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Preliminary investigation of economic performance and accidents in the UK fishing fleet

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Executive Summary

- This report presents the findings of a preliminary investigation into the relationship between vessel accidents and the operational and financial performance of vessels in the UK fishing fleet in the period 2008-2016. The analysis uses MMO and Seafish data on operational and financial performance of the UK fleet and MAIB data on fishing vessel accidents.
- The relationship between financial performance and accidents was investigated using statistical analyses and probability modelling. The statistical analyses aimed to identify correlations between the annual rate of accidents and the economic performance of the UK fishing fleet at segment and vessel level. In parallel, two probability models were developed to analyse the effect of specific financial variables on the probability of a vessel having an accident.
- There was a negative correlation between financial performance and rate of accidents in three segments of the UK fishing fleet (demersal trawlers under 18m, vessels using other gears and vessels using passive gears). The rate of accidents was lower in years when average vessel profits in the segment were higher. Scallop dredgers showed the opposite relationship, with higher rates of accidents when average profit was higher.
- The average financial performance of vessels involved in an accident was different from that of vessels not involved in an accident. The sign and magnitude of those differences varied by segment, suggesting that fleet safety is influenced by both operational and financial factors.
- The results of the probability model showed a very small negative relationship between the net profit of vessels and accident probability. Operational factors such as gear type and fishing area had a much larger impact on accident probability than net profit.
- The preliminary findings reported here indicate a relationship between the financial performance of UK fishing vessels and the occurrence of vessel accidents. Furthermore, operational factors appear to play a significant role

in the rate and probability of vessel accidents. Further research on the topic will help refine the preliminary findings presented here.

Introduction

This report addresses the question: is there a relationship between operational and financial performance of vessel businesses and vessel safety in the UK fishing fleet?

Previous investigations of accidents in the UK fishing fleet have highlighted financial performance as one of the factors that influences vessel safety. As the Marine Accident Investigation Branch (MAIB) noted in 2002: "*The MAIB concludes there is a correlation between the economic fortunes of the industry and safety. When the fishing is good and the prices are high, safety improves.*"[1] The existence of a relationship between the financial performance of the fleet and safety statistics is pointed out in other MAIB reports on the fishing industry. Financial pressures can affect safety by leading owners and skippers to operate with fewer crew, reduce spending on/investment in safety and maintenance, or increase working hours and thus fatigue. Such cost cutting measures can make fishing practices more dangerous, contributing to the incidence of vessel accidents[2].

Although financial performance has been named as a factor influencing vessel safety, this relationship had not yet been formally investigated in the UK. This report presents the results of a preliminary investigation into the relationship between vessel safety and financial performance in the UK fishing fleet, in which we investigated at individual vessel level rather than overall fleet level.

The investigation uses UK fishing fleet operational data provided by the Marine Management Organisation (MMO), vessel level financial data provided by Seafish and marine accident data for UK fishing vessels supplied by MAIB.

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[1] MAIB (2002) *Report on the analysis of fishing vessel accident data 1992 to 2000*, MAIB, Southampton, July 2002.

[2] MAIB (2008) *Analysis of UK fishing vessel safety 1992 to 2006,* MAIB, Southampton, November 2008.

Methods

Data

The data on the UK fishing fleet used in the analysis comprises:

- Vessel level operational data provided by the MMO, 2008-2016;
- Vessel level financial data provided by Seafish, 2008-2016;
- Data on marine accidents provided by the MAIB, 1993-2016.

Although MAIB data is available from 1993, a comprehensive time series of economic data for the UK fishing fleet is only available from 2008. Therefore the time period covered by this analysis is 2008-2016.

Caveats to the data

Ships registered to the United Kingdom are required by the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 to report accidents to the MAIB. However, underreporting of accidents is known to occur among owners of fishing vessels[3]. Underreporting is believed to occur particularly for less severe accidents, or accidents which did not involve the Coastguard, as the Coastguard reports all incidents they are involved in to the MAIB. Underreporting of accidents may also be more prevalent in relation to smaller vessels, as larger vessels tend to operate under strict health and safety policies which typically require reporting all accidents.

Seafish financial data are estimated based on fishing revenue data for every active vessel from MMO and actual costs and earnings data collected for a sample of UK

[3] MAIB (2002) *Report on the analysis of fishing vessel accident data 1992 to 2000*, MAIB, Southampton, July 2002.

fishing vessels. Seafish collects sample data every year as part of its annual Fleet Economic Survey. Survey coverage varies between fleet segments[4].

Statistical analyses

Two separate analyses were carried out by Seafish using the MAIB data on accidents in the UK fishing fleet: segment level analysis and vessel level analysis. Both analyses used the same fleet segmentation and marine accident type classification, as described below.

Fleet segmentation

The UK fishing fleet is diverse and comprises a wide variety of vessels which vary in terms of size, main fishing area, primary gear type, and target species, among other factors. These factors can affect a vessel's risk of accident. For the statistical analyses, the UK fishing fleet was divided into seven segments, each grouping vessels based on main gear type, target species and vessel size. The fleet segments used in the analyses are:

- Demersal trawl vessels under 18m;
- Demersal trawl vessels over 18m;
- Nephrops trawl vessels;
- Scallop dredgers;
- Vessels using passive gears;
- Vessels using other gears;
- Low activity vessels.

The criteria used for the segmentation are shown in Appendix 1: Methods.

[4] Seafish annual reports on the Economics of the UK fishing fleet can be found at https://www.seafish.org/article/industry-economics

Marine accident types

The following types of accidents are analysed separately:

- Loss of control casualties (affecting the vessel);
- Other marine casualties (any marine casualty that is not a loss of control event, affecting the vessel);
- Occupational accidents (affecting workers).

For full definitions of each type of accident, its degree of severity and the rationale for its classification in the analysis, see Appendix 1: Methods.

For these analyses, the accident type is assigned based on the first accident type recorded in the MAIB dataset. In cases where the accident consisted of a chain of events - for example a loss of control followed by another marine casualty - only the first event type is used in the analyses.

These analyses cover all reported accidents involving fishing vessels from 2008 to 2016, regardless of the outcome (i.e. people injured, lives lost or vessels lost).

Segment level analyses

This analysis searched for correlations between the annual rate of accidents and the economic performance of UK fishing fleet segments. Vessels were assigned to a fleet segment each year based on the main gear type, target species and vessel size for that year.

The analysis used the annual accident rate - the number of accidents per thousand days at sea - for each accident type and fleet segment. As the number of vessels in the UK fishing fleet has decreased from 2008 to 2016, the total number of accidents was deemed an unreliable indicator of trends in safety.

The annual accident rate for each fleet segment was compared to a series of economic indicators. These indicators were averages per vessel within each fleet segment and include days at sea, operating profit, operating profit per kilowatt day at sea (kWdas)[5] and, for vessels using passive gears, total turnover[6].

A linear correlation analysis was conducted for each pair of time series (accident rates and economic indicators 2008-2016), per fleet segment, accident type and economic indicator. Each correlation analysis was described in terms of its statistical significance and strength of relationship. The statistical significance of the relationship is indicated by its p-value: a p-value under 0.05 indicates a statistically significant relationship between the two variables. The strength of the relationship was assessed using its R-squared value: the value of R-squared indicates the amount of variation on accident rates explained by the financial variable.

Low activity vessels were not included in this analysis. Economic data for low activity vessels is not as robust as that for active vessels, as low activity vessels include many part-time vessel owners who also run non-fishing businesses, for which Seafish does not hold economic data.

To remove the effects of monetary inflation, all financial figures are adjusted to 2017 equivalent values using the HMS Treasury deflator.

Vessel level analyses

For each fleet segment we compared average operational and financial performance of vessels involved in an accident at any point during the period 2008-2016, to the operational and financial performance of vessels not involved in an accident during this period. For the whole of the analysis period (2008-2016), accident vessels were assigned to the segment to which they belonged in the year of their accident.

[5] Using operating profit per kWdas rather than day at sea reduces the bias created by differences in engine size within vessels in the same segment.

[6] In small scale fishing businesses (such as vessels in the segment “using passive gears”) wages tend to be much more loosely defined than in larger businesses. In addition, owners of smaller scale vessels may regard operating profit as wages. Hence for these vessels total turnover can be considered a better indicator of vessel profit.

Operational and financial indicators compared in the analysis include annual turnover (sum of fishing and non-fishing income), total operational costs and operating profit per vessel, as well as turnover, costs and operating profit per unit of effort (kWdas) for each vessel. Low activity vessels are not included in this analysis. All financial figures were adjusted to 2017 equivalence.

Probability modelling

In parallel with the Seafish statistical analyses, Lina-Lotta Lahdenkauppi, student at the School of Economics of the University of Edinburgh investigated the relationship between economic performance and vessel accidents in the UK fishing fleet as part of a dissertation research project[7]. The dissertation was supervised by Serguei Plekhanov.

Two probability models were developed to estimate the effect of changes in specific financial variables on the probability of a vessel having an accident.

Fleet segmentation

The probability models used fleet segmentation based on vessel length:

- Vessels under 15m;
- Vessels 15-24m;
- Vessels over 24m.

[7] Fishing Vessels' Economic Performance and Accident Likelihood: Is there a link? By Lina-Lotta Lahdenkauppi. The University of Edinburgh, 2018.

These length groups were selected based on the different legal safety requirements[8] and regulations for vessels of different lengths. All gear types were included together per length group.

Marine accidents

The probability models did not differentiate between accident types. Any type of event (marine casualty or occupational accident, as defined in Appendix 1) was regarded as an accident. Similar to the statistical analyses, the probability models used only the first accident type recorded in the MAIB dataset and included all accidents regardless of the outcome.

Probability models

Both probability models assessed one primary financial variable in addition to a combination of operational variables, and analysed the effect of changes in these variables on accident probability.

In the first model the main financial variable of interest was annual net profit of fishing vessels. In this model a higher net profit was hypothesised to lower accident probability.

In the second model the main financial variable of interest was monthly value of landings per unit of effort (VPUE), with effort measured as kWdas. The model analysed the effect of VPUE in the previous month on accident probability in the next month (i.e. VPUE in January and accident probability in February). Higher recent VPUE was expected to decrease a vessel’s accident probability.

Both models also took into account the possible effect of changes in operational factors, such as vessel age, days at sea, main fishing gear used (by number of days at sea), main fishing area (by number of days at sea) and year, on accident probability. Accident probability was expected to increase with vessel age and days

[8] Maritime and Coastguard Agency (MCA) (2018) Fishing vessels: classification, registration and inspection. Available at: https://www.gov.uk/guidance/fishing-vessel-classification-registration-and-inspection

at sea. In addition, the second probability model took into account changes to accident probability based on the vessel's accident record (number of accidents in previous years).

The full methodology used for the probability modelling can be found in Appendix 2: Probability modelling.

Overview of the UK fishing fleet 2008-2016

There were 4,637 active vessels (fishing for at least one day) in the UK fishing fleet in 2016. The number of active vessels decreased by 259 between 2008 and 2016[9].

In the period 2008-2016 there were between 147 and 292 fishing vessel accidents per year. The last three years (2014 to 2016) had the lowest numbers of accidents recorded in the period analysed. The majority of accidents recorded were marine casualties.

Figure 1: Number of active vessels and number of accidents by type in the UK fishing fleet, 2008-2016 (source: Seafish, MAIB)

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[9] Seafish Fleet Economic Performance Dataset. Available at: https://www.seafish.org/article/industry-economics

Findings

Statistical analysis

Segment level

All combinations of fleet segments and accident types were investigated for correlations between financial performance and accident rates. Only those combinations of fleet segment and accident type showing a statistically significant correlation between accident rates and financial performance are presented in this section.

There were statistically significant correlations between average annual financial performance and accident rates for four fleet segments: scallop dredgers, vessels using other gears, vessels using passive gears and demersal trawlers under 18m. Scallop dredgers, vessels using other gears and demersal trawlers under 18m showed a statistically significant correlation between average annual operating profit per vessel in the segment and their rate of marine casualties. Vessels using passive gears showed a statistically significant correlation between average annual turnover per vessel and their rate of occupational accidents.

