## Title:

# An analysis of lifejacket wear, environmental factors, and casualty activity on marine accident fatality rates

**Author Note:**

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## Abstract:

Drowning and fatalities at sea are a large concern globally. In the UK, many sea rescues are performed by the Royal National Lifeboat Institution, and this study investigates 6 years' worth of their rescue data to better understand causation of drowning and what makes an incident at sea high risk. A Poisson model is applied to numerous factors recorded as part of each rescue, including environmental conditions (visibility, sea state, etc.), lifejacket wear, and response times for rescue. Increased lifejacket wear is shown to be significantly correlated with lower fatality rates across all spectrum of activities. Survivability among those casualties wearing life jackets was 94 %. A seasonal signal is clearly present, with a higher proportion of life at risk incidents occurring during winter months, and a higher than predicted number of fatalities during this time. The analysis identifies high risk groups of beach/sea users, with one of the most at risk being people fishing from shore. Incident survivability is shown to decrease at different rates per activity, as time to rescue increases. This study provides clear evidence that a co-ordinated approach to sea safety is required, and suggests that increased lifejacket wear among coastal and marine users would have a dramatic effect on reducing the number of drowning related deaths each year.

**Keywords:**

Personal flotation device; sea safety; drowning; commercial fishing; RNLI

## 1. Introduction

The Royal National Lifeboat Institution (RNLI) is the largest maritime lifesaving organisation in the UK and it currently provides both lifeboat and lifeguard cover, with 238 lifeboat stations and in excess of 240 lifeguard units around Great Britain and Ireland. On average, RNLI lifeboats are called to attend in excess of 8,500 incidents per year around the UK. Of these, approximately 350 (4.1 %) represent an incident whereby there was a verified life at risk (LAR) each year. Of all LAR incidents, 140 (40 %) involve a fatality. A LAR incident is defined as an incident where either a life was lost, or would have been lost had it not been for the actions of the RNLI. There is a broad increase in water based-activity across the UK, and it is important for the RNLI to understand what that will mean for the number of incidents they are likely to be tasked to respond to. The sea is used extensively for both recreational and commercial activities, yet it is an environment that is notoriously unpredictable and quick to change. Factors such as inexperience, inappropriate equipment, mechanical failure, and horseplay mean that each year around the UK coastline, thousands of people get into difficulty at sea. Indeed, the combination of these factors has earnt commercial fishing the reputation as one of the most dangerous professions in the UK (McGuinness and Utne, 2016). Over the past 11 years in the UK fishing fleet alone, there have been on average 245 accidents, 16 vessels lost, 52 injuries and 8 fatalities each year, with the overall size of the UK fishing fleet estimated to be 6191 vessels (MMO, 2017). Both commercial and leisure users that get into trouble may be able to self-rescue (i.e. get themselves to shore, or be rescued by crew mates), or attract help from passing vessels, but many will require the assistance of the coastguard or emergency services such as the RNLI in order to get out of their predicament. Thus, in the context of this article, a service is defined as a rescue response performed by the RNLI.

Most research on maritime accidents and fatalities focus on commercial activities (Jin *et al*., 2002; O'Connor and O'Connor, 2006; Marvasti, 2017), as a result of the requirement from bodies such as the International Maritime Organisation (IMO, 1999) to report and investigate occupational fatalities (McGuinness and Utne, 2016). One of the most well-established lines of research is that of assessing the impact of weather conditions on the number and severity of fishing vessel incidents. Wind speed is regularly investigated in terms of accident and incident causation, as it is shown to be a primary factor in fishing vessel stability (Niclasen *et* al., 2010). Generally, as might be expected, an overall decline in weather conditions increases the likelihood of an incident per vessel (Wu *et al*., 2009), however, there are less journeys made in inclement weather and the overall number of incidents is shown to decrease as a result (Marvasti and Dakhlia, 2017). More recently, studies have attempted to quantify the impact of the most severe weather conditions that a particular fishing fleet may encounter, such as extratropical cyclones and large-scale sea ice coverage. The study of Rezaee *et al*. (2016) was one of the most comprehensive to address these factors, primarily because results were interpreted by commercial fishing vessel type (e.g. crab fishing, seal fishing, etc.). The results showed that differing fishing types were predominantly affected by different types of weather influence, as a result of differing vessel configurations and the relative locality of fishing grounds per species type. A study of passenger vessels explicitly linked the occurrence of crew injuries during incidents on cruise liners and ferries to that of passenger injuries, with obvious implications for crew training and competence (Yip *et al*., 2015).

Comparatively few studies have addressed boating more generally, or recreational boating specifically, although a few have attempted to quantify the impact of lifejacket use on the outcome of leisure boating incidents (Cummings *et al*., 2011; Wright *et al.,* 2013; Bugeja *et al*., 2014; Viauroux and Gungor, 2016). However, published studies on the trends in the UK are either generally either dated or entirely focused on commercial activities rather than recreational boating (Reilly, 1980; Matheson, 2001; Roberts, 2004). There is a much larger focus on understanding and preventing incidents that might be termed lifeguard incidents in the leisure sector, such as rip current rescues (Gallop *et al*., 2016, Pitman *et al*., 2016), but not incidents further offshore.

In order to reduce drowning in the UK, it is first important to fully understand the chain of causation influencing accidents and incidents in UK waters, and to appreciate the factors that influence the fatality rate of incidents. To date, no published studies have addressed the deficit of information regarding causation of UK maritime accidents, and no studies have taken a holistic approach incorporating both commercial and leisure craft, as well as small manual craft such as surfboards and bodyboards. Therefore, this study makes use of operational RNLI data spanning the period 2011-2016 in order to better understand the causes of maritime incidents in UK waters.  For ease of reference, the non-standard abbreviations used throughout this article are summarized in Table 1.

Table 1. Royal National Lifeboat Institution abbreviations used throughout this article.

| Abbreviation | Text in full | Brief description |
|---|---|---|
| RNLI | Royal National Lifeboat Institution | The name of the UK's largest maritime rescue charity |
| AIC | Abbreviated Incident Category | The broad categories used by the RNLI to group incidents into types based on activity (such as fishing) |
| LAR | Life at Risk | An incident where either a life was lost, or one would have been lost had it not been for the RNLI's intervention |
| RoS | Return of Service | The log pertaining to an individual incident that was attended by the RNLI |
| SST | Sea Surface Temperature | A measure of water temperature |

## 2. Data and Methods

Here we outline the way in which RNLI data is collected and how it has been supplemented with external data sets, and the processing steps taken for analysis.

