinks. Wearing a properly fitted, well-maintained immersion suit is essential for protecting crewmembers from the effects of cold water immersion, particularly if recovery is delayed. In fact, the adjusted regression model for crewmembers immersed in water for any amount of time found that immersion suit use was not statistically significantly associated with survival when controlling for other factors such as distance from shore and life-raft use, both of which were strongly associated with survival in that model. Conversely, the adjusted regression model for crewmembers immersed for over 30 min found that immersion suit use was associated with almost six times greater odds of survival, while distance from shore was not statistically significantly associated with survival. These findings show that immersion suit use is an important survival factor, especially if immersion lasts for more than 30 min.

In addition to the protective effects of immersion suits, this study found that crewmembers who were able to exit the water by boarding a life-raft were much more likely to survive than crewmembers who were unable to reach a life-raft. The strong survival factor of life-raft use was apparent in both of the adjusted models, indicating that life-rafts saved lives whether the crewmembers had been immersed in water for just a few minutes or for over 30 min. Not surprisingly, life-raft use was a stronger predictor of survival than immersion suit use, since life-rafts keep the occupants out of the water.

Having access to lifesaving equipment such as immersion suits and life-rafts is clearly critical to survival. For lifesaving equipment to be effective, crewmembers must also know how to use the equipment correctly while under extreme psychological stress. Marine safety training and monthly emergency drills are designed to provide crewmembers with the knowledge and skills they need to respond to vessel sinkings and other vessel emergencies (Dzugan, 2010; USCG, 2009).

For both crewmembers immersed for any amount of time and crewmembers immersed for more than 30 min, the odds of surviving immersion following a vessel sinking were greater when weather conditions were not identified as a contributing factor in the sinking. Severe weather and sea conditions may not only directly contribute to a sinking occurring, but may also hinder search and rescue operations, potentially leaving crewmembers vulnerable to the harsh conditions for extended periods of time. NIOSH has recommended that vessel operators pay close attention to weather forecasts and make proactive decisions to stay in port when seas are too rough for the vessel to operate safely (NIOSH, 2010). Many factors may influence operational decisions related to weather conditions, including fishery management policies. A growing body of literature suggests that economic pressures generated by certain fishery management policies can play an important role in the decisions made by vessel operators to fish in severe weather conditions (FAO, 2016). When creating or modifying fishery management policies, regulators should consider the potential safety repercussions of those policies, and make efforts to enact policies that mitigate hazards. This should go beyond simply considering a quota-based management system. For instance, when regulators are considering developing new fisheries in the Arctic, a discussion should acknowledge the greater distance from US Coast Guard search and rescue assets and possibly consider further training requirements for crewmembers, more frequent US Coast Guard examinations, or special vessel requirements for vessels participating in the fishery.

The distance from shore of the sinking was a strong predictor of survival for crewmembers immersed for any amount of time, with the odds of surviving nearly 40 times higher when the sinking occurred within three miles of shore. This could indicate that sinkings that occur within three miles from shore receive a more rapid rescue response. Remote fishing operations occurring far from shore may be subject to delayed rescue, even in calm weather and sea conditions. These findings support recent fishing safety regulations by the US Coast Guard that are targeted at vessels meeting certain criteria. For instance, in the Coast Guard Authorization Act of 2010 and the Coast Guard and Maritime Transportation Act of 2012 (USCG, 2015), commercial fishing vessels operating beyond three miles from shore are now required to undergo a dockside safety exam by the US Coast Guard every five years to ensure vessels are in compliance with applicable safety regulations. Important to consider though, is that distance from shore was not significantly associated with survival of long-term immersion, meaning that regardless of how close a crewmember is to shore, if rescue is delayed and immersion persists, immersion suits and life-rafts are essential for exposure protection and survival.

The primary limitations to this study are the small size of some groups within the study population, and differences in data completeness among individual cases and variables across cases. Small sample size and missing data can both contribute to limiting the statistical power of the analyses and therefore the ability to detect real differences between survivors and crewmembers who died. Differences in data completeness may be due to differences in US Coast Guard investigations. For example, some variables were collected more consistently, or in greater detail for crewmembers involved in fatal sinkings, and for crewmembers who died. Other types of information were more consistently collected for survivors, as they were often able to actively participate in investigations. For some variables, the proportion of missing data was so high that they could not be included in the analyses. For example, date of birth was missing for nearly half of all crewmembers, meaning it was not possible to include crewmember age in the logistic regression models.