With the exception of scallop dredgers, all of these correlations were negative, with years of higher average operating profits or turnover per vessel associated with lower accident rates. This was the case for demersal trawlers under 18m, vessels using other gears and vessels using passive gears (Figures 3 to 6). For scallop dredgers, however, years of higher average profits per vessel corresponded with years of higher rates of marine casualties (Figures 1 and 2).

The correlation between average annual financial performance and accident rates was not statistically significant in two fleet segments: demersal trawlers over 18m and Nephrops trawl vessels.

The plots below show the four fleet segments which were found to have a statistically significant correlation between accident rate and financial performance.

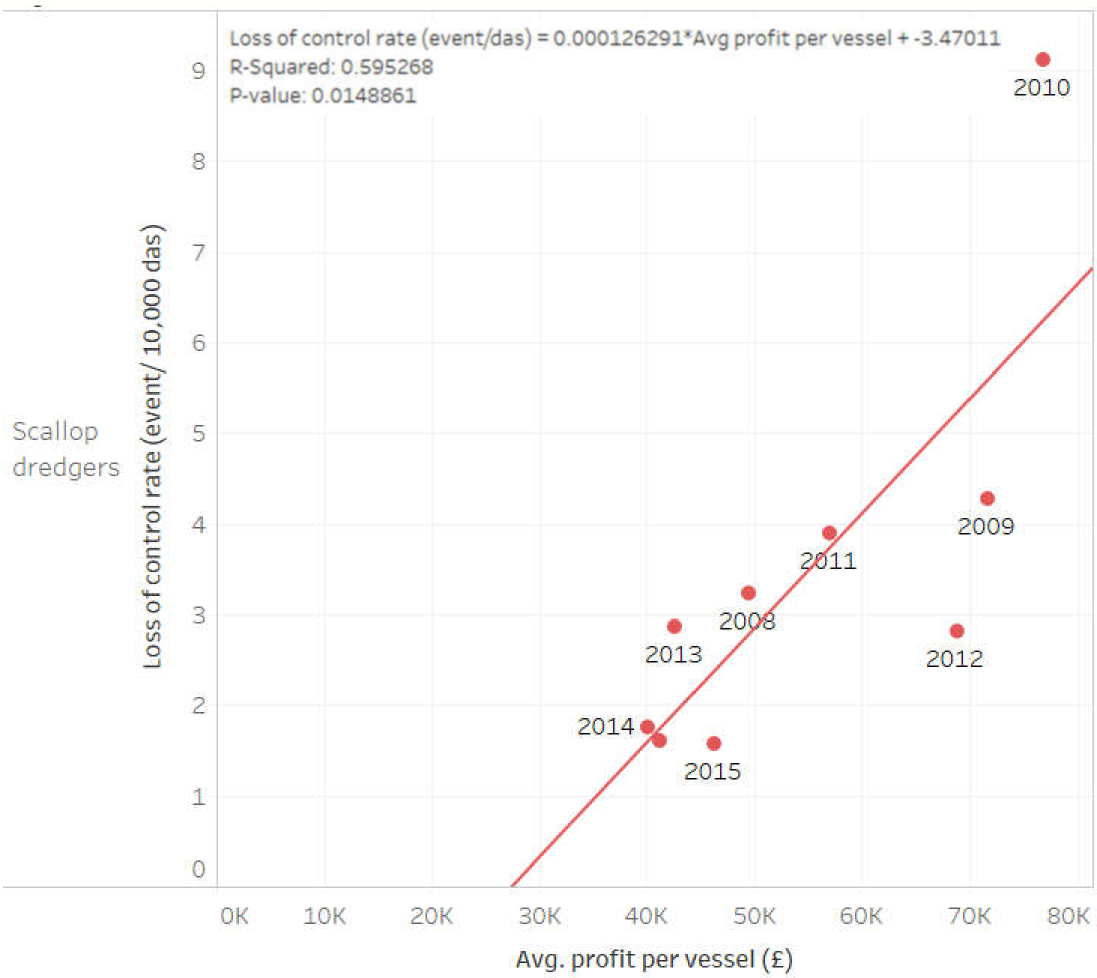

Figure 1: Correlation between average annual operating profit per vessel and annual loss of control casualty rate – scallop dredgers (source: Seafish, MAIB) .

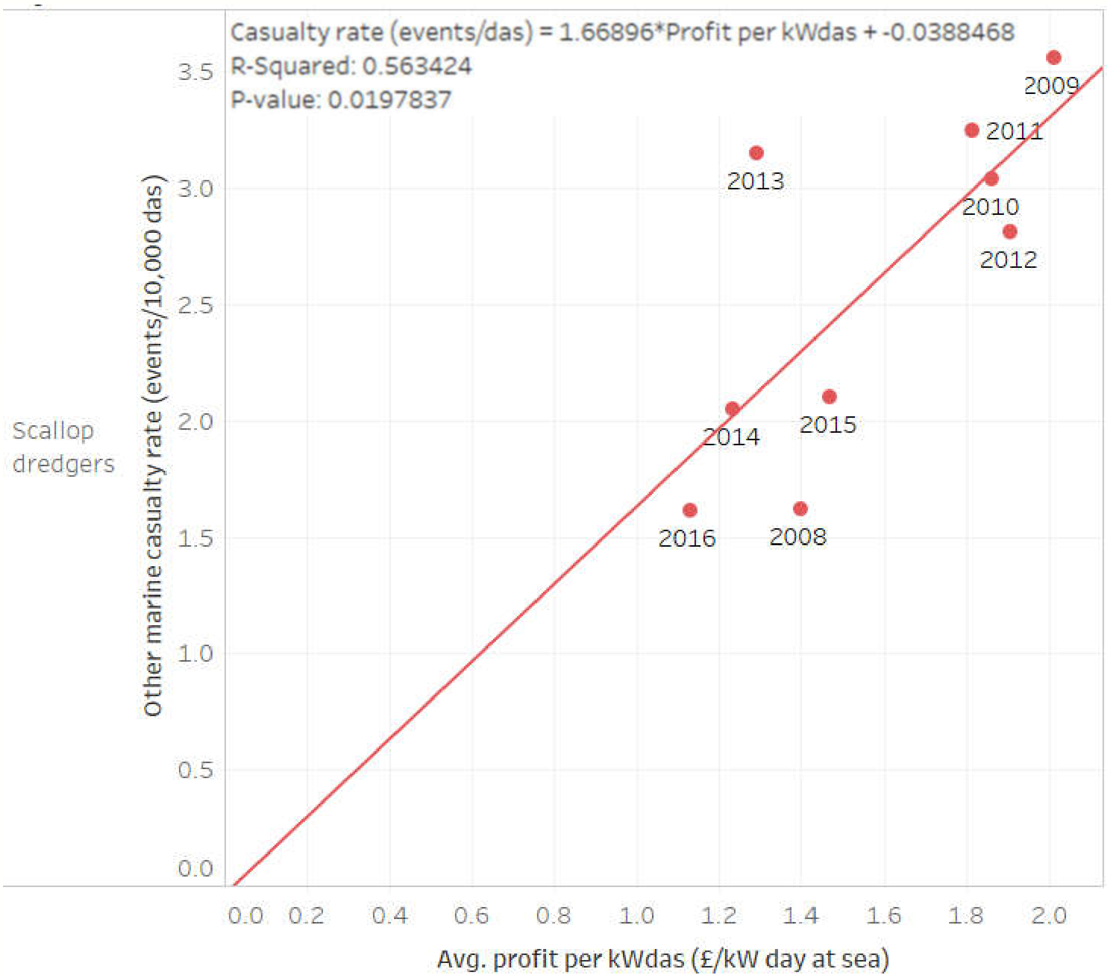

Figure 2: Correlation between average annual operating profit per kWdas per vessel and annual other casualties rate – scallop dredgers (source: Seafish, MAIB)

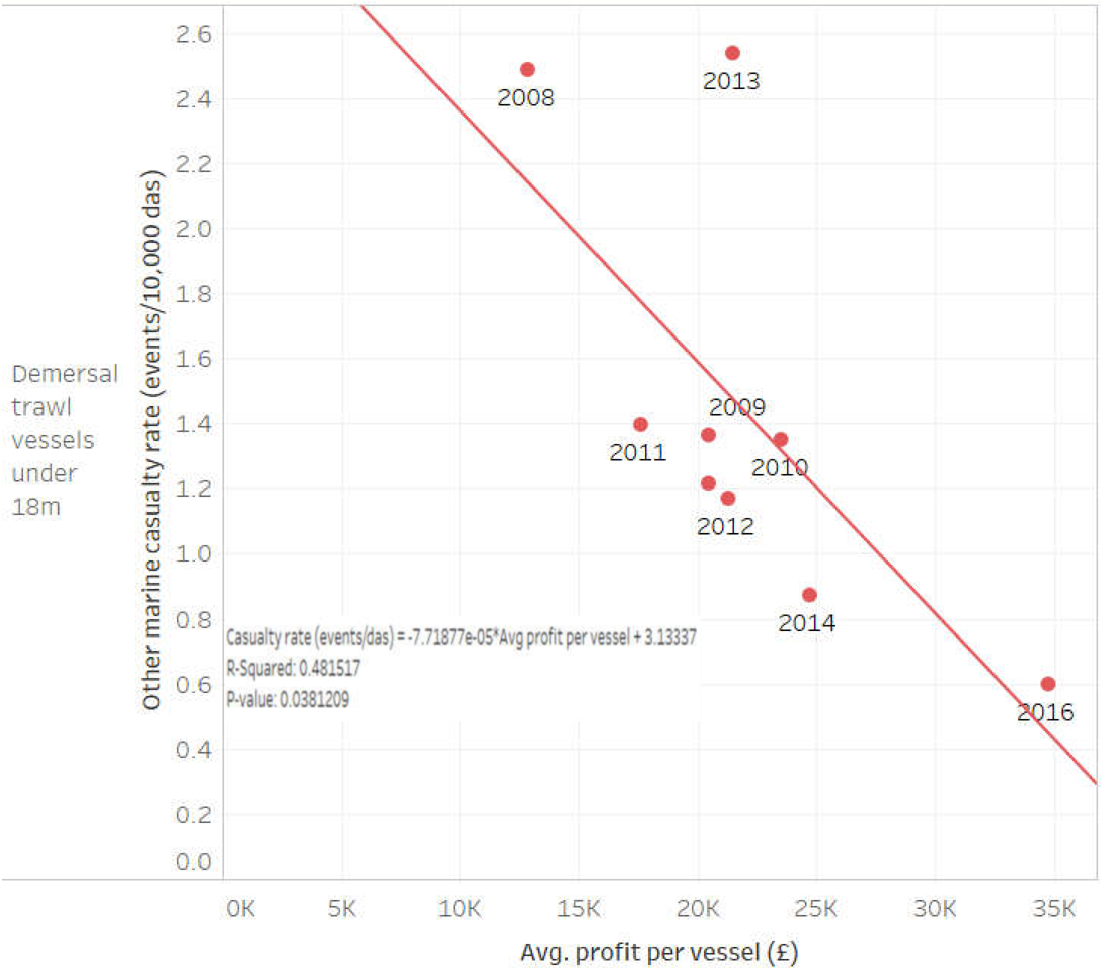

Figure 3: Correlation between average annual operating profit per vessel and annual other casualty rate – demersal trawlers under 18m (source: Seafish, MAIB)