### 2.1 Data

The RNLI collects data every time a lifeboat is launched, with each individual entry being termed a Return of Service (RoS). Each RoS contains information on casualty location, number of people involved, casualty activity, casualty behaviour (lifejacket use, influence of drugs/alcohol, etc.), and meteorological conditions (wind speed, wave height, visibility, sea state etc. at incident location). This study makes use of 6 years' worth of RoS data (2011-2016) supplied by the RNLI. Although more is available, the RNLI has only recorded information about lifejacket utilisation since 2011, and therefore in order to fully incorporate this parameter into the analysis, only data since 2011 will be used. The data also contains information about whether a life was saved or lost as a result of this rescue effort. Initially, the entry for life saved/lost is made by the crew, but it is subsequently verified by the RNLI HQ based on the narrative and conditions in order to ensure parity in reporting across the organisation.

Much of the meteorological information recorded is qualitative and based on the experienced coxswain's estimates of conditions. When entering the data for the RoS, they are prompted to select the appropriate conditions from a drop-down, which lists all the appropriate terms. Wind speed and sea state are all recorded as per the terminology on the Beaufort scale, and this allows conversion from qualitative terms to a quantitative value for the mean wind speeds and wave heights associated with the relevant level of the Beaufort scale. The conversion applied is listed at Table 2. As a result of this qualitative approach to meteorological data uncertainties do exist as to the reliability of the data. However, a study by Wheeler (2005), comparing qualitative recording of wind speed in ships logs to measured data, showed estimates to be consistent and reliable with 43 % of all observations correct, and a further 33 % only ± 1 Beaufort Scale category from the true value. Therefore, in the scope of this research, wind observations are deemed suitably robust to be included for further analysis.

Table 2. Conversion matrix for reported terminology in RoS data. All conversions based on Met Office Beaufort Scale.

| Wind speed | | Sea state | | Visibility | |
|---|---|---|---|---|---|
| Reported Term | Converted value [knots] | Reported Term | Converted value (wave height [m]) | Reported term | Converted value Visibility [miles]) |
| Calm | 0 | Glass Calm | 0 | Nil | 0 |
| Light Airs | 2 | Calm | 0.1 | Poor | 2 |
| Light Breeze | 5 | Smooth | 0.2 | Fair | 3.5 |
| Gentle Breeze | 9 | Slight | 0.6 | Good | 5 |
| Moderate Breeze | 13 | Choppy | 2 | Very Good | 7.5 |
| Fresh Breeze | 19 | Rough | 3 | Excellent | 10 |
| Strong Breeze | 24 | Very Rough | 4.75 | | |
| Near Gale | 30 | High | 7 | | |
| Gale | 37 | Very High | 10.75 | | |
| Severe Gale | 44 | Phenomenal | 14 | | |
| Storm | 52 | | | | |
| Violent Storm | 60 | | | | |
| Hurricane | 64 | | | | |

One crucial parameter not recorded in RoS data is sea surface temperature (SST). In order to incorporate this into the dataset, average monthly SSTs were obtained for 10 representative stations around the UK coastline, and each RoS incident was mapped to the nearest SST station. The appropriate representative SST for the incident month was then assigned to the RoS entry, in order to provide some indication of likely SST at the incident. As a result of this averaging approach, the SST is the parameter used for further analysis with the poorest data quality overall.

## 2.2 Methods

In this paper, a simple stepwise log-linear (Poisson) regression model is described and applied to just the LAR incidents within the RoS data. The way RoS data is collected means that you get one entry per lifeboat incident, which may have multiple fatalities or lives saved. The data was therefore separated out into individual entries for individual people. This was achieved by splitting the RoS entry into multiple entries, based on the sum of lives saved and lost as a result of that service. The narrative for each entry was used to attribute the correct lifejacket characteristics to each individual in the incident. The result is that of 2094 RoS entries for services where a life was at risk, the dataset is expanded to reflect the 3119 individuals who were either saved or lost their lives in the 2094 services.

The dependent variable for the model will be the occurrence of a fatality ($Y_i$), binary coded with 1 equal to a loss of life. The model estimates the likelihood of a fatality based on the balance of independent variables, as follows;

$$\exp(Yi) = \alpha + \beta_1\chi_1 + \beta_2\chi_2 + \cdots + \beta_k\chi_k \tag{1}$$

where $\alpha$ is a constant, $\beta$ is a partial regression coefficient and $\chi$ is an explanatory independent variable. The model starts empty and is able to add any variables inside the significance threshold (set at 0.05), and remove any variables outside this threshold through forward selection and backward elimination. Goodness of fit was evaluated at each step using the R-squared value. The variables offered to the model were SST, four dummy binary variables for the four types of activity each RoS entry is classified into (Leisure, Commercial, Person, Other), whether there was physically a person in the water, the swell height, whether service was conducted at night, wind speed at incident, time taken to reach casualty from the RNLI receiving the information, visibility at incident, sea state, and whether the casualty was wearing a lifejacket. The variables were checked for collinearity, and this was found in the casualty category variables (as the sum of the four dummy variables by default has to be equal to 1). Therefore, the commercial category was removed as it was not statistically significant.

Table 3. Poisson regression coefficients and associated P-Values for the likelihood of fatality in life at risk incidents.

| Label | Factor | Measurement | Coef | P-Value |
|---|---|---|---|---|
| | Constant | | -0.100 | |
| $\beta_1$ | Lifejacket Use | 1 if lifejacket used, 0 otherwise | -1.277 | 0.000 |
| $\beta_2$ | Leisure Activity | 1 if a leisure incident, 0 otherwise | -1.234 | 0.000 |
| $\beta_3$ | ‘Other' Activity | 1 if an ‘other’ incident (not leisure, commercial, or people), 0 otherwise. Typical ‘other’ incidents might include flying or motor vehicles. | 0.673 | 0.000 |
| $\beta_4$ | Person In Water | 1 if the casualty had entered the water, 0 otherwise | 0.3368 | 0.000 |
| $\beta_5$ | ‘Person’ Activity | 1 if a ‘person’ activity where no craft involved (such as walking), 0 otherwise | -0.233 | 0.039 |
| $\beta_6$ | Sea Surface Temperature | Temperature in °C (range from 6.65 to 17.75) | -0.0526 | 0.000 |
| $\beta_7$ | Visibility | Distance in miles (range from 0 to 10) | -0.0299 | 0.030 |
| $\beta_8$ | Time to Reach Casualty | Time taken (minutes) to reach casualty from moment RNLI informed of incident | 0.001688 | 0.000 |

## 3. Results

Table 3 reports the results of the log-linear regression, and shows the variables deemed to be statistically significant ($P<0.05$) in influencing the likelihood of a fatality. Lifejacket use had the greatest impact on likelihood of fatality, with a coefficient in excess of -1, significant at 99.9 %. Similarly, leisure activity was associated with a large magnitude (-1.2) reduction in fatalities ($P<0.001$). The category of activity associated with the greatest increase in fatalities is the ‘Other’ category ($P<0.001$). Most (>90 %) of the entries in this category are for other vehicles, either aircraft or motor vehicles, entering the water, and are associated with a high fatality rate. A service involving a person physically in the water, as opposed to in trouble on a boat, also increased the likelihood of a fatal incident ($P<0.05$). Increases in SST are associated with increased survivability ($P<0.001$), as is an increase in visibility ($P<0.05$). Increases in the time taken for the RNLI to reach a casualty are also associated with increased fatality rates among victims ($P<0.001$).