Several potential survival factors investigated in this study were found to have large, but not statistically significant, odds ratios for surviving cold water immersion with large confidence intervals around the odds ratio estimate. One potential explanation for these results is that these factors have a true effect on survival which this study was not powered to detect. Arguably the most important of these results relates to marine safety training. This study found the odds of survival for crewmembers with formal marine safety training was more than twice the odds of survival than crewmembers without safety training in each of the scenarios examined. However, this association was not statistically significant. If this finding were indicative of a true effect, it would provide important additional evidence in support of NIOSH recommendations that all crewmembers should take marine safety training (NIOSH 2010).

Continued data collection over a longer time period, combined with a more robust dataset with complete case information from thorough US Coast Guard investigations, could address the limitations of this study and would improve the assessment of factors promoting crewmember survival in future analyses.

5. Conclusion

This study identified several factors associated with crewmember survival of cold water immersion following fishing vessel sinkings in Alaska, including the use of immersion suits and life-rafts. There is a need for primary prevention of vessel sinkings; however, when vessels sink despite those efforts, having access to well-maintained, serviceable lifesaving equipment and the knowledge and skills to use it properly are critical factors for survival. Due to differences in climate, geography, and fishing methods, these findings might not be generalizable to other fishing regions in the US, especially those with warmer waters. Future research should investigate the causes of vessel sinkings in other regions, as well as the factors associated with crewmember survival in those areas.

Acknowledgements

None.

Authors' contributions

Devin Lucas contributed to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work; drafting the work; and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Samantha Case, Jennifer Lincoln, and Joanna Watson contributed to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work; and drafting the work.

Funding

The authors report that there was no funding source for the work that resulted in the article or the preparation of the article.

Institution and Ethics approval and informed consent

The work was performed at the National Institute for Occupational Safety and Health, Western States Division office in Anchorage, Alaska. This work did not involve human subjects research and was not reviewed by an IRB. Informed consent was not relevant for this work.

Disclosure

The authors declare no conflicts of interest.

Disclaimer

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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Journal of Safety Research xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

Predicting commercial fishing vessel disasters through a novel application of the theory of man-made disasters

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ARTICLE INFO

Article history:
Received 22 January 2020
Received in revised form 11 June 2020
Accepted 30 July 2020
Available online xxxx

Keywords:
Occupational safety
Maritime
Disaster incubation
Drift

ABSTRACT

Introduction: Vessel disasters (e.g., sinkings, capsizings) are a leading contributor to fatalities in the U.S. commercial fishing industry. Primary prevention strategies are needed to reduce the occurrence of vessel disasters, which can only be done by developing an understanding of their causes and risk factors. If less serious vessel casualties (e.g., loss of propulsion, fire, flooding) are predictors of future disasters, then reducing vessel casualties should in turn reduce vessel disasters and the accompanying loss of life. *Method:* This case-control study examined the association between vessel casualties and disasters using fishing vessels in Alaska during 2010–2015. *Results:* The findings show that vessels that experienced casualties within a preceding 10-year period were at increased odds of disaster. Other significant predictors included safety decal status and hull material. *Practical Applications:* The results of this analysis emphasize the importance of implementing vessel-specific preventive maintenance plans. At an industry level, specific prevention policies should be developed focusing on high-risk fleets to identify and correct a wide range of safety deficits before they have catastrophic and fatal consequences.

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1. Introduction

"On the afternoon of April 21, 2015, a fire broke out in the forepeak machinery space on the uninspected fishing vessel Northern Pride *while underway in the vicinity of Portlock Bank, Alaska. Smoke and fire spread quickly to the main cabin and wheelhouse, prompting the captain to broadcast a Mayday alert. The captain then ordered his crew to don their immersion suits and abandon ship into the vessel's inflatable life raft .... Shortly after rescue, the* Northern Pride *capsized.*" (National Transportation Safety Board [NTSB], 2016)

"About 0300 local time on June 10, 2015, the uninspected commercial fishing vessel Kupreanof *began taking on water while transiting from Juneau to Bristol Bay, Alaska. About two and a half hours later, the vessel sank in 420 feet of water. All four crewmembers were rescued without injury by the Coast Guard soon after abandoning ship.*" (NTSB, 2017)

"About 1600 on July 23, 2016, the commercial fishing vessel Ambition *started taking on water in its lazarette while transiting in the Bering Sea near the northern entrance to False Pass off the Alaska Peninsula. The vessel began sinking by the stern, and efforts by the crew to determine the source of the flooding were unsuccessful. After the captain transmitted a distress call over VHF radio at 1832, the five crewmembers donned immersion suits and abandoned the vessel into the water and onto a good Samaritan vessel.*" (NTSB, 2018)

Vessel casualties are consequences of failures within vessel-specific components or systems that may result in the loss of electrical power, propulsion, and steering. These failures, as well as human error, may also cause flooding, fires, and groundings. Vessel casualties are often resolved at sea or in port and do not cause loss of life or property. However, as shown in the above excerpts from fishing vessel sinking investigations, sometimes these failures are not immediately resolved, initiating chains of events that lead to vessel disasters (e.g., sinkings, capsizings) and associated fatalities.