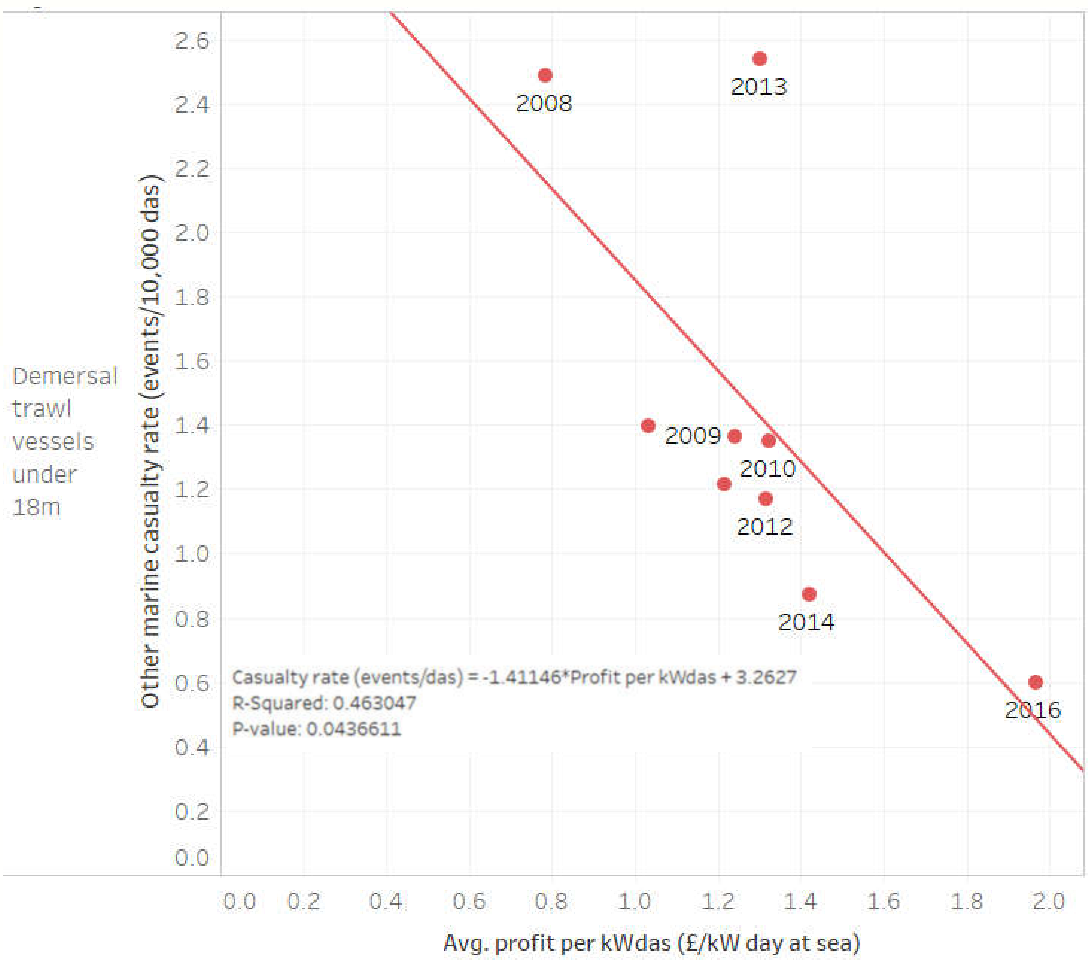

Figure 4: Correlation between average annual operating profit per kWdas per vessel and annual other casualty rate – demersal trawlers under 18m (source: Seafish, MAIB)

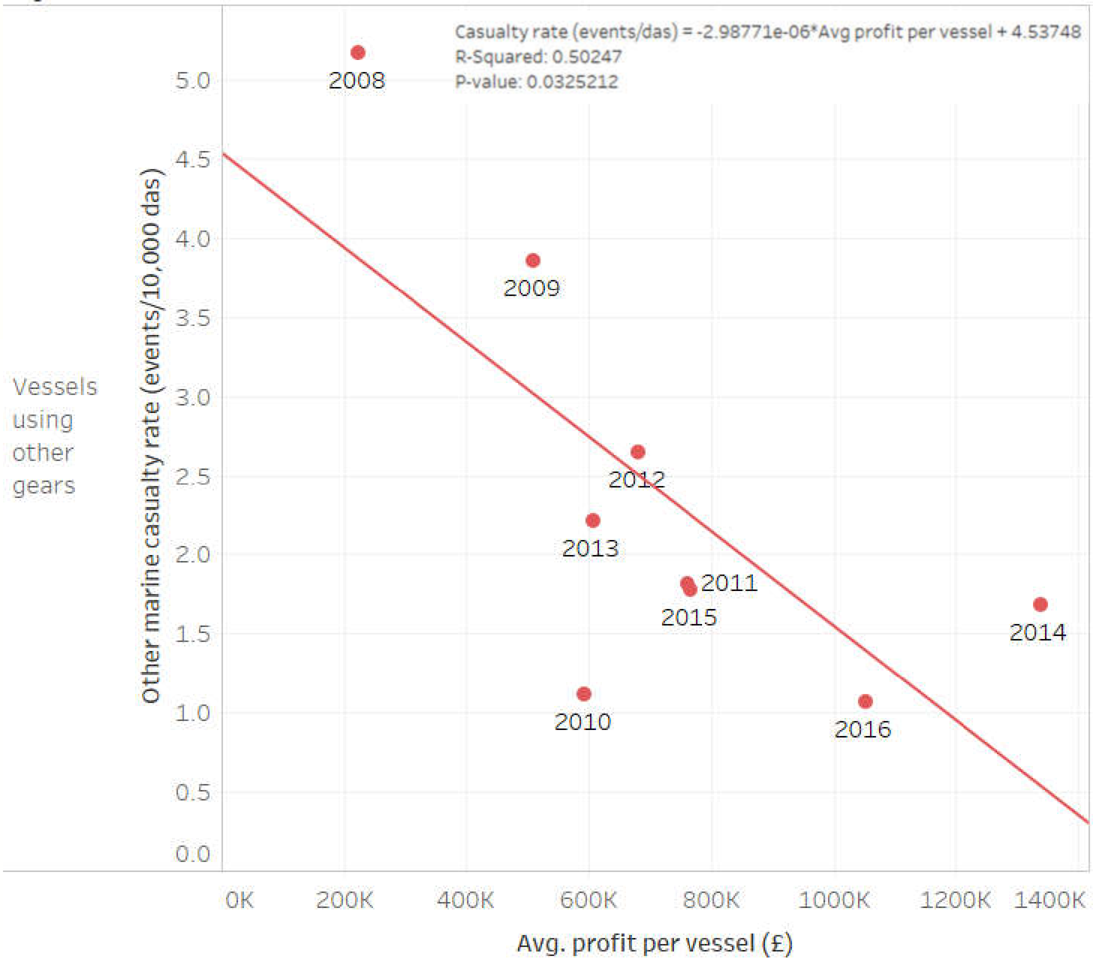

Figure 5: Correlation between average annual operating profit per vessel and annual other casualty rate – vessels using other gears (source: Seafish, MAIB)

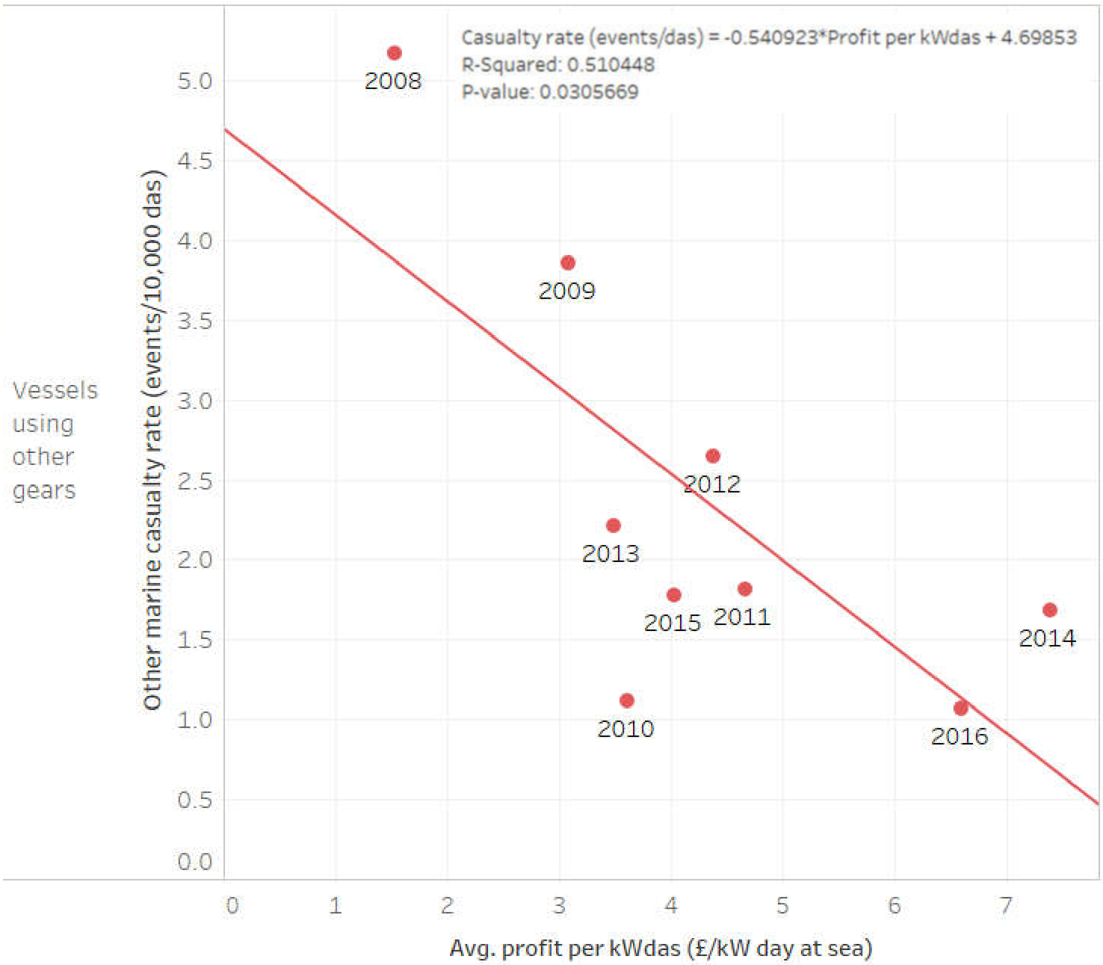

Figure 6: Correlation between average annual operating profit per kWdas per vessel and annual other casualty rate – vessels using other gears (source: Seafish, MAIB)

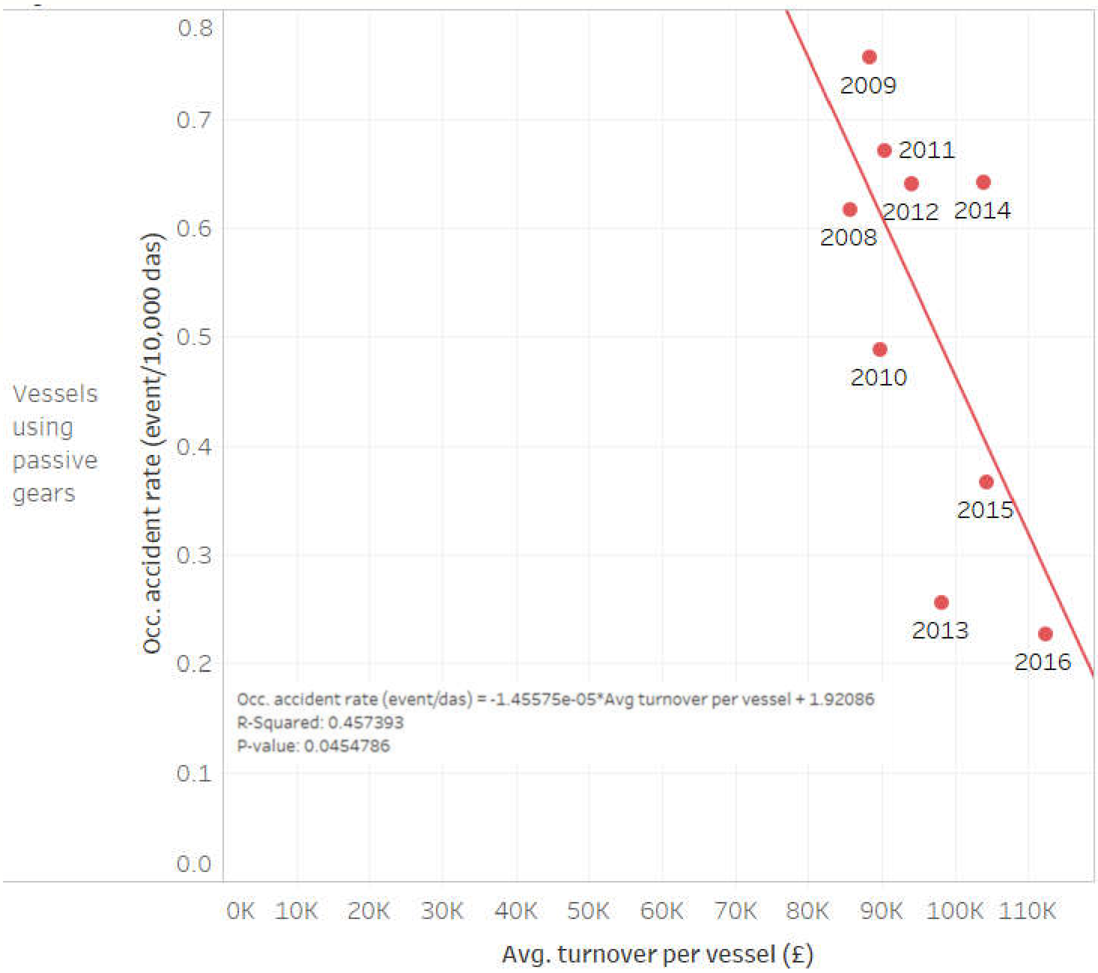

Figure 7: Correlation between average annual turnover per vessel and rate of occupational accidents – vessels using passive gears (source: Seafish, MAIB)

Vessel level

The number of vessels that were involved in each type of accident at some point during the period 2008-2016 is shown in Figure 8 for each fleet segment. Demersal trawl vessels under 18m and vessels using passive gears showed the highest proportion of vessels not reporting any type of accident from 2008 to 2016.