### 3.1 Lifejackets

The wear of lifejackets was seen to have the highest magnitude impact on survivability in life at risk incidents (Table 3). Therefore, more investigation into lifejacket wear was undertaken. Plotting the percentage of survivors wearing lifejackets against the time to rescue shows the impact that a lifejacket has on survivability over time. There is an increase in percentage of survivors rescued wearing lifejackets from 35 % rescued after 10 minutes, compared to 55 % at 60 minutes and ~80 % of survivors rescued after 120 minutes are shown to be wearing lifejackets (Figure 1a). This figure provides a basic predictive capacity for survivability, for example, if 10 people were to get into a LAR situation at sea, on average only two of the individuals would have the ability to survive without the aid of a lifejacket. Therefore, if a rescue asset will take two hours to reach or find a casualty, in order to survive two hours in the water, 80 % of people would require the assistance of a lifejacket. This of course does not account for other factors such as the onset of hypothermia. The overall percentage of incidents involving individuals wearing a lifejacket is 42.4 %, however, among those wearing a lifejacket, 94.1 % survived their incident (Figure 1b), versus 73.1 % survival of people not wearing a lifejacket.

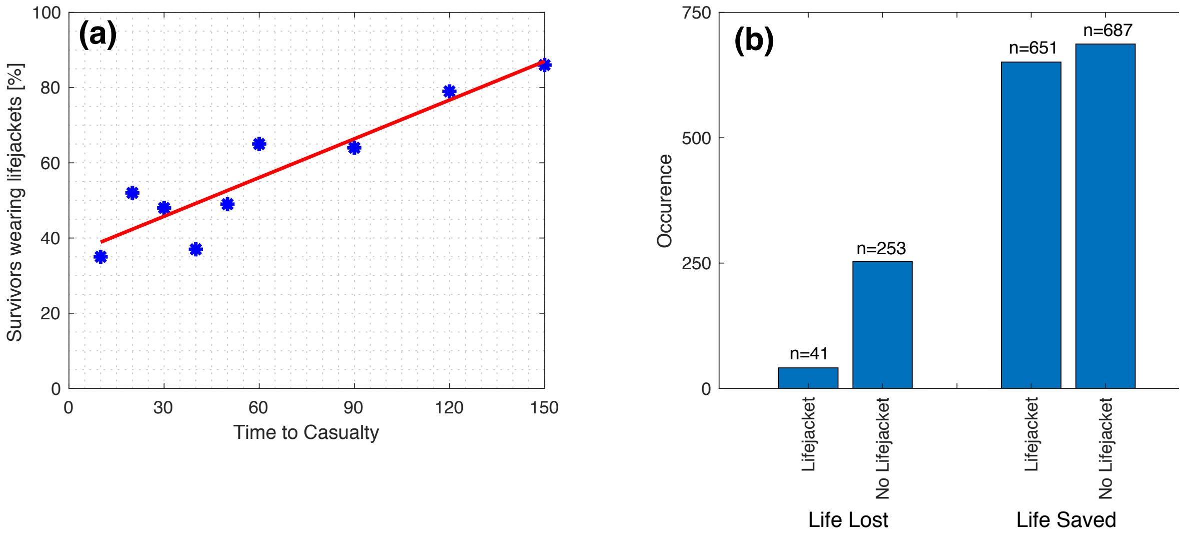


**Figure 1.** The impact of lifejacket wear on survivability during life at risk incidents, including: (a) the percentage of survivors found wearing lifejackets over time to casualty, showing that a greater number of people need to wear lifejackets in order to survive longer during life at risk incidents; and (b) the total split of lifejacket wear among survivors and fatalities.

### 3.2 Seasonality / SST

SST was shown to be a high magnitude factor from the multivariate regression, and further analysis showed there to be statistically significant difference in the mean SST for fatalities and survivors. SST in fatalities was shown to be 1.03 °C cooler ($P<0.000$), with 95 % confidence intervals at 0.78 °C and 1.28 °C. The actual difference is small, and the standard deviations are large (3.21 for survivors and 3.25 for fatalities). Instead of looking at individual SST trends on an individual case-by-case basis, we have subsequently looked at the occurrence of fatalities by month. The eight months between October and May see an above average proportion of LAR incidents when compared to the distribution of all RNLI incidents (Figure 2a), with the largest proportion occurring in the 3 months centered on February. In terms of actual fatalities within those LAR incidents, the five months between November and March see the greatest proportion of fatalities, with proportions in January double that of any other month (Figure 2b). These months incorporate British winter, and therefore reflect lower average SSTs. In terms of fatalities, the casualty type also changes with the seasons (Figure 3). In summer months, the proportion of fatalities in leisure users is seen to increase from 20 % in winter to around 45 %. Conversely, the percentage of commercial fatalities increases from 5% in summer months, to 25 % in winter months.

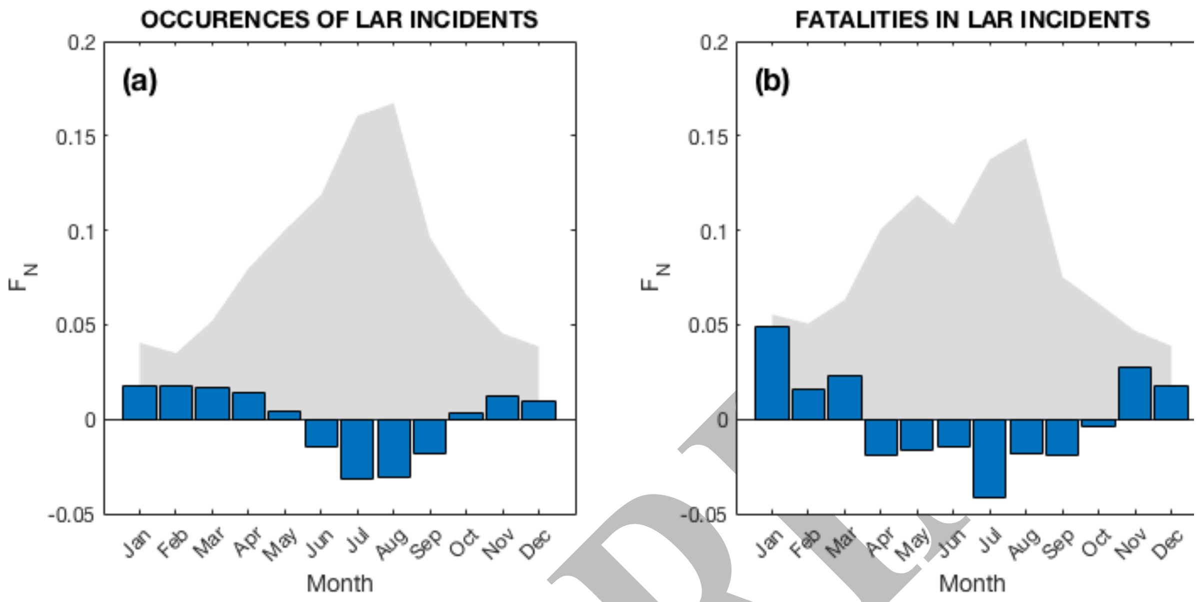


**Figure 2.** Seasonality in incident profile. (a) The spread of all (non-life at risk) incidents throughout the year (grey shaded area) compared against the spread of LAR incidents (bars), with positive bars indicative of greater than average occurrence and negative values indicative of lower than average occurrence. (b) Spread of all life at risk incidents throughout the year (grey area), against the occurrence of fatalities throughout the year (blue bars).