Catastrophic vessel disasters are the leading contributor to occupational fatalities in the United States (US) commercial fishing industry, which is consistently one of the most hazardous industries nationwide (Bureau of Labor Statistics, 2018). During 2000–2014, 204 separate fatal vessel disasters resulted in 344 worker deaths in U.S. fisheries, representing 50% of all fishing industry fatalities (Lucas & Case, 2018). Fishing vessel disasters involve a sequence of events that results in a final catastrophic event, such as a vessel sinking (Lucas & Case, 2018). Fatal vessel disasters in the United States during 2000–2014 most frequently began with flooding (25%), instability (19%), struck by a large wave (19%), and collision (12%; Lucas & Case, 2018).

As the leading cause of occupational fatalities, vessel disasters are a vital area to target prevention efforts. Prevention of vessel

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https://doi.org/10.1016/j.jsr.2020.07.005
0022-4375/Published by Elsevier Ltd.

Please cite this article as: S. L. Case and D. L. Lucas, Predicting commercial fishing vessel disasters through a novel application of the theory of man-made disasters, Journal of Safety Research, https://doi.org/10.1016/j.jsr.2020.07.005

disasters has the potential to save many lives, especially since a single disaster can place multiple workers in danger at the same time. For most fishing vessels in the United States, there are no safety requirements concerning their construction, maintenance, and watertight integrity. Current regulations vary based on vessel size, year built, and area of operation, but largely focus on secondary prevention of death through the carriage of lifesaving equipment used during vessel emergencies (United States Coast Guard [USCG], 2009). Primary prevention strategies are needed to reduce the occurrence of vessel disasters, which can only be done by first understanding their causes and risk factors.

Given the potential for vessel casualties to directly initiate a disaster, the broader role of vessel casualties in fishing vessel safety needs to be better understood. If a vessel experiences casualties over time, then that history of casualties may be a leading indicator of larger problems with the vessel that could trigger a future vessel disaster. This hypothesis is supported by the theory of man-made disasters developed by Turner (1978), which states that disasters involving complex man-made systems, such as fishing vessels, are not chance events. Instead, a sequence of events, often starting years prior to the disaster, occurs and escalates to the eventual disaster (Pidgeon & O'Leary, 2000; Turner, 1978; Turner & Pidgeon, 1997). In this sequence of events, a disaster incubation period exists in which unnoticed, misunderstood, or ignored events accumulate. Instead of recognizing these precursor events as warning signs of an impending disaster, workers fail to perceive the warning events as such or fail to adequately assess the risk (Pidgeon & O'Leary, 2000; Turner, 1978; Turner & Pidgeon, 1997). This results in a drift toward failure over time in which the tolerance for safety threats, perhaps subconsciously, increases (Dekker, 2011; Dekker & Pruchnicki, 2014). This can occur as safety, productivity, and other goals compete, reducing safety margins. Until a catastrophic failure occurs, workers and organizations believe hazards are adequately controlled (Dekker, 2011; Dekker & Pruchnicki, 2014; Pidgeon & O'Leary, 2000; Turner, 1978; Turner & Pidgeon, 1997).

If vessel casualties are indeed a predictor of a future vessel disaster, then reducing vessel casualties should in turn reduce vessel disasters and the accompanying loss of life. This association has not been previously examined. The purpose of this study was to test the novel hypothesis that fishing vessel casualties are leading indicators of future vessel disasters using data from fishing vessels operating in Alaskan waters during 2010–2015.

2. Methods

2.1. Study design

A case-control study design was used. Cases were identified from the Commercial Fishing Incident Database (CFID), a system managed by the National Institute for Occupational Safety and Health (NIOSH) that stores data on marine casualties in the U.S. commercial fishing industry (Lucas & Case, 2018). A commercial fishing vessel was included as a case in this study if it was involved in a vessel disaster in Alaskan waters during 2010–2015. A vessel disaster was defined as any catastrophic event that occurred to a vessel resulting in the entire crew abandoning the vessel, such as a sinking or capsizing.

