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

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A B S T R A C T

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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(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 (≤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′/≥50′); vessel age (< 25 years/≥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:

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

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

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).

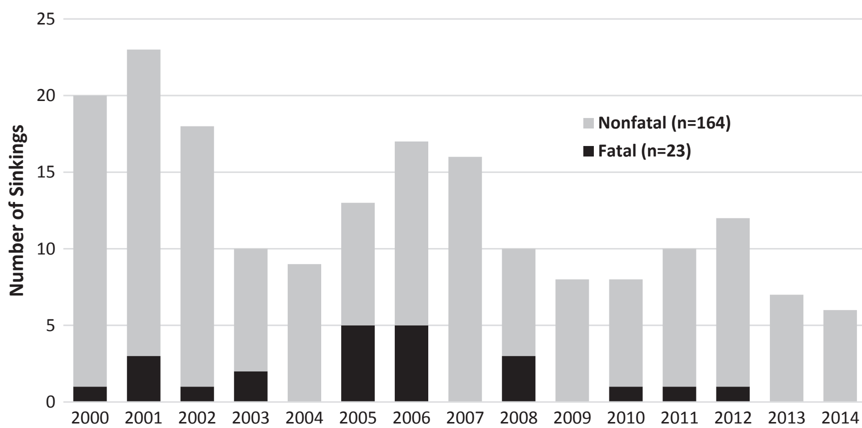

Fig. 1. Frequency of fishing vessel sinkings, Alaska, 2000–2014.

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.

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.

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).

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.

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.

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.

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.

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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.

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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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