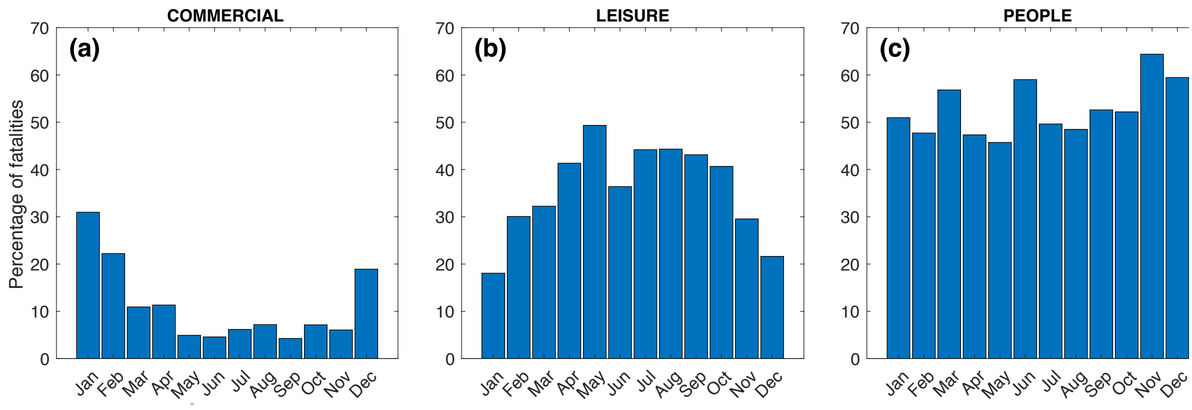


**Figure 3.** Percentage of fatalities per month broken down by casualty category (excluding 'Other' fatalities).

### 3.3 Activity

When considering fatalities during all incidents (not just those deemed life at risk), analysis of activity type can show strong trends in the percentage of fatalities. Multivariate analysis highlighted how of the four broad categories of incident, the 'Other' category (typically motor vehicles and aircraft) showed a strong positive correlation with fatality. That is echoed in Table 4, where incidents are further broken down by activity. Motor vehicle incidents typically result in the most fatalities, with 80 fatalities per 1,000 incidents. Flying also features highly with 60 fatalities per 1,000 incidents. These two activities are atypical of the remainder in the chart, as it is highly unlikely (other than in cases of self-harm or suicide) that the people undertaking these activities ever anticipated coming into contact with the sea or beach. Although these activities have a high fatality rate, their overall occurrence is low, with only 225 motor vehicle and 183 flying incidents over the study period (Table 4). Of the typical coastal activities, scuba diving results in a high level of fatalities (68 per 1,000), as does angling from the shore (63 per 1,000), but again the relative number of incidents is low overall (545 and 384, respectively). These activities both incur more fatalities than incidents involving suicide or self-harm (60 per 1,000), where often the intention is for a fatal event to occur. However, there are many more incidents of this nature. Over the reporting period, there were 4558 suicide or self-harm attempts, of which 275 resulted in a fatality. The suicide and self-harm is actually an under prediction of the true rate, as the RNLI only attributes this category to incidents where the casualty is thought to be alive at the moment the lifeboat is called to assist, else the services are recorded as body recovery operations. Waterside activity is the only other activity that results in fatalities in excess of 50 times per 1,000 incidents, with significant numbers of incidents overall (2050). When the fatality rate is plotted against the percentage of fatalities wearing lifejackets, taken from Table 4, there is a clear trend of lower lifejacket wear in activities that have higher fatality rates (Figure 4). Flying and motor vehicle accidents are omitted, as these are both activities where there was never any intended interaction with the coast and therefore there is no scope for education or prevention. Of the two, the main anomaly is that of flying, which has high fatality rate and high lifejacket wear.

This may be a function of the fact that although lifejackets are generally readily available on aircraft, the impact can be catastrophic and regardless of the preparation taken by casualties prior to impact (such as donning the lifejacket), the impact itself proves fatal. Clearly lifejacket wear is inappropriate for some activities, such as scuba diving or walking, both of which feature low lifejacket wear rates.

The presentation of data in these broad groups of activity still somewhat obscures the trends. It is possible to investigate the type of accident on board vessels (Figure 5), and also for activities involving people on the shore (Figure 6). When the type of incident onboard vessels is investigated, the most severe outcome appears to be a man overboard (Figure 5a). On average, across all vessel incidents, a man overboard typically results in 53 fatalities per 1,000 incidents, however, there is great variation within the class. The highest fatality rate is for a man overboard a commercial fishing vessel, where fatality rates reach 108 per 1,000. Also experiencing a high man overboard fatality rate is Other Marine traffic (78 per 1,000) and Angling from a Boat (70 per 1,000). Motorboating and Sailing fatalities resulting from man overboard incidents are comparatively low (both at 31 per 1,000). Second to Man Overboard events, are those incidents involving fire, explosion, capsize or collision (Figure 5b). On average, these result in fatalities in 28 per 1,000 incidents, however, the Commercial Fishing category is again far higher (73 per 1,000). Second within this category is Angling from a Boat (43 per 1,000), and the remaining categories all register less than 40 fatalities per 1,000 incidents involving fire, explosion, capsize or collision. The third most severe vessel incident category is that of person ill (e.g. heart attack, stroke, etc.) on board (Figure 5c), resulting in 25 fatalities per 1,000 on average. However, within this category there is very little variation between activity types.

For incidents involving non-craft activities (swimming, walking, etc.), falls from cliff are the most severe cause of accidents (Figure 6a), resulting in 93 fatalities per 1,000 incidents. Within this, there is a much higher fatality rate among people that get into trouble angling from shore, where the fatality rate is 190 fatalities per 1,000 incidents. Second is walkers (99), followed by Waterside Activity, Others, and Climbers (83, 73, and 63 per 1,000 respectively). The second most serious type of incident is people ending up in the water, with an average of 75 fatalities per 1,000 incidents. The trend is as per falls from a cliff, whereby Anglers from Rocks are most at risk (126), followed by Walkers (92), Waterside Activity (68), Others (48), and Climbers (37).