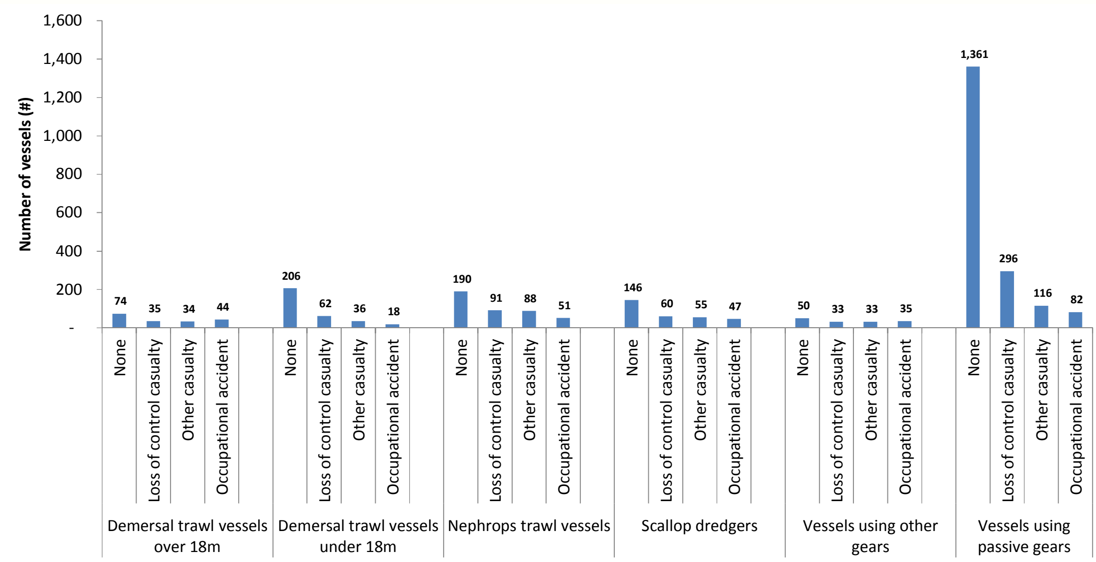

Figure 8: Numbers of vessels per fleet segment and accident type, 2008 to 2016 (source: Seafish, MAIB)

For scallop dredgers and vessels using passive gears, vessels reporting any type of accident from 2008 to 2016 were, on average, larger in size than vessels not involved in an accident. Nephrops vessels involved in an occupational accident were also an average larger than Nephrops vessels involved in a marine casualty or vessels that did not report an accident (Figure 9).

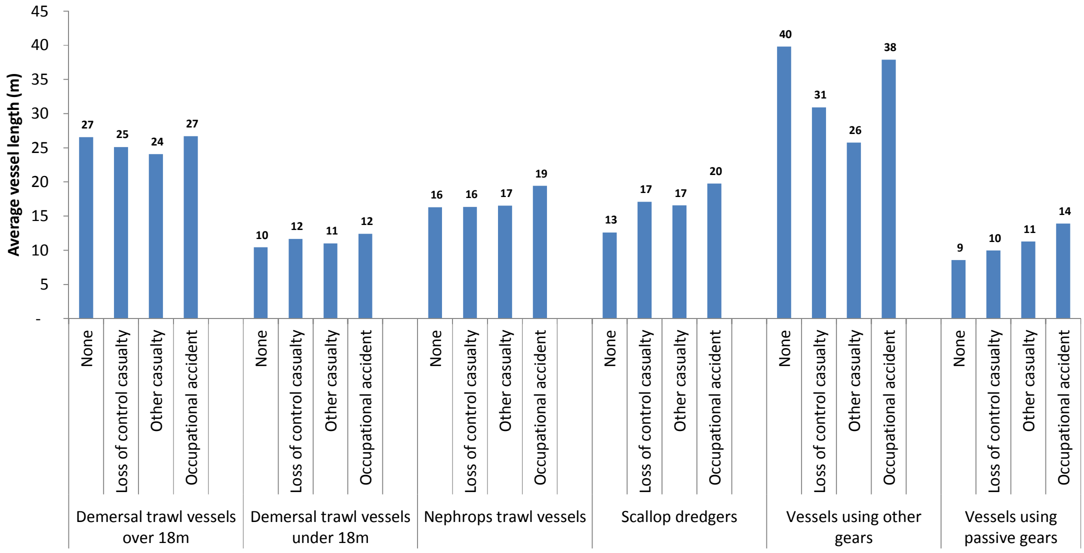

Figure 9: Comparison of average vessel length by fleet segments by accident type, 2008-2016 (source: Seafish, MAIB)

In most fleet segments, vessels involved in an occupational accident had higher levels of activity (days at sea) than other vessels in their respective segments (Figure 10). For scallop dredgers and vessels using other gears, vessels involved in any type of accident showed higher levels of days at sea than vessels not involved in an accident, suggesting that the longer a vessel is at sea, the more likely it is to have an accident.

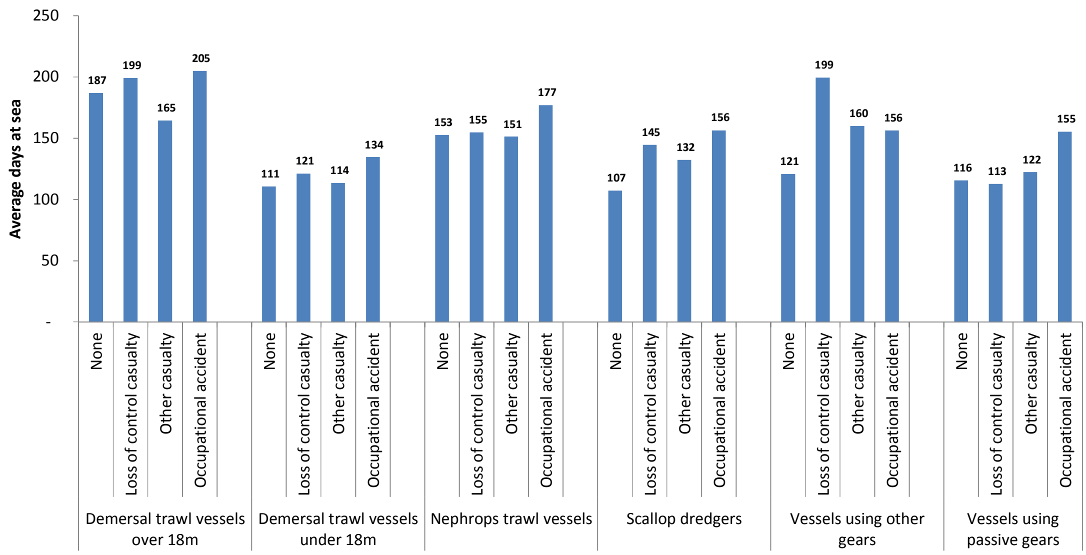

Figure 10: Comparison of average days at sea across fleet segments by accident type, 2008-2016 (source: Seafish, MAIB)

Average annual turnover per vessel, average annual operating costs per vessel and average annual operating profit per vessel were evaluated.

There were differences in average annual performance within all fleet segments in terms of average annual turnover, costs and profit between vessels involved in an accident and those that were not. In terms of average performance per kWdas different patterns arose among fleet segments.

Demersal trawl vessels under 18m and vessels using passive gears

In the segments demersal trawl vessels under 18m and vessels using passive gears, vessels involved in any type of accident were on average larger (as seen in Figure 9) and had higher average turnover, costs and profit per kWdas than vessels not involved in an accident. This pattern was particularly apparent in vessels using passive gears, where average profit per kWdas was £1.4/kWdas for vessels not involved in an accident and £2.2/kWdas for vessels involved in an occupational accident (Figures 11 and 12).

Nephrops trawl vessels

Nephrops trawl vessels involved in an accident showed on average slightly higher turnover and costs per kWdas. Conversely, their average profit per kWdas was very similar to Nephrops vessels not involved in an accident (average profit ranged between £0.9/kWdas and £1.1/kWdas) (Figure 13).

Demersal trawl vessels over 18m

Demersal trawl vessels over 18m involved in any type of accident showed slightly lower values of average turnover, costs and profit per kWdas than vessels not involved in one. Vessels in this segment which were involved in a marine casualty had an average profit of £1.0/kWdas, while vessels not involved in any accident event had an average profit of £1.3/kWdas (Figure 14).

Scallop dredgers

Scallop dredgers involved in any type of accident were found to have lower turnover, costs and profit per kWdas on average compared to vessels not involved in an accident. Vessels in this segment that were involved in any type of casualty had an average profit of £1.4/kWdas, while vessels not involved in any event had an average profit of £1.6/kWdas (Figure 15).

Vessels using other gears

A similar pattern was observed in vessels using other gears. Vessels in this segment that were involved in any type of accident were shown to have lower turnover, costs and profit per kWdas, on average, compared to vessels not involved in an accident. The average profit for vessels in this segment involved in a loss of control casualty was £1.9/kWdas compared to £6.1/kWdas for vessels not involved in any event (Figure 16).