Cases were limited to decked catcher and tender vessels. Catcher vessels are those that are used to harvest fish and shellfish, whereas tender vessels transport fish from the catcher vessels to port. Processing vessels (i.e., vessels that include onboard factories for production and packaging) were excluded from the study, in part because there were no vessel disasters involving processing vessels during the study period. Skiffs were also excluded as cases in this study because they are small (typically under 26′ in length) and undecked, a considerable contrast to catcher and tender vessels. In rare instances where a vessel experienced more than one disaster during the study period (e.g., vessel capsized or grounded in 2011 but was salvaged; later sank in 2014), the vessel was only included as a case once, at the time of the first disaster.

Controls were defined as commercial fishing vessels that were active in Alaskan waters during 2010–2015 and did not experience a vessel disaster during that time, in Alaska or elsewhere. Because fisheries landings data were confidential and therefore not available, a list of unique commercial fishing vessels most likely to be active in Alaska was developed for each year in the study period using two other data sources: (a) annual lists of commercial fishing vessels licensed to operate in Alaskan waters obtained from the State of Alaska Commercial Fisheries Entry Commission (CFEC) Commercial Vessel Database (State of Alaska, n.d.); and (b) annual lists of vessels with federal fishery permits obtained from the National Oceanic and Atmospheric Administration (NOAA) Fisheries Alaska Region (NOAA, n.d.). These two data sources provided the best publicly available proxy for active vessels. Alaska statutes AS 16.05.475 and AS 16.43.150(d) indicate that vessel licenses must be renewed whenever a vessel is to be used in a particular year for commercial fishing in state waters, whereas state limited entry permits must be renewed annually irrespective of whether the permits are actually used in a particular season (Registration of Fishing Vessels, 2007; Terms and Conditions of Entry Permit; Annual Renewal, 2007). Federal fishery permits were used to include a small number of vessels that could potentially operate solely in federal waters and would not otherwise be included in the CFEC list. The two lists were merged, and duplicate vessels were dropped before control selection. Skiffs and processing vessels were excluded from the sampling frame to align with cases as described above.

For each case, three control vessels were randomly selected from the list of all vessels active during the same year. For example, there were 10 cases in 2010; therefore, 30 control vessels were randomly selected from the list of vessels active in 2010. This process was repeated for each year of the study period. Cases and controls were incorporated into a master dataset for additional data collection and analysis.

2.2. Data collection on exposure variables

Vessel casualty history was the primary risk factor of interest in this study. Vessels that are federally documented and/or have any interaction with the U.S. Coast Guard can be found in their Marine Information for Safety and Law Enforcement (MISLE) system. Vessel casualties are required to be reported to the Coast Guard (Notice of Marine Casualty, 1994). When reported, casualty data are associated with the vessel within its activity history in MISLE. NIOSH researchers with access to MISLE reviewed activity histories for each vessel to identify any reported casualties within 10 years prior to the disaster or when the control was selected (i.e., inclusion year) (Table 1). Casualty history was only collected for vessels built at least 10 years prior to the study inclusion year.

Table 1
Distribution of cases and controls by year with casualty history parameters.

Inclusion Year	Cases (n = 70)	Controls (n = 210)	10-Year Casualty History Timeframe
2010	10	30	2001–2010
2011	14	42	2002–2011
2012	14	42	2003–2012
2013	12	36	2004–2013
2014	10	30	2005–2014
2015	10	30	2006–2015

Please cite this article as: S. L. Case and D. L. Lucas, Predicting commercial fishing vessel disasters through a novel application of the theory of man-made disasters, Journal of Safety Research, https://doi.org/10.1016/j.jsr.2020.07.005

In addition to vessel casualty history, documentation status was determined for each based on its registration number. Commercial fishing vessels at least five net tons are required to be federally documented (Vessels Requiring Documentation, 1993). A vessel was classified as federally documented if it had an official number assigned (e.g., 123456). In contrast, a state registered vessel only had a registration number with the State of Alaska (e.g., AK0001K).

Fishing vessel safety decal status was obtained from MISLE. A fishing vessel safety decal is issued after a successful dockside examination by the Coast Guard or an approved third-party organization, showing compliance with federal regulations, including carriage of lifesaving equipment (USCG, 2007). Safety decal status was recorded as current or expired if the vessel had a safety decal on or prior to the disaster date (cases), or anytime during or prior to the inclusion year (controls).

Other vessel characteristics included in this study were vessel age, length, and hull material. Due to the high correlation of length and tonnage, length was included as the preferred variable given the emphasis on vessel length in commercial fishing vessel safety regulations. Data on these characteristics were obtained from the original CFID, CFEC, or NOAA source as applicable. Vessel age was determined for each vessel as the difference between the inclusion year and year built.

Table 2
Characteristics of case and control vessels.

	Cases ($n = 70$)		Controls ($n = 210$)	
	n	%	n	%
10-Year Casualty History				
No Casualties	50	74.6	179	90.9
One or More Casualties	17	25.4	18	9.1
Not applicable (<10 years old)	3	–	13	–
Documentation				
Federally Documented	59	84.3	181	86.2
State Registered	11	15.7	29	13.8
Fishing Vessel Safety Decal				
Current	24	34.3	84	40.0
Expired	22	31.4	47	22.4
None	24	34.3	79	37.6
Age (years)				
<25	13	18.6	45	21.4
≥25	57	81.4	165	78.6
Length (feet)				
<50	42	60.0	170	81.0
50–78	22	31.4	33	15.7
≥79	6	8.6	7	3.3
Hull Material				
Fiberglass	29	41.4	121	57.6
Aluminum	7	10.0	45	21.4
Steel	18	25.7	17	8.1
Wood	16	22.9	27	12.9

2.3. Analysis

Data analysis was performed using Stata SE v15.1 (StataCorp, 2017). A descriptive analysis of the sampling frame, cases, and controls was conducted to explore characteristics of each. Logistic regression was used to calculate odds ratios (OR) and 95% confidence intervals (CI) to measure the association between the exposure variables and the outcome (disaster). Unadjusted ORs were calculated for casualty history (one or more casualties / no casualties), documentation (federally documented / state registered), fishing vessel safety decal status (current / expired / none), vessel age (<25 years / ≥25 years), vessel length (<50′ / 50-78′ / ≥79′), and hull material (fiberglass / aluminum / steel / wood). The categories for length and age were chosen based on current or proposed fishing vessel safety regulations. The multivariable model included all variables. Post-regression diagnostics including goodness of fit and variance inflation factors were performed to assess model fit and multicollinearity. Because 10-year casualty history was not applicable for vessels less than 10 years of age, those vessels were excluded from models examining casualty history.

3. Results

3.1. Characteristics of sampling frame, cases, and controls

Characteristics of the sampling frame, cases, and controls are described below. Table 2 also presents cases and controls for comparison.

3.1.1. Sampling frame

Based on CFEC and NOAA records, 7,309 total unique decked catcher and tender vessels operated in Alaska during 2010–2015, with 5,956 active vessels per year on average. Most fishing vessels were federally documented (5,584, 76.4%). Vessels were a mean 42′ in length (26–194′) and built in 1979 (1907–2015). Over half of vessels were fiberglass (3,798, 52.0%), followed by aluminum (1,794, 24.5%), steel (879, 12.0%), and wood (810, 11.1%).

3.1.2. Cases

Seventy fishing vessels were identified as cases during the six-year study period, averaging nearly 12 vessel disasters per year in Alaska. Of these, the majority were nonfatal events (66, 94.3%). Three types of initiating events caused the majority of disasters: running aground (21, 30.0%), flooding (12, 17.1%), and instability (10, 14.3%). Most vessel disasters were sinkings (45, 64.3%), followed by groundings (18, 25.7%). In seven other disasters (10.0%), the vessels capsized, burned, or otherwise experienced severe damage but remained afloat.

Most cases were federally documented (59, 84.3%). On average, cases were 48′ in length (26–110′) and were built in 1973 (1927–2011). At the time of disaster, vessels were a mean 40 years old (1–84 years), with three vessels less than 10 years. Hull material was most often fiberglass (29, 41.4%), steel (18, 25.7%), or wood (16, 22.9%). Cases were nearly evenly distributed among the three decal status categories. Twenty-four vessels (34.3%) had a valid decal at the time of disaster, with an additional 22 (31.4%) operating with an expired decal.

Seventeen of the 67 cases that were ≥10 years old at the time of disaster (25.4%) had a history of vessel casualties within the preceding 10 years. Of these, the most common initiating event for disasters was running aground (7, 41.2%), followed by engine failure, fire, flooding, and instability, resulting in two disasters each. Overall, the 17 cases reported 24 total casualties, ranging from 1-3 casualties per vessel. The leading prior casualty types were grounding (8, 33.3%), loss of power (6, 25.0%), flooding (3, 12.5%), and loss of steering (3, 12.5%). For five vessels, the initiating event of the disaster was the same type as at least one of its prior casualties: grounding (4) and fire (1).

3.1.3. Controls

In total, 210 controls were randomly selected. Controls were predominantly federally documented (181, 86.2%). Vessels were a mean 41′ in length (26–149′) and, on average, built in 1978. The mean vessel age of controls based on inclusion year was 34 years (0–94 years). Thirteen vessels were less than 10 years old. The majority of controls were fiberglass (121, 57.6%) or aluminum (45, 21.4%). Most controls had either a valid (84, 40.0%) or expired (47, 22.4%) decal during their inclusion year.

Eighteen of the 197 controls that were ≥10 years old at the time of inclusion (9.1%) reported 24 total casualties within the

Please cite this article as: S. L. Case and D. L. Lucas, Predicting commercial fishing vessel disasters through a novel application of the theory of man-made disasters, Journal of Safety Research, https://doi.org/10.1016/j.jsr.2020.07.005

preceding 10-year period, with individual vessels reporting 1–3 casualties. The leading types of casualties among controls were grounding (7, 29.2%), loss of propulsion (5, 20.8%), and collision (5, 20.8%).

3.2. Predictors of disaster

In the unadjusted models, the significant predictors of disaster were: having one or more casualties within 10 years (OR = 3.38; 95% CI = 1.62–7.04); vessel length of 50–78′ (OR = 2.70; 95% CI = 1.43–5.10) or ≥79′ (OR = 3.47; 95% CI = 1.11–10.86), and a steel (OR = 4.42; 95% CI = 2.03–9.61) or wood hull (OR = 2.47; 95% CI = 1.18–5.18) (Table 3). The multivariable model showed that casualty history and steel hull remained significant. In addition, having an expired decal was significantly associated with increased risk of disaster (OR = 2.41; 95% CI = 1.09–5.30). Post-regression diagnostic tests found no evidence for poor model fit (Pearson $\chi^2 = 58.4$; $p = 0.253$) or multicollinearity (Mean VIF = 1.76).

4. Discussion

The Commercial Fishing Industry Vessel Safety Act (CFIVSA) of 1988 was the first U.S. legislation to establish safety standards for the fishing industry (Hiscock, 2002). The regulations, implemented in the early 1990s, require most fishing vessels to carry survival equipment, such as personal flotation devices (PFDs), immersion suits, life-rafts, throwable flotation devices, distress signals, emergency position indicating radio beacons (EPIRBs), and fire extinguishers (USCG, 2009). Access to this lifesaving equipment resulted in increasing case-survivor rates for vessel disasters in Alaska, from 78% in 1991–1993, to 92% in 1994–1996, to 94% in 1997–1999 (NIOSH, 2002), and research has shown that immersion suit and life-raft use improves chances of survival when immersed in cold water after fishing vessel sinkings (Lucas et al., 2018). While this is a remarkable improvement in survivability, vessel disasters continue to occur and contribute to the high rate of fatalities in the fishing industry (Lucas & Case, 2018). In addition to ensuring crewmembers have the skills and equipment needed to survive, there is a clear need for prevention of fishing vessel disasters altogether.

While other studies have described the more direct causes and risk factors of fishing vessel disasters (Jin et al., 2002; Lincoln & Lucas, 2010; Lucas & Case, 2018), this is the first to explore historical patterns of vessel safety problems that may be less directly associated with the onset of disaster. The theory of man-made disasters suggests that disasters are the result of failure of foresight; that is, the inability to recognize and mitigate warning signs and safety threats (Pidgeon & O'Leary, 2000; Turner, 1978; Turner & Pidgeon, 1997). The theoretical framework for this study posited that vessel casualties are safety threats that are often ignored, or even considered successes through no loss of life or property. Vessel casualties may not be merely mechanical failures; rather, they may be indicative of breakdowns in the larger systems and demands in place that affect decision-making. The findings support our hypothesis and show an elevated risk of disaster when a vessel has experienced casualties within a preceding 10-year period, even after adjusting for a host of other factors. As vessel casualties occurred in the disaster incubation period, competing demands related to money, time, and compliance with regulations may have led to a misinterpretation of, or increased tolerance for, risk. In most cases, there was no apparent link between the prior casualty type(s) and the initiating events of the vessel disaster (e.g., a prior flooding issue is not fully resolved or repaired, resulting in progressive flooding and sinking), lending more support to the theory that these events often arise through decreasing safety margins rather than more direct associations.

In a more immediate and practical sense, vessel owners and operators should be cognizant of the association between casualties and disasters, and work to establish a strong safety management system on their vessels that emphasizes risk assessments and preventive maintenance. Different strategies are needed to address the variety of casualty types, such as fire, flooding, steering failure, and loss of propulsion and power. For instance, fire prevention includes inspecting and maintaining fuel lines and ventilation systems, identifying leaks in hoses and piping systems, practicing good housekeeping, and repairing electrical wiring that could serve as potential ignition sources (USCG, 2006). Flooding prevention includes in-depth inspection and maintenance of the vessel hull and through-hull fittings, inspection and testing of high-water alarms and bilge pumps before each trip, and stocking a damage control kit (USCG, 2006). All vessel owners and operators should

Table 3
Factors associated with fishing vessel disasters.

	Unadjusted OR (n = 280*)	95% CI	Adjusted OR (n = 264)	95% CI
10-Year Casualty History				
No Casualties	1	–	1	–
One or More Casualties	**3.38**	**1.62–7.04**	**2.98**	**1.29–6.89**
Documentation				
Federally Documented	1	–	1	–
State Registered	1.16	0.55–2.47	2.15	0.83–5.53
Fishing Vessel Safety Decal				
Current	1	–	1	–
Expired	1.64	0.83–3.23	**2.41**	**1.09–5.30**
None	1.06	0.56–2.02	1.59	0.74–3.42
Age (years)				
<25	1	–	1	–
≥25	1.20	0.60–2.38	0.56	0.23–1.38
Length (feet)				
<50	1	-	1	-
50–78	**2.70**	**1.43–5.10**	1.37	0.56–3.34
≥79	**3.47**	**1.11–10.86**	1.23	0.28–5.54
Hull Material				
Fiberglass	1	–	1	–
Aluminum	0.65	0.27–1.59	0.42	0.13–1.28
Steel	**4.42**	**2.03–9.61**	**3.29**	**1.12–9.68**
Wood	**2.47**	**1.18–5.18**	2.26	0.92–5.58

* Unadjusted models included all 280 vessels except for 10-year casualty history (n = 264), due to the exclusion of the vessels <10 years in that model.

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formalize a maintenance plan for their vessel and systems, and adhere to the established maintenance schedule (NIOSH, 2016). Being proactive, rather than reactive, improves vessel safety and may reduce lost days at sea.

The concept of preventing vessel casualties, and thus disasters, is not new. In the early 2000s, the Coast Guard determined that some fishing vessels operating in the Bering Sea were also conducting processing activities but failed to meet the classification and load line standards required for processing vessels (USCG, 2015). The Coast Guard engaged industry members and used its regulatory authority to develop the Alternate Compliance and Safety Agreement (ACSA) for some factory trawlers and freezer longliners (USCG, 2015). This program includes specific safety standards that participating vessels must comply with to conduct minimal processing activities. ACSA focuses on primary prevention of vessel disasters by addressing vessel stability, propulsion, vital piping systems, fire prevention, and electrical generation machinery (USCG, 2015). Lucas et al. (2014) conducted an evaluation of ACSA and found that the rate of serious casualties decreased after vessels complied with ACSA requirements.

More recently, the Coast Guard Authorization Act of 2010 and the Coast Guard and Marine Transportation Act of 2012 included a provision for the Coast Guard to develop an Alternative Safety Compliance Program (ASCP) for commercial fishing vessels ≥50′ in length and ≥25 years of age (USCG, 2017). The ASCP was suspended during development in lieu of a voluntary program (Voluntary Safety Initiatives and Good Marine Practices) (USCG, 2017). However, like ACSA, the guidance includes prevention measures involving firefighting equipment, machinery and electrical safety, flooding control, stability standards, and material condition (USCG, 2017). While our study did not find evidence of elevated risk based on length or age after controlling for other factors, it is likely that compliance with these guidelines would result in reductions in vessel casualties and disasters, similar to ACSA. Regardless of whether the ASCP is revived in future rulemaking efforts, specific prevention programs should be developed to target high-risk fleets and their safety problems, based on quantitative risk assessments.

The findings of this study also support the Coast Guard's dockside examination program, as vessels with expired decals had higher odds of disaster than those with current decals. The dockside examination and safety decal are not equivalent to vessel inspections and thus do not focus on the condition of the vessel itself, but rather on the carriage and maintenance of lifesaving equipment, and functionality of critical systems (e.g., navigation, communication, firefighting, alarms) (USCG, 2007). However, the examinations provide an opportunity for Coast Guard personnel to meet with fishing vessel owners, operators, and crewmembers to educate them on fleet-specific risks and good marine practices. The Coast Guard has found that, within a given year, as dockside examination activity increases, vessel losses decrease (USCG, 2006). Like vessel casualty history, decal status could be a proxy for beliefs and behavior around safety on fishing vessels.

Documentation status is a determining factor in which regulations apply. There are additional requirements for documented vessels operating beyond the boundary lines, which, according to the regulations, "follow the trend of the seaward high-water shorelines and cross entrances to small bays, inlets, and rivers" (Requirements for Commercial Fishing Industry Vessels, 1991). These requirements include CPR and first aid training, emergency drills, safety orientation, high water alarms, bilge pumps, and some machinery guards (Requirements for Commercial Fishing Industry Vessels, 1991). Our analysis did not reveal evidence to indicate any difference in risk between federally documented and state registered vessels.

Vessels with steel hulls were more likely to experience a vessel disaster than vessels with fiberglass hulls. It is possible that this finding has little to do with the actual hull material and more to do with different exposures typically experienced by vessels of various sizes and configurations. For instance, steel vessels tend to be larger than fiberglass vessels and fish farther off shore for longer periods of time, often year-round. These exposures to more hazardous conditions for longer duration may explain why steel hulled vessels were more likely to experience vessel disasters than smaller fiberglass vessels operating in protected waters during summer months. In this analysis, it was not possible to control for differences in exposures between vessels. Future research may find new ways to measure and control for varying levels of exposure to hazards.

Aging of the fleet is a concern in the commercial fishing industry. Vessels in the North Pacific fleet, for example, are 40 years old on average, with many built in the 1970s (McDowell Group, 2016). This is consistent with the age of vessels included in this study. Increased vessel age was not found to be a significant risk factor for disaster, but this is most likely because the age of cases and controls were similar, with most vessels in both groups ≥25 years. Therefore, we cannot rule out increased age as a risk factor. Newer vessels may provide a host of benefits, including improved safety by meeting the modern build standards for new construction (McDowell Group, 2016). However, vessel replacement costs and obtaining the financing for new builds may be a barrier, particularly for vessel owners that are not associated with large seafood companies (McDowell Group, 2016).

5. Conclusions

Vessel disasters are the leading cause of work-related fatalities among commercial fishermen in the United States. Although the likelihood of surviving these events has increased since the introduction of safety standards in 1988, their continued occurrence is a concern. This is the first study to identify vessel casualties as a predictor of future disasters. Vessel casualties are just one of many risks in commercial fishing vessel safety. Additional research applying the man-made disaster theory and drift (toward failure) should focus on identifying other threats and ways to explain and control drift in the fishing industry. Efforts should be made by the Coast Guard, marine safety trainers, and researchers to work collaboratively with industry members to voluntarily enhance preventive policies and procedures onboard fishing vessels.

Several study limitations should be considered. As of this writing, no historical data are readily available on all active fishing vessels in the United States. Landings data are confidential on state and federal levels, and federal documentation records were determined to be an unreliable proxy for activity. Therefore, only Alaskan vessels were included in this study, leaving the generalizability of the findings outside of Alaska unknown. However, a joint project by NOAA Fisheries, the Coast Guard, and NIOSH to consolidate and track active vessels in federal fisheries is underway. These vessel data may be used in future research. Further, vessels were not included based on landings, which could mean that some non-operational vessels were inadvertently included in the population from which the controls were selected. The impact of this was minimized by primarily using licensed vessels, which better represent an intent to operate compared to vessel permits that automatically renew. In addition, it is possible that vessel casualties were underreported to the Coast Guard, particularly in situations where the casualty was resolved at sea or when Coast Guard assistance was not required. This could result in nondifferential misclassification of the 10-year casualty history. Lastly, examining the role of vessel systems and characteristics is only one component of understanding and preventing catastrophic

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disasters. Although vessel casualties may be indicative of other failures, such as inadequate maintenance schedules or operating in dangerous conditions, this study does not explicitly account for or quantify other factors that may also contribute to disasters, including fatigue, inattention, seasonality, weather, operating region, fishery, or policies. Future safety research in the fishing industry should explore these issues to determine to what extent each contributes to adverse events. Because of the considerable differences in how fishing operations are conducted, such research should be specific to fisheries and regions to ensure that safety solutions have the maximum effect as they are appropriately tailored.

Acknowledgements

The authors thank Jennifer Lee for assisting with data collection for the study.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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