Table 4. Fatality rate per 1,000 incidents broken down by RNLI Abbreviated Incident Category, including the percentage of fatalities wearing a lifejacket, and the average number of fatalities per year.

| **Abbreviated Incident Category** | **Total number of incidents** | **Fatalities per 1,000 incidents** | **Percentage of fatalities wearing a lifejacket** | **Average number of fatalities per year** |
|---|---|---|---|---|
| Motor Vehicles | 225 | 80 | 5.6 | 3 |
| Scuba Diving | 545 | 68 | 5.4 | 6 |
| Angling from Shore | 384 | 63 | 4.2 | 4 |
| Suicide and Self Harm | 4558 | 60 | 0.4 | 46 |
| Flying | 183 | 60 | 72.7 | 2 |
| Waterside Activity | 2050 | 51 | 4.8 | 17 |
| Swimming | 1210 | 36 | 2.3 | 7 |
| Climbing | 271 | 30 | 12.5 | 1 |
| Walking | 2914 | 22 | 1.6 | 11 |
| Other Marine Vessels | 1259 | 21 | 15.4 | 4 |
| Commercial Vessels | 3043 | 16 | 30.6 | 8 |
| Small Craft (e.g. kayaking, canoeing) | 5724 | 6 | 16.2 | 6 |
| Angling from a Boat | 3644 | 5 | 50.0 | 3 |
| Motorboating | 5708 | 3 | 26.3 | 3 |
| Sailing | 7451 | 3 | 28.6 | 4 |
| Jumping in to Water | 31 | 0 | 0 | 0 |

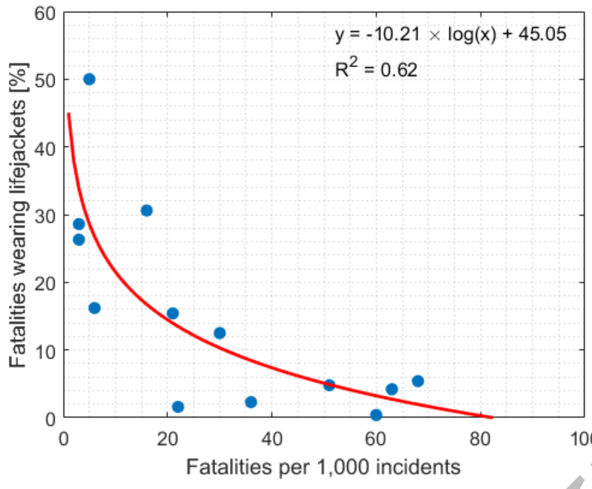


**Figure 4.** The percentage of fatalities wearing lifejackets plotted against the number of fatalities per 1,000 incidents for each activity type (outlined in Table 4). The identified anomalous activities (motor vehicles and aircraft) are omitted.

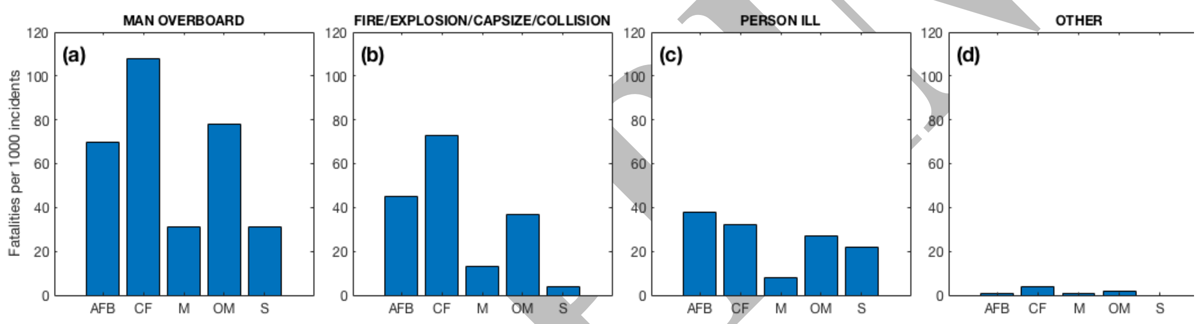


**Figure 5.** Fatality rates among vessel incidents, broken down by incident type: (a) Man overboard; (b) Fire/explosion/capsize/collision; (c) Person ill on board; and (d) other incidents. Type of vessel is also recorded, including Angling from a boat (AFB), Commercial Fishing (CF), Motorboating (M), Other Marine (OM), and Sailing (S).

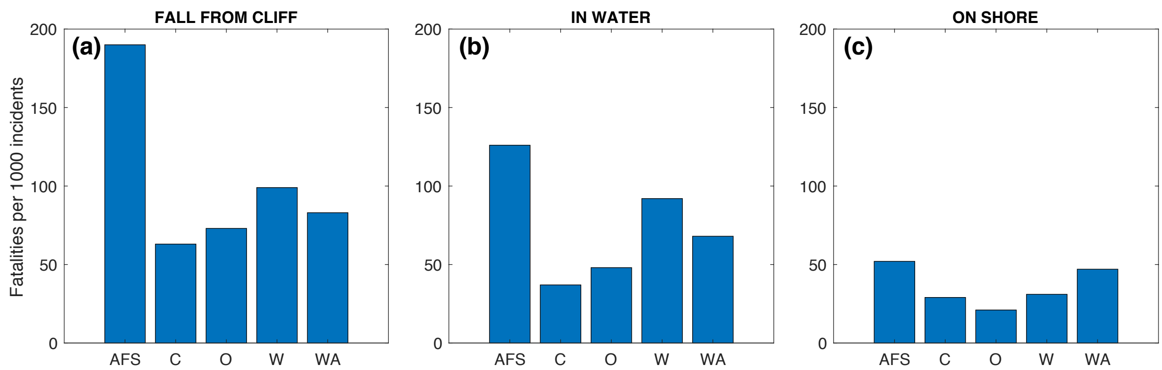


**Figure 6.** Fatality rates among incidents involving people not using vessels or crafts, broken down by incident type: (a) Fall from cliff; (b) Person in water; and (c) Person on shore. Casualty activity is also recorded, including Angling from Shore (AFS), Climbing (C), Other (O), Walking (W), or Waterside Activity (WA).