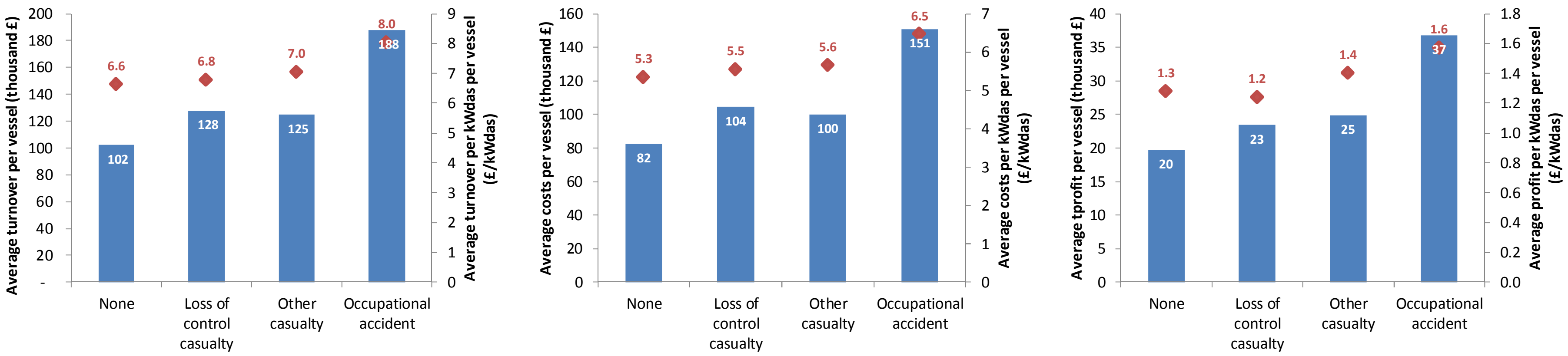

Figure 11: Comparison of average 2008-16 financial performance (total and per day at sea) per accident type in demersal trawlers under 18m (source: Seafish, MAIB)

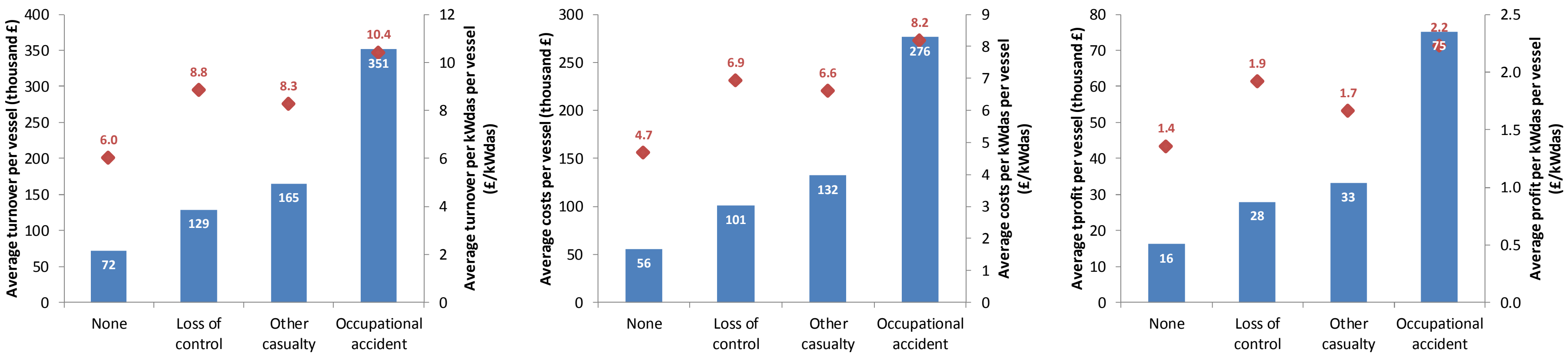

Figure 12: Comparison of average 2008-16 financial performance (total and per day at sea) per accident type in vessels suing passive gears (source: Seafish, MAIB)

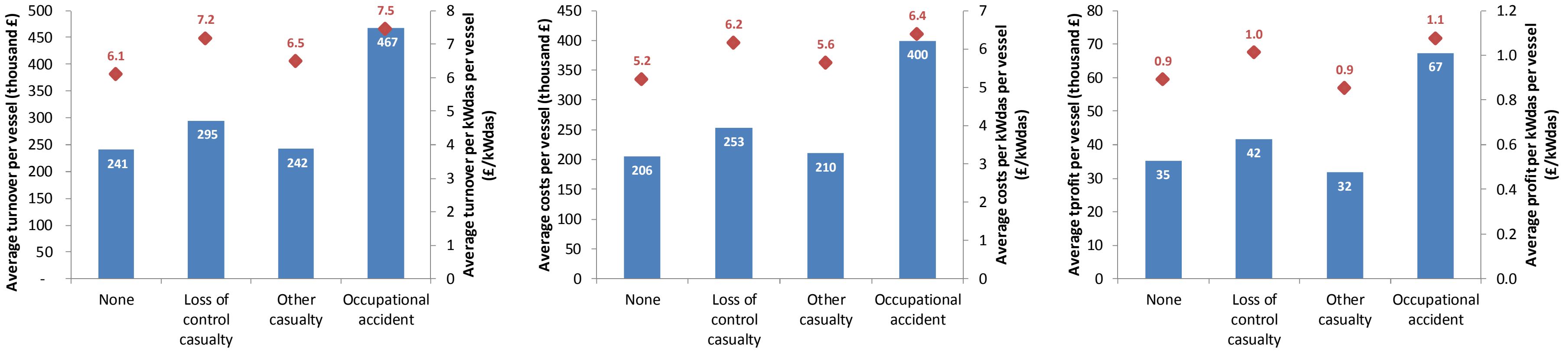

Figure 13: Comparison of average 2008-16 financial performance (total and per day at sea) per accident type in Nephrops vessels (source: Seafish, MAIB)

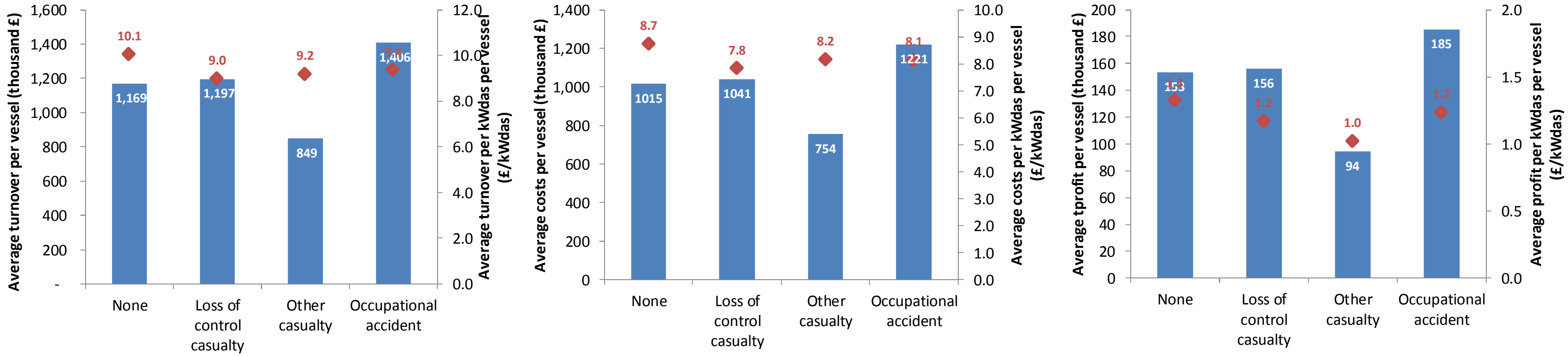

Figure 14: Comparison of average 2008-16 financial performance (total and per day at sea) per accident type in demersal trawlers over 18m (source: Seafish, MAIB)

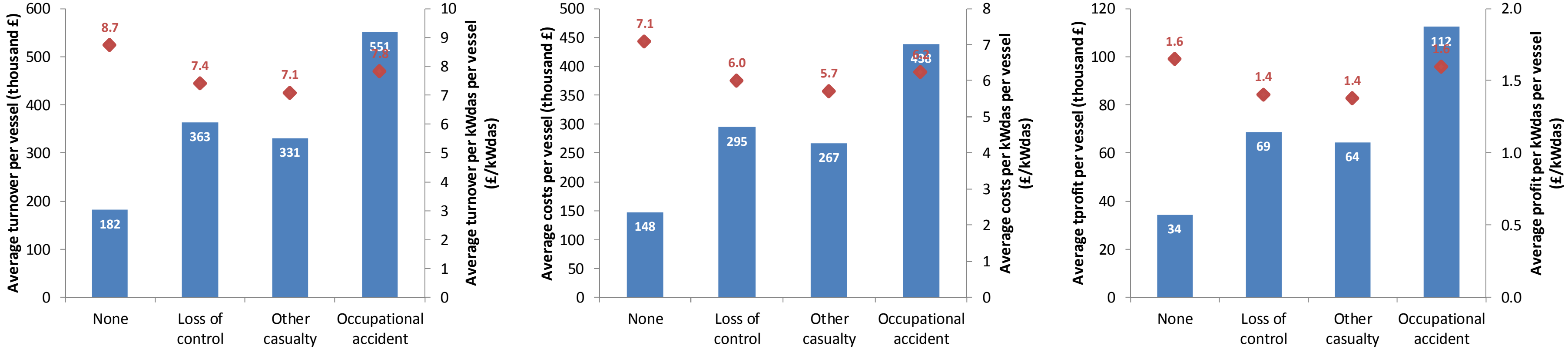

Figure 15: Comparison of average 2008-16 financial performance (total and per day at sea) per accident type in scallop dredgers (source: Seafish, MAIB)

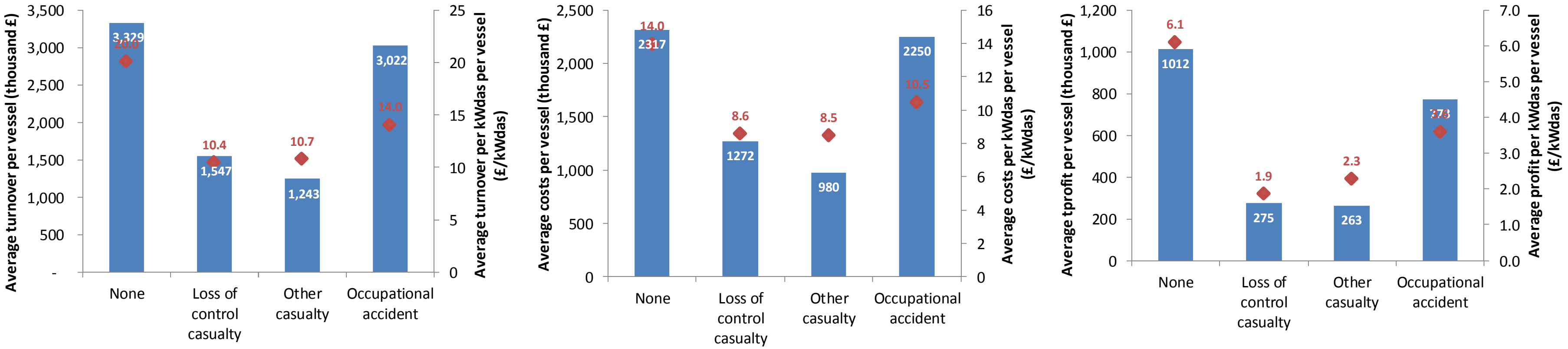

Figure 16: Comparison of average 2008-16 financial performance (total and per day at sea) per accident type in vessels using other gears (source: Seafish, MAIB)

Probability modelling

Model 1: net profit

The first probability model analyses the effect of changes in net profit on accident probability.

The results from the model showed a statistically significant, albeit extremely weak, relationship between net profit and accident probability in 15-24m vessels and over 24m vessels. For vessels 15-24m in length, an increase of £1,000 in net profit decreased accident probability by 0.000023 percentage points (pp). In over 24m vessels the magnitude of this relationship was even smaller.

According to the model, operational factors like main gear type and main area of fishing had a greater effect on accident probability than net profit. Within the 15-24m length group, vessels using pots and traps and beam trawlers had an accident probability 23pp and 14pp higher, respectively, than fixed/drift netters. Furthermore, for 15-24m vessels, accident probability was 36pp higher in area 7FG (Bristol Channel and Celtic Sea) than in area 4 (North Sea).

Model 2: VPUE

The second model analysed the effect of monthly VPUE on accident probability. The model considered the effect of VPUE in a given month on accident probability in the following month.

The model results showed a statistically significant relationship between VPUE and accident probability in 15-24m vessels. The effect was small: an increase in VPUE of £1/kWdas in a given month resulted in an accident probability 0.02pp lower the following month.

For 15-24m vessels the model also showed a statistically significant, albeit weak, relationship between previous accidents and accident probability. A vessel involved in two or more accidents in the past had a higher accident probability by 0.6pp. Having been involved in one accident in the past did not have a statistically significant effect on accident probability.

The full results and tables from the probability models can be found in Appendix 2: Probability model.

Discussion

Segment level analysis

The analysis at fleet segment level found a statistically significant correlation between average annual financial performance and accident rates in four fleet segments: scallop dredgers, vessels using other gears, vessels using passive gears and demersal trawlers under 18m in length. In demersal trawlers under 18m, vessels using other gears and vessels using passive gears years of higher average operating profits per vessel correlated with years of lower accident rates. These relationships match the statements previously made by MAIB (see Section 1: Introduction) that safety improves when the fishing industry has good financial performance which allow expenditure on safety and maintenance, and hiring enough crew. Therefore, by monitoring the financial health of the fishing industry, regulators and stakeholders can identify particular segments of the fleet which could be at a particular risk of higher accident rates as a result of poor financial prospects. Decreasing weight of landings or prices; or increasing fishing costs (fuel, gear) can be indicators of potential deterioration of the financial prospects of fishing vessels, with possible implications on vessel and fisher's safety.

Scallop dredgers on the other hand exhibited a positive relationship between operating profits and accident rates, whereby years of higher average profits per vessel corresponded with years of higher rates of marine casualties. The reasons for this apparent reversal of the expected relationship are unclear and further research is needed to identify them. The segment "scallop dredgers" comprises vessels with a range of lengths and engine sizes operating in different areas around the UK. It should be noted that in some fishing grounds around the UK there are regulations on scallop dredging based on vessel length, such as the Western Waters effort cap for vessels over 15m length[10], that may result in significant operational differences

[10] Marine Management Organisation (2018) Manage your fishing effort: Western Waters crabs and scallops. Available at: https://www.gov.uk/guidance/manage-your-fishing-effort-western-waters-crabs

between dredgers of different length groups in these areas. Breaking down the scallop dredger segment into smaller sub segments based on length or main fishing area may help explain the trend observed in this segment.

In all four segments listed above the value of R-squared in segment analyses was between 0.46-0.60, indicating that the financial variable explained between 46% and 60% of the variation in accident rates in the segment. Hence the financial situation of the fleet, although an important one, is not the only factor that affects fishing vessel safety, as could be expected. This finding also matches MAIB studies on fishing vessel safety, which acknowledge the effect on safety of elements such as operational factors (fishing effort, area of fishing, age of vessel) or the weather[11].

Vessel level analysis

In most fleet segments, vessels involved in an accident showed differences in average operational and financial performance when compared to vessels never involved in an accident. The sign (positive or negative) and magnitude of these differences varied between segments.

In demersal trawl vessels under 18m and vessels using passive gears, vessels involved in any type of accident were on average larger and show higher average values of performance indicators per kWdas than vessels not involved in an accident. Larger vessels in these segments could have a higher probability of being involved in an accident than smaller vessels simply because they have the capacity to spend more time at sea. However these results may be partly influenced by a likely underreporting of events in smaller vessels as discussed in Section 3.1.

Within the group of vessels using other gears there was a considerable degree of variation in average vessel length between vessels involved in an accident and vessels not involved. On average, vessels not involved in an accident or involved in an occupational accident were larger than vessels involved in a marine casualty.

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[11] MAIB (2008) *Analysis of UK fishing vessel safety 1992 to 2006,* MAIB, Southampton, November 2008.

This particular segment comprises a variety of gears and fishing areas, and it is possible that this variation within the group influenced these results.

In three segments (demersal trawl vessels over 18m, scallop dredgers and vessels using other gears), vessels involved in accidents showed lower average values of financial performance indicators per kWdas than vessels never involved in an accident. These results suggest that vessels in these three segments that were involved in an accident during the analysis period had a poorer financial performance per unit of effort compared to vessels that were not involved in an accident. The main factors driving financial performance of (weight of landings, price) have not been investigated and can be explored in further research. This finding implies that catch rates and productivity (weight and value of landings per unit of effort, fishing costs per unit of effort) may also be a key factor behind vessel accidents: vessels achieving lower catch rates may be driven to increase their fishing effort to compensate their lower returns, thus increasing their exposure to accidents.

Probability models

The results of two separate probability models pointed to a statistically significant, but very small, effect of the financial performance of vessels (net profit, VPUE) on accident probability. The apparent contradiction in results between the statistical analysis and the probability models may be partly explained by the different fleet segmentation and accident type classification.

The models also indicated that operational parameters such as main gear type and main area of fishing had a greater effect on accident probability than financial performance. These findings match the results of the segment level analysis, which point to the influence of other factors (as well as financial) on vessel safety.

Conclusions

The findings of this preliminary analysis do not strongly suggest any particular policy or business responses to reduce the rates of accidents in the UK fishing fleet, but indicate the direction for future analyses to identify more clearly whether there are any causal relationships that may justify raising awareness and encouraging policy makers and business owners to consider specific relationships involving safety.

Appendix 1: Methods

Fleet segmentation

Table 1 shows the segmentation criteria used in the statistical analysis.

Table 1: Fleet segments and segmentation criteria

Fleet segment	Main gear by number of days at sea	Main species landed by value	Vessel length	Average length of vessels in the segment (m)
Demersal trawl vessels over 18m	Demersal trawls and seines	Not Nephrops	18m or over	25.9
Demersal trawl vessels under 18m	Demersal trawls and seines	Not Nephrops	Under 18m	10.8
Nephrops trawl vessels	Demersal trawls and seines	Nephrops		16.7
Scallop dredgers	Dredges	Scallops, queen scallops, cockles		14.6
Vessels using passive gears	Drift nets and fixed nets, longliners, hooks, pots and traps			9.1
Vessels using other gears	Miscellaneous or unidentified gears, pelagic trawls and seines, beam trawls			35.7
Low activity	Any vessel with an annual fishing income under £10k			6.7

Table 2 shows the annual numbers of vessels in each segment 2008-2016.

Table 2: Number of active vessels per fleet segment in the UK fishing fleet, 2008-2016 (source: Seafish)

Fleet segment	Year								
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Demersal trawl vessels over 18m	172	185	173	152	144	146	136	153	138
Demersal trawl vessels under 18m	358	325	316	308	306	280	286	285	274
Nephrops trawl vessels	450	416	390	362	367	345	343	310	319
Scallop dredgers	186	216	216	260	245	292	289	318	272
Vessels using passive gears	1,708	1,660	1,722	1,842	1,803	1,726	1,766	1,682	1,801
Vessels using other gears	138	118	118	109	123	109	111	104	121
Low activity	1,884	1,917	1,833	1,762	1,772	1,729	1,634	1,732	1,712

MAIB accident types

The MAIB dataset 1993-2016 records two accident types: marine casualties and occupational accidents.

A **marine casualty** is defined as an event or sequence of events that has resulted in any of the following and has occurred directly by or in connection with the operation of a ship:

- the death of, or serious injury to, a person;
- the loss of a person from a ship;
- the loss, presumed loss or abandonment of a ship;
- material damage to a ship;
- the stranding or disabling of a ship, or the involvement of a ship in a collision;

- material damage to marine infrastructure external of a ship, that could seriously endanger the safety of the ship, another ship or any individual;
- pollution, or the potential for such pollution to the environment caused by damage to a ship or ships.

An **occupational accident** is defined as an event that does not involve any actual or potential casualty to a vessel. Examples of occupational accidents include slips and falls or loss of control of a tool or piece of equipment.

Marine casualties were far more common in the MAIB dataset than occupational accidents: 82% of all events on fishing vessels recorded in the MAIB dataset between 1993 and2016 were marine casualties.

Table 3: Number of events by type in the UK fishing fleet 1993-2016 (source: MAIB)

Type of event	Number of occurrences	% of occurrences
Marine casualty	7,300	82%
Occupational accident	1,618	18%

Marine casualties and occupational accidents in the MAIB dataset are allocated a degree of severity:

- Very serious: involving total loss of the ship, loss of life, or severe pollution;
- Serious: resulting in immobilization of main engines, extensive accommodation damage, severe structural damage, pollution or necessitating towage or shore assistance;
- Less serious: a casualty or occupational accident not classed as very serious or serious.

The MAIB database 1993-2016 recorded 11 different types of marine casualties:

- Capsizing/listing;
- Collision;
- Contact;
- Damage to ship or equipment;
- Fire/explosion;
- Flooding/foundering;
- Grounding/stranding;
- Hull failure;
- Loss of control[12];
- Non-accidental event;
- Unknown.

Of these, loss of control was the most common type in fishing vessels and they were mostly classed as less serious. The remainder of marine casualty types (including capsizing, fire, grounding or collision, among others) were less frequent, but tended

[12] A total or temporary loss of the ability to operate or manoeuvre the ship, failure of electric power, or to contain on board cargo or other substances.

to be classed as serious or very serious more often.

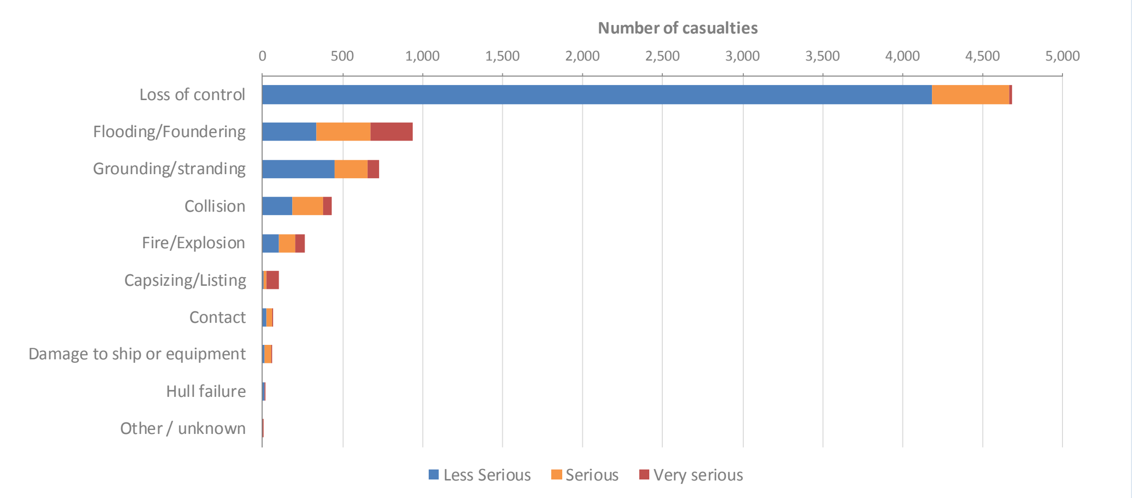

Figure 17: Number, type and severity of marine casualties in UK fishing vessels 1993-2016 (source: MAIB)

Appendix 2: Dissertation

Fishing Vessels' Economic Performance and Accident Likelihood: Is there a link?

By Lina-Lotta Lahdenkauppi*
Exam No: B059209
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Abstract

This dissertation commissioned by Seafish studies the link between fishing vessels' economic performance and their likelihood to suffer an accident. Data from Seafish, the Marine Management Organisation and the Marine Accident Investigation Branch for the period of 2008-2016 is used. The topic is approached by analysing two different economic performance indicators. Previous literature is used for model specification. First, the effect of net profit on accident likelihood is studied. Results from logit and probit models indicate that higher net profit decreases the likelihood of suffering an accident for vessels over 15 metres in length. The effect, however, is very small. The second approach studies the effect of value per unit of effort (VPUE) on accident probability. The value derived from time spent at sea is a crucial driver of fishing decisions. Findings indicate that a higher VPUE decreases accident likelihood for vessels with an overall length between 15 and 24 metres. Findings also indicate that having suffered more than two accidents in the past increases the accident likelihood of a vessel. Gear type, fishing area and year also influence accident probability. The dissertation concludes by considering alternative econometric methods that are able to take unobserved heterogeneity into account in estimation.

Content

1 Introduction

“Commercial fishing is by far the most hazardous occupation in the UK” (Roberts, 2010, p. 49). The dangerous nature of commercial fishing, however, is not a recent result. Shilling (1966) described trawler fishing as one of the most dangerous occupations already 52 years ago. Jensen (2014) reports that “the fatal rate for United Kingdom fishermen for 1996-2005 was 115 times higher than that of the general workforce in Great Britain” (p. 48). Despite continuous efforts to improve fishermen’s safety at sea, the dangers of commercial fishing remain an acute problem not only in the United Kingdom but also around the globe. A deeper understanding of the immediate and underlying causes of fishing vessel accidents is needed to improve the guidelines and regulations as well as safety and training programmes enforced by national and international authorities. Protecting the lives and well-being of fishermen is a most important challenge worldwide.

Economic pressures are potentially one of the greatest driving forces in the fishing industry (MAIB, 2008). However, research on the relationship between economic performance and fishing vessels’ accident likelihood is sparse. Moreover, there are no available studies analysing the role of economic performance on fishing vessel safety for the UK fishing fleet. To address this gap in the research the purpose of this paper is to determine whether there is a link between the economic performance of fishing vessels and their likelihood to suffer an accident. The analysis will be conducted for UK based fishing vessels fishing in UK territorial waters.

This paper develops two approaches in order to uncover the nature of the relationship between economic performance and accident likelihood. The first approach analyses the effect of net profit on accident likelihood by constructing logit and probit models. The second approach considers the impact of ‘value per unit of effort’, a measure for value landed per time spent at sea, on accident probability. Again, probit and logit models are developed for the estimation of effects.

This research has been commissioned by Seafish in assistance with the Marine Accident Investigation Branch (MAIB). Seafish is the UK industry authority on seafood. It "aims to be the main source of information and analysis for industry, Government and media on all issues concerning the UK seafood industry" (Seafish, 2017). The MAIB is a governmental body responsible for investigating marine accidents in the UK territorial waters and internationally for UK based vessels. The MAIB maintains a database of all reported accidents, issues safety recommendations and publishes detailed reports on serious accidents.

The paper is structured as follows. In Section 2, I provide a review of previous literature on the determinants of fishing vessel accidents. Moreover, an overview of accident trends of UK based vessels in UK territorial waters is provided. Section 3 presents the data used in the analysis. Section 4 describes the accident probability models developed for the purpose of this study. I present and discuss the results in sections 5 and 6. Section 7 concludes.

2 Review of Previous Literature and Accident Trends

2.1. Determinants of fishing vessel accidents

As established in the introduction, commercial fishing is a dangerous industry (Chauvin, Le Bouar & Lardjane, 2017; Roberts & Carter, 2015; Roberts, 2010). This section reviews selected studies and publications that have analysed determinants of fishing vessel accidents. To reflect the purpose of this paper, the focus will lie on studies which address indicators of economic performance. This review will serve as a basis for later model development and discussion of results.

Jin, Kite-Powell and Talley (2001) analyse determinants of fishing vessel total losses and injuries using ordered probit and negative binomial regressions. The researchers find that accident type has the largest influence on the probability of a vessel total loss and the extent of crew injuries. Capsizing and sinking accidents lead to the highest probability of a total loss, whereas fire/explosion and capsizing accidents are expected to lead to the highest numbers of crew fatalities. Moreover, the researchers find that the probability of a vessel total loss decreases as the price of catch rises. Likewise, an increase in the price of catch is found to lead to fewer fatalities. The researchers thus establish that the price of catch varies inversely with accident probability.

Jin et al. (2002) develop a model for fishing vessel accident probability for fishing areas off the northeastern United States. They use logit regressions for the analysis of daily data between 1981 and 1993. Findings from the study show that higher wind speeds as well as being closer to the shore increases accident likelihood. Moreover, medium-sized vessels (2-50 gross registered tons) have a higher accident probability compared to small and large vessels. The results also indicate that certain fishing areas increase accident likelihood by more and that accident likelihood is lowest in the spring. Building on this study, Jin and Thunberg (2005) analyse fishing vessel accidents off the northeastern coast United States. In addition to confirming findings similar to the 2002 study, the researchers find that increases in the value of landings decrease accident probability. They conclude that accident probability is influenced by weather, fishing area, season, vessel characteristics as well as economic return.

Further studies addressing the effect of economic performance on accident likelihood include Jensen et al. (2014). The researchers review and compare trends of fatal injury incidence rates in the fishing industry internationally. The researchers conclude that "fishing quotas regulations have grown more intense over the years with strong financial impact and most possibly negative impact on the safety standards" (p. 47). Moreover, a comprehensive Marine Investigation Report (2012) issued and authored by the Transportation Safety Board of Canada (TSB) establishes that "actions that maximize profit at the expense of safety are common and have contributed to loss of life" (p. 63). Economic pressures to improve profit margins might lead vessel owners to take part in multiple fisheries, stack licences and pool catches, focus maintenance on avoiding breakdown, and focus spending on increasing productivity instead of safeguarding against accidents which are viewed as unlikely (Transportation Safety Board, 2012). In addition, the report by TSB discovers that many fishermen attempt to take actions to lower their operational costs by reducing crew or hiring inexperienced crew, reusing old gear and delaying preventative maintenance. These findings demonstrate how economic pressure may lead to decisions and actions that compromise the safety of fishermen.

In addition to economic performance and environmental as well as operational factors, the role of human performance is a crucial determinant of fishing vessel accidents. Håvold (2010) states that "analyses of safety among fishermen and fishing vessels should go beyond direct causes and effects of accidents like sinking and capsizing falls". Håvold (2010) claims that the main reason for accidents in the fishing industry is human error. It is important to note that the economic performance of a fishing vessel is likely to have a significant influence on human performance and error. Lack of financial resources could restrict the ability of vessel owners to hire sufficient numbers of experienced crew or their ability to provide sufficient safety training. Human error is more likely to occur when crew members suffer from fatigue due to being overworked. Likewise, less experienced crew members are more error-prone thereby increasing the accident probability of a vessel.

Human error as a determinant of accidents is evident also from MAIB accident investigation reports. In the MAIB 2016 Annual Report, multiple accident investigations started in 2016 report human factors as safety issues. More specifically, these include e.g. lack of training and training comprehension, insufficient use of personal floating devices and cultural and language barriers. Lack of financial resources to provide training or to enforce a safety culture on board can potentially be an underlying cause leading to human error and increased accident likelihood.

Lastly, it has to be noted that under-reporting of accidents is a major problem hindering research into the determinants of fishing vessel accidents. Håvold (2010) notes that according to a survey conducted by Rogaland Research in Norway in 2004, 71% of accidents were never reported to the Norwegian Maritime Directorate. Of course, this figure is an estimation by one study only, and further cannot be generalized to the UK. However, it can serve as a proxy for the order of magnitude of under-reporting. The potentially high degree of under-reporting is good to bear in mind in the following where accident trend statistics for the UK fishing industry are presented.

2.1. Fishing vessel accident trends in the UK

Information presented below has been drawn from an MAIB database of all accidents by UK fishing vessels in UK territorial waters. The review of accident trends is intended to provide context for the later model development and analysis.

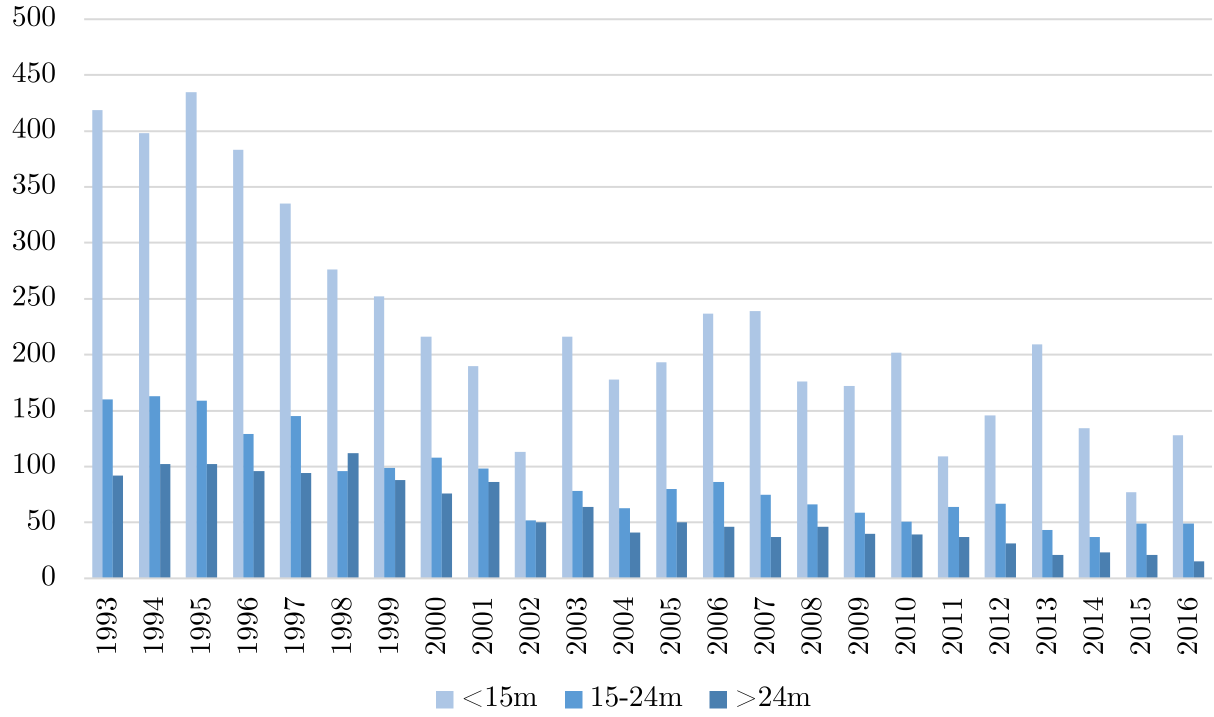
The MAIB classifies marine accidents into Marine Casualties and Marine Incidents. For the purpose of this dissertation, the term accident is used for both Marine Casualties and Marine Incidents and the two will be treated as one category. The term accident is used in an identical manner by the MAIB (MAIB, 2016). Moreover, the MAIB classifies accidents into two types:

- Casualty with a ship: when a vessel, its equipment or cargo is affected by an accident.
- Occupational accident – where an accident affects only a person.

In this paper, accidents may be classified into casualties with ships and occupational accidents only in the review of accident trends. Throughout the rest of the paper, the term accident denotes both types of occurrences.

Figure 1 below shows the annual number of accidents by vessel length for 1993-2016. There is a downward trend in the number of accidents during the 23 year period. The trend is evident for all three length groups. Moreover, the higher frequency of accidents for vessels less than 15 metres in length represents the makeover of the UK fishing fleet. In 2016, vessels with overall length <10m made up 78.8% of the UK fishing fleet, whereas vessels with overall length <15m made up 89.9% of the fleet (Marine Management Organisation, 2016).

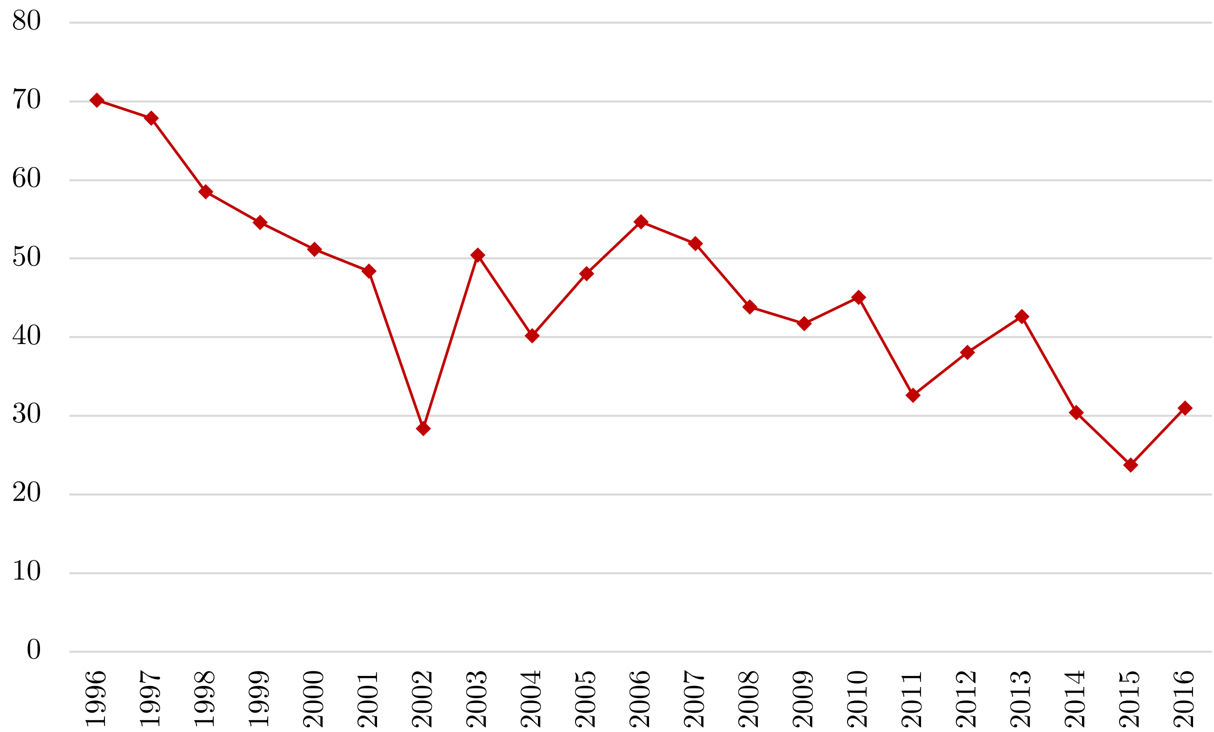
Figure 1: Number of accidents by vessel length 1993-2016



Source: MAIB accident database.

Not only the number of accidents, but also the number of vessels in the UK fishing fleet has decreased. The size of the UK fishing fleet decreased by 28.6% between 1996 and 2016 (Marine Management Organisation, 2016). Using the size of the UK fishing fleet and the annual number of accidents, Figure 2 shows the accident rate per 1000 fishing vessels for 1996-2016.

Figure 2: Accident rate per 1000 fishing vessels 1996-2016

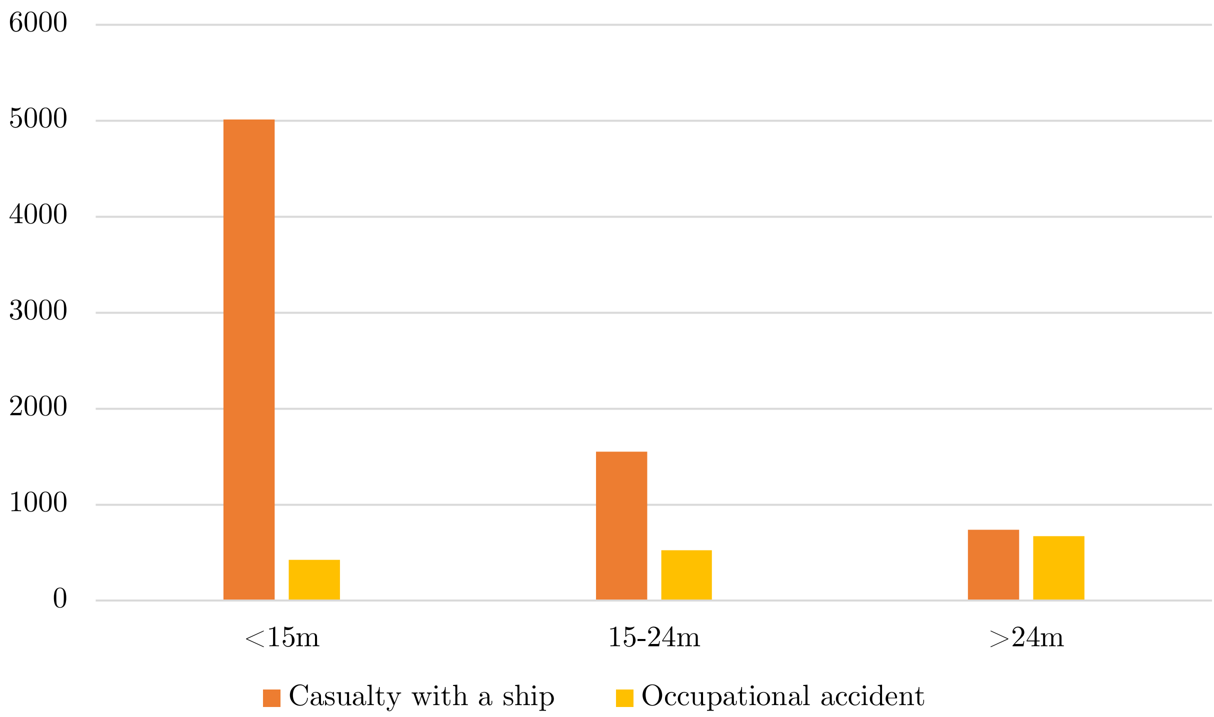


Source: MAIB accident database and MMO UK Sea Fisheries Statistics 2016.

Again, there is a downward trend in the overall accident rate for fishing vessels during the 20 year period. However, the accident rate has not changed significantly since 2002 and remains high despite being lower than in the 1990s. Improvements in the safety of the fishing industry must still continue to take place.

Figure 3 shows that most casualties with ships occur for vessels less than 15 metres in length, whereas occupational accidents are most common for vessels more than 24 metres in length. This finding could be explained by the higher number of crew members in larger vessels or smaller issues with under-reporting of injuries by larger vessels which are subject to more stringent safety regulations. The figure consists of all reported casualties with ships and occupational accidents that occurred between 1993 and 2016.

Figure 3: Type of accident by vessel length



Source: MAIB accident database.

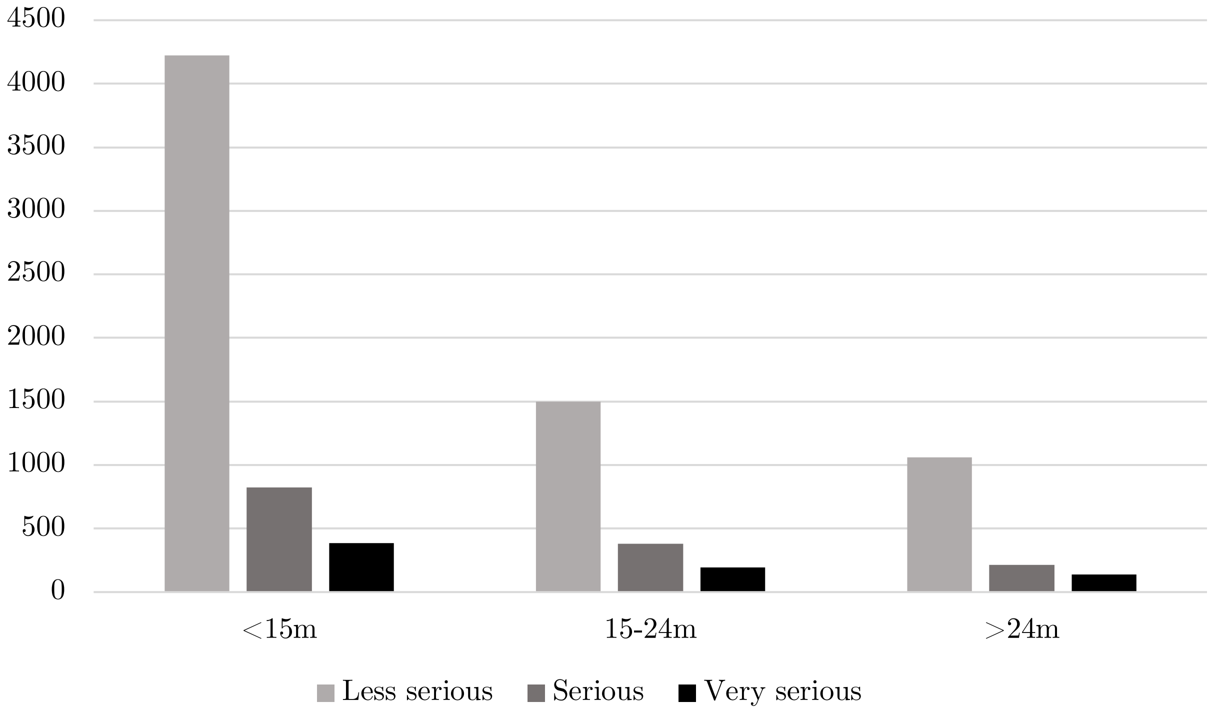
Severities of accidents suffered by the three length groups are presented in Figure 4. The pattern is similar for all length groups. As could be expected, less severe accidents occur most frequently and very severe accidents least frequently. Again, the figure is based on all reported fishing vessels accidents that occurred between 1993 and 2016.

Table 1 contains the most frequent types of casualties by severity in 1993-2016. Nearly 80% of less severe casualties with ships are classified as loss of control events. Loss of control is the leading type also for severe casualties, whereas flooding/foundering is the most frequent type among very severe occurrences.

Table 2 presents the leading deviations that led to occupational accidents in 1993-2016. The severity category 'severe' is omitted since it only contained one event. The leading deviation leading to less severe occupational accidents is loss of control by 45.5%. Very severe accidents are caused by slipping, stumbling, falling and fall of persons, almost

80% of very severe occupational accidents are classified with the category as a leading cause.

Figure 4: Accident severity by vessel length



Source: MAIB accident database.

Table 1: Most frequent types of casualty events by severity

Less Serious	Serious	Very serious
Loss of control (78,7%)	Loss of control (33,6%)	Flooding/Foundering (46,6%)
Grounding/Stranding (8,5%)	Flooding/Foundering (23,9%)	Capsizing/Listing (13,7%)
Flooding/Foundering (6,3%)	Grounding/Stranding (14,3%)	Grounding/Stranding (13,3%)

Source: MAIB accident database.

Table 2: Most frequent deviations leading to occupational accidents by severity

Less Serious	Very serious
Loss of control (total or partial) of machine, means of transport or handling equipment, handheld tool, object, animal (45,5%)	Slipping - Stumbling and falling - Fall of persons (78,4%)
Slipping - Stumbling and falling - Fall of persons (24,4%)	Loss of control (total or partial) of machine, means of transport or handling equipment, handheld tool, object, animal (11,8%)
Breakage, bursting, splitting, slipping, fall, collapse of Material Agent (15,8%)	Deviation by overflow, overturn, leak, flow, vaporisation, emission (4,6%)

Source: MAIB accident database.

3 Data

As indicated in the previous section, data on all accidents by UK vessels in UK territorial waters is provided by the MAIB. The database covers the period 1993-2016. Data includes detailed information about the time, location, type, causes and weather conditions of an accident. In addition, key technical parameters of a vessel are included. Vessels in the database are identified by a unique registration number, which is used for matching the MAIB dataset with the other used datasets.

Data on economic performance is provided by Seafish and the UK Marine Management Organisation (MMO). Seafish constructs a fleet economic performance dataset annually. It consists of Fleet Survey data and official effort, landings and capacity data for all active UK fishing vessels provided by the MMO. This study uses information from vessel accounts submitted to Seafish by vessel owners as part of the Fleet Survey conducted by Seafish annually. Information from the accounts is supplemented by non-financial information contained in the Fleet Economic Performance dataset which is available for 2008-2016. The fleet economic performance dataset segments vessels into different classes. Only active vessels, which by the definition of Lawrence, Moran

Quintana and Motova (2016, p. 35) is “any UK registered fishing vessel that recorded any amount of landings in the year considered” are included in the analysis. Vessels are identified by a unique registration number in the Seafish dataset, allowing it to be matched with other datasets.

Further economic performance data including processed effort and landings data by month is provided by the MMO. The amount of effort and landings data collected from a vessel, as well as the data collection method, depends on vessel length. The primary data collection method for activity data for vessels over 10 metres in length is a fishing logbook. It includes data on fishing activity by individual vessels for each day of a fishing trip. Logbooks include details of the catch (by species), fishing gear used and the area where fish were caught. In addition, fishermen supply a landing declaration with accurate weights of catch. Lastly, information from sales notes, which are usually submitted by registered buyers, provide information on the first sale values of fish. Supplying the information detailed above is legally required for all over 10 metre vessels. Reporting requirements have been set out by EU legislation (Marine Management Organisation, 2018). Vessels under 10 metres in length are not legally required to submit logbooks and landings declarations, but they can supply them voluntarily. However, registered buyers are required to supply sales notes, allowing accurate collection of first sale values of fish. Hence, data on the effort for vessels less than 10 metres in length is estimated from sales notes, which has implications for the credