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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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A B S T R A C T

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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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 ($n = 169$).

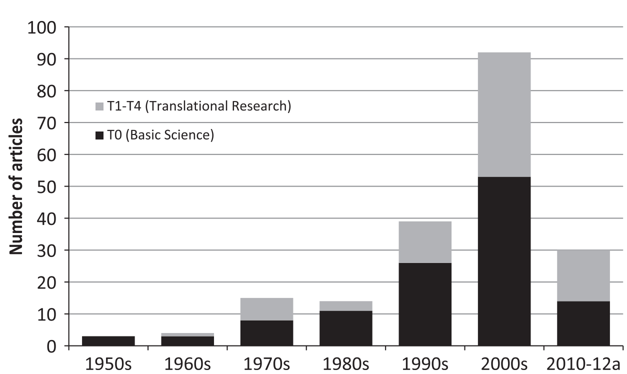

Fig. 1. Number of articles published on fishing industry safety by decade and translational research phase. [a]Three-year period.

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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