### 3.4 Time to casualty

The multivariate regression showed that as time to casualty increased, survivability decreases. This again varies by incident, and has been presented in Figure 7. Time to casualty is the time taken from the point at which the RNLI is informed of an incident to the moment they reach the casualty. The RNLI is normally informed of an incident at sea immediately in order to give the crew time to assemble prior to making a decision to launch. Therefore any delay in launching is taken into account by this metric, as it focusses on the point in time at which information was first received. In the highest risk activities, the survivability drops rapidly with time, such as is observed in suicide/self-harm incidents and those involving scuba diving. There are some incidents where survivability stays relatively high for a period, before dropping away, such as incidents where the casualty may conceivably still have some form of craft for flotation (Small Craft, and Fire/Explosion/Capsize/Collision). The lowest initial survivability is for a casualty that has fallen from a cliff, with only 45 % surviving after the first 5 minutes. Conversely, swimmers and small craft users have a near 100 % survivability chance within the initial 5 minutes. Small craft incidents are anomalous among the data, as survivability remains at near 100 % for up to 25 minutes, before dropping off rapidly to around 20 % after 55 minutes.

## 4. Discussion

Maritime activity is notoriously dangerous, with commercial fishing widely regarded as one of the most dangerous professions. Hitherto, there has been no holistic investigation of UK maritime incidents that encompasses recreational boating, commercial activities, and people on the shore that get into trouble in the water or on the coast. In order to provide insight into the causes and factors influencing UK incidents, a log-linear regression was applied to 6 years' worth of RNLI incident data, for incidents where a life was deemed to be at risk.

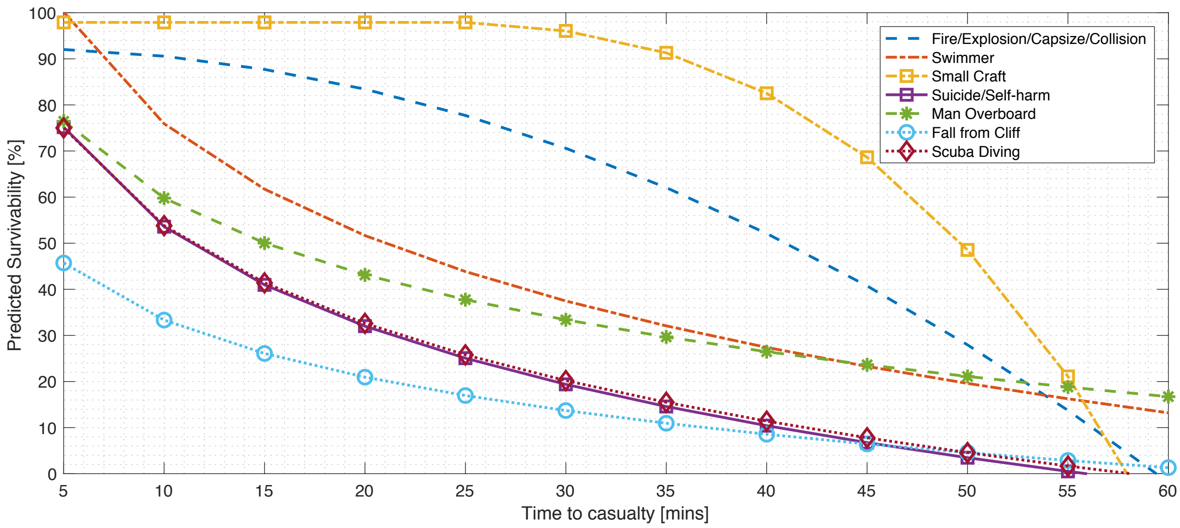


**Figure 7.** Predicted survivability of a Life at Risk incident as a function of the time taken to reach the casualty, calculated as the percentage of lives saved per 5 minute time interval.

## 4.1 Key findings

The wear of lifejackets had the most bearing on the multivariate analysis. The recording of this information has only been undertaken by the RNLI since 2011, and this is what limited the data analysis to just the 2011 – 2016 returns. The overall number of casualties in life at risk incidents wearing lifejackets was found to be 42.2 %. This was slightly higher than other studies: 19.8 % (Viauroux and Gungor, 2016) in recreational boating; and 19.5 % (O'Connor and O'Connor, 2005) in all Australian boating rescues. It is interesting that the rate of wear is slightly higher than other studies as this dataset includes all RNLI incidents, including activities such as walkers falling from cliffs, whom would naturally not be expected to be wearing lifejackets. Lifejacket wear among fatalities was 13.9 %, comparable with other studies citing 15.5 % (MAIB, 2016), but significantly higher than the 5 % quoted for commercial fishing fatalities (O'Connor and O'Connor, 2006). The most significant finding is that in life at risk incidents, 94 % of people who were wearing a lifejacket at the time of the incident survived their experience.

The distribution of life at risk incidents showed a clear signal of seasonality, broadly linked to sea surface temperature. Despite a comparatively low overall number of incidents during the winter, there was a higher than expected rate of life at risk incidents during winter months, and within the distribution of life at risk incidents, there was again a higher proportion of fatalities than expected during winter months. Sea surface temperature and visibility were returned as significant by the regression analysis, whereas wave height and wind speed at incident were not. These are not insignificant as a result of their omissions, it may just be that visibility and sea surface temperature were adequate descriptors for the seasonality trend. Much research has been done on the effects of cold water shock, and the link to death and rapid incapacitation is well documented (Harnett and Bulani, 1982; Tipton, 1989). The reduction in overall incidents reflects a shift in demographic, with less pleasure craft out in cold conditions. More winter incidents are attributable to commercial traffic as the industry doesn’t have a seasonal peak in the same way that leisure uses do. The over-representation of life at risk incidents and fatalities in winter demonstrate that when incidents do occur they are typically more serious. Cold water shock will be one mechanism by which the severity of an incident is increased (Golden *et al*., 1997). Storminess is also increased through the winter months, with large waves more likely to incapacitate someone in the water both through overtopping but also increased skin heat flux and faster onset of hypothermia (Ducharme and Brooks, 1998). Increased wave height also likely to make searching for a casualty harder among the waves. The adverse weather conditions also impact the speed with which a rescue asset such as a lifeboat or search and rescue helicopter can be deployed and make it onto scene to affect a rescue. A study by Siljander *et al*. (2015) demonstrated that in extreme waves, a 33 knot rescue asset was reduced to a maximum speed of just 16 knots, hugely impacted response time over longer distances.

In terms of casualty activity, scuba diving, angling from shore, and suicide/self-harm had the highest fatality rates (aside from motor vehicles entering the water). Investigation of scuba diving accidents has shown that many were avoidable had there been better preparation for the dive, monitoring throughout and improved personal skills, although 27 % of diving fatalities were attributed to non-diving related medical problems (Cumming *et al.*, 2010). One of the most surprising statistics was that of high fatality rates among people fishing from the shore. The high fatality rate among this group is likely a function of the fact that at the onset of the activity, the individuals had no intention of ever entering the water, and were therefore totally unprepared to deal with the situation they found themselves in. This means they are highly unlikely to be wearing a lifejacket, indeed in this study none of the 25 fatalities from angling on shore were wearing a lifejacket. There is an increasing bank of evidence supporting the concept of rogue waves, and this may be one mechanism by which fishermen are swept from the shoreline (Nikolkina and Didenkulova, 2011). Here we postulate that the nature of the sport means fishermen are often looking for the best spot, which can be characterized at times by isolation from others and remote in terms of access. This may subsequently reduce the chances of alarm being raised, and therefore reduces the chance of rescue. Often, these fishermen are operating from rocks, and the nature of the nearshore means that energetic wave action after they fall in may be forcefully pushing them into rocks. It is conceivable that this energetic motion increases the chance of injury and unconsciousness, which could ultimately contribute to drowning and high fatality rates.

Time to casualty is an important factor in survival for some activities. In activities where the casualty likely has a means of buoyancy (e.g. a craft to hold on to), survivability is increased for longer, such as in the small craft and capsize/collision cases. In other activities, prevention is more important, because as soon as the incident takes place the mortality rate is high, such as in people falling from cliffs. Survivability is highest in people that intended to be in the water as part of their activity, such as swimmers. This is likely linked to preparedness for the conditions they encounter (i.e. good swimming ability, appropriate swimwear). Survivability in some cases is inextricably linked to lifejacket wear, such as man overboard. In these cases, survivability remains higher for longer among those people wearing lifejackets.

**4.2 Data reliability**

It is important to acknowledge that the SST parameter used in this study was a monthly average value, taken from the nearest of the 10 representative stations around the UK coastline, and is therefore the least reliable of data sources used. The location of representative stations were chosen in such a way that on average the difference in temperature between neighbouring stations was less than 1 °C (mean difference = 0.79), to ensure good spatial coverage of SST gradients around the coast. Despite the lower accuracy of the SST dataset to other recorded parameters, it is useful in highlighting the difference in conditions between winter and summer, with the overall average temperature at all stations 4.6 °C warmer during the months of May – Oct, compared to Nov – Apr. Although high resolution accurate measurements are required to draw solid conclusions on the effect of SST on fatality, the way SST has been employed here is a useful means of explaining the increase in fatalities during winter months (Figure 2).

Wind speed values used here were also qualitative estimations made by lifeboat coxswains. Although previous studies have shown the qualitative estimation of wind speed by crews to be reliable (Wheeler, 2005), it would be of interest for a future study to evaluate the effectiveness of estimations in a blue light environment such as this. Wind speed values were not deemed significant by the regression model in this study and therefore the effect of any errors in the wind dataset has limited consequence on the findings of the study.

**4.3 Applications**

In the UK, the wear of lifejackets is not legally mandated aboard any vessel (although there is a legal requirement for employers and commercial operators to supply enough lifejackets for crew, employees and passengers). The evidence presented here for the efficacy of lifejacket wear is compelling, and indicates that a behavioral shift towards increased lifejacket wear (whether through legislation or education) would dramatically influence the number of fatalities at sea each year. There is qualitative evidence of this throughout the dataset, for example, of the 23 fatalities involving fishing from shore, 6 narratives describe a casualty being found face down in the water. The wear of a lifejacket would ensure the casualty's head remains out of the water, potentially enhancing the chance of survival. It is important to note here the difference between buoyancy aids and lifejackets, as a buoyancy aid alone would not ensure the casualty's head remains out of the water. Additionally, one narrative reports the lifeboat crew observing the casualty disappear under the water as they approached. A further 7 searches resulted in the lifeboat being unable to locate the casualty. Perhaps, equipped with a lifejacket, this chance of being found may increase as a result of the casualty's ability to stay buoyant, and attract attention using the incorporated light and/or whistle, and in some cases, flares. Unfortunately, the RNLI data does not currently record which device was being worn by the casualty. A number of barriers to lifejacket use have been identified, including the perceived lack of comfort, an overestimation of swimming ability, and a lack of confidence that a lifejacket would be effective in saving life (Quistberg *et al.*, 2014). Statistics such as those presented in this study are an effective means of combatting the perception that a lifejacket is unlikely to preserve life. However, much work is required to overcome some other barriers to use, such as the perceived discomfort associated with wear. One such initiative undertaken by Seafish and the RNLI is to work with fishermen to develop a lifejacket that they felt was fit for purpose. Seafish are a Non-Departmental Public Body set up to raise standards across the seafood industry, and they therefore have a vested interest in promoting and monitoring safety at sea. In their study of a commercial setting (fishing boats), wearers of lifejackets consistently reported that the issue they face with regard to wearing a lifejacket was its suitability for wear during normal working conditions, with some interfering with the job, or being fouled by fish guts (Seafish, 2006).

With regard to temporal risk for different activity types, there is therefore a clear need to focus winter management efforts on commercial traffic, and summer efforts towards leisure users. Professional fishermen are a prime target audience in efforts to reduce the occurrence of fatal incidents during winter (stormier) months. In an interactive study involving fishing skippers taking part in a fishing campaign, despite the occurrence of extreme conditions, at no point did any participant elect to return to the safety of port or cease operations (Morel *et al.*, 2008). Instead, they tried to mitigate risk through a number of strategies, including sailing to another local fishing ground. It is clear that classic safety interventions are not appropriate with this group, and further work is required to ascertain how best to change the culture surround fishing.

People angling from rocks has been demonstrated to be a high risk group. This activity group is a high priority for education and intervention, as the mitigation (wearing a lifejacket) is a comparatively simple fix. One of the issues the RNLI has encountered is a reluctance to engage with safety advice from outsiders. In response, one approach might be to get fishing tackle shop owners on board, as these are often trusted and revered sources of advice for anglers. More complex will be understanding how to intervene or manage scuba diving incidents better, or to reduce the number of coastal suicide and self-harm attempts.

## 5. Conclusions

The findings of this study represent the first comprehensive overview of maritime accidents in the UK, incorporating both commercial and leisure vessels, as well as beach users requiring rescue by lifeboat. Multivariate analysis was used to quantify the influence of various factors on fatality rate during life at risk incidents at sea, based on a record of 2094 RNLI incidents and the outcomes for the 3119 people involved.

The wear of lifejackets was shown to have a significant impact on survivability of incidents, with only 22.7 % of casualties shown to have been wearing lifejackets, but of those, 94.1 % survived their incident. The analysis identified individuals angling from shore to be a particularly high risk group of individuals, with one of the highest rates of fatality. These people are certainly a group that would benefit from lifejacket education, although they will often think there is no risk of entering the water and it is therefore likely going to be challenging to engage them in lifejacket education. There is a clear seasonal signal in the data, which shows there are less incidents overall during winter months, however, there is an over-representation of life at risk incidents during these months. This is likely a combination of lower water temperatures which increases the likelihood of cold water shock, and also higher wave heights and increased storminess, which will accelerate heat loss from the body and reduce the likelihood the casualty can be located for rescue among the waves. A larger proportion of winter incidents were attributable to commercial activities, whereas the summer months were associated with increased leisure incidents.

In terms of management, intervention, and prevention, this research has successfully highlighted target groups and areas for intervention. The most obvious is that of lifejacket intervention for appropriate groups (such as small craft users and boaters). Moving forwards, the increased survivability associated with lifejacket wear is clearly demonstrable, and this finding should be used to underpin drives to make the wear of lifejackets compulsory for activities at sea whereby the intention is not to enter the water. Ultimately, the best approach is to ensure all water-users are prepared for any eventuality, which involves not just the availability of appropriate emergency equipment, but also the mandated wear and use of such equipment.

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## 6. References

Bugeja, L., Cassell, E., Brodie, L.R., and Walter, S.J., 2014. Effectiveness of the 2005 compulsory personal flotation device (PFD) wearing regulations in reducing drowning deaths among recreational boaters in Victoria, Australia. *Injury Prevention*, 20: 387–392.

Cumming, B., Peddie, C., and Watson, J., 2010. A Review of the Nature of Diving in the United Kingdom and of Diving Fatalities (1998-2009). *Recreational Diving Fatalities Workshop Proceedings,* pp 99–118.

Cummings, P., Mueller, B.A., and Quan, L., 2011. Association between wearing a personal floatation device and death by drowning among recreational boaters: a matched cohort analysis of United States Coast Guard data. *Injury Prevention,* 17: 156–159.

Ducharme, M.B., and Brooks, C.J., 1998. The effect of wave motion on dry suit insulation and the responses to cold water immersion. *Aviation, Space, and Environmental Medicine*, 69(10): 957–964.

Gallop, S.L., Woodward, E., Brander, R.W., Pitman, S.J., 2016. Perceptions of rip current myths from the central south coast of England. *Ocean & Coastal Management,* 119: 14–20. DOI: 10.1016/j.ocecoaman.2015.09.010.

Golden, F St C., Tipton, M.J., and Scott, R.C., 1997. Immersion, near-drowning and drowning. *British Journal of Anaesthesia*, 79: 214–225.

Harnett, R.M., and Bulani, M.G., 1982. The involvement of cold water in recreational boating fatalities: causal analysis. *Accident Analysis and Prevention,* 14(2): 147–154.

IMO, International Maritime Organization, 1999. Collection and analysis of casualty statistics of fishing vessels and fishermen. Doc. FSI 7/6/2, 29 January 1999.

Jin, D., Kite-Powell, H.L., Thunberg, E., Solow, A.R., and Talley, W.K., 2002. A model of fishing vessel accident probability. *Journal of Safety Research*, 33: 497–510.

MAIB, Marine Accident Investigation Branch, 2016. Lifejackets: A review. MAIB, Southampton.

Marvasti, A., 2017. Determinants of the risk of accidents in the Gulf of Mexico commercial fisheries. *Ocean and Coastal Management*, 148: 282–287.

Marvasti, A., and Dakhlia, S., 2017. Occupational safety and the shift from common to individual fishing quotas in the Gulf of Mexico. *Southern Economic Journal*, 83(3): 705–720.

Matheson, C., Morrison, S., Murphy, E., Lawrie, T., Ritchie, L., and Bond, C., 2001. The health of fishermen in the catching sector of the fishing industry: a gap analysis. *Occupational Medicine*, 51(5): 305–311.

McGuinness, E., and Utne, I.B., 2016. Identification and analysis of deficiencies in accident reporting mechanisms for fisheries. *Safety Science*, 82: 245–253.

MMO, Marine Management Organisation, 2017. UK Sea Fisheries Statistics 2016, MMO, London.

Morel, G., Amalberti, R., and Chauvin, C., 2008. Articulating the differences between safety and resilience: the decision-making process of professional sea-fishing skippers. *Human Factors*, 50(1): 1–16.

Niclason, B.A., Simonsen, K., and Magnusson, A.K., 2010. Wave forecasts and small-vessel safety: a review of operational warning parameters. *Marine Structures*, 23(1): 1–21.

Nikolkina, I., and Didenkulova, I., 2011. Rogue waves in 2006-2010. *Natural Hazards and Earth Systems Sciences*, 11: 2913–2924. doi:10.5194/nhess-11-2913-2011.

O’Connor, P.J., and O’Connor, N., 2005. Causes and prevention of boating fatalities. *Accident Analysis and Prevention*, 37: 689–698.

O'Connor, P.J., and O'Connor, N., 2006. Work-related maritime fatalities. *Accident Analysis and Prevention*, 38: 737–741.

Pitman, S.J., Gallop, S.L., Haigh, I.D., Masselink, G., and Ranasinghe, R., 2016. Wave breaking patterns control rip current flow regimes and surfzone retention. *Marine Geology*, 382: 176–190.

Quistberg, D.A., Quan, L., Ebel, B.E., Bennett, E.E., and Mueller, B.A., 2014. Barriers to lifejacket use among adult recreational boaters. *Injury Prevention,* doi: 10.1136/injuryprev-2013-040973.

Reilly, M.S.J., 1980. Mortality from occupational accidents to United Kingdom fishermen, 1961–1980. *British Journal of Industrial Medicine,* 42: 806–814.

Rezaee, S., Pelot, R., and Finnis, J., 2016. The effects of extratropical cyclone weather conditions on fishing vessel incidents' severity in Atlantic Canada. *Safety Science*, 85: 33–40.

Roberts, S.E., 2004. Occupational mortality in British commercial fishing 1976-95. *Occupational Environmental Medicine*, 61: 16–23.

Seafish, 2006. Lifejacket and buoyancy aid acceptability trials. Seafish Technology Report SR587, Edinburgh, UK.

Siljander, M., Venäläinen, E., Goerlandt, F., and Pellikka, P., 2015. GIS-based cost distance modelling to support strategic maritime search and rescue planning: A feasibility study. *Applied Geography*, 57: 54–70.

Tipton, M.J., 1989. The initial responses to cold-water immersion in man. *Clinical Science,* 77(6): 581–588.

Viauroux, C., and Gungor, A., 2016. An empirical analysis of life jacket effectiveness in recreational boating. *Risk Analysis*, 36(2): 302–319.

Wheeler, D., 2005. An Examination of the Accuracy and Consistency of Ships' Logbook Weather Observations and Records. *Climatic change*, 73: 97–116.

Wright, M., Ibrahim, F., Ghosh, E., and Shah, N., 2013. Risk Assessment and Performance Measurement Research: Research Report GSB CL2566 R3V3, Greenstreet Berman, Reading, UK.

Wu, Y., Pelot, R.P., and Hilliard, C., 2009. The influence of weather conditions on the relative incident rate of fishing vessels. *Risk Analysis*, 29: 985–999 DOI: 10.1111/j.1539-6924.2009.01217.x

Yip, T.L., Jin, D., and Talley, W.K., 2015. Determinants of injuries in passenger vessel accidents. *Accident Analysis and Prevention*, 82: 112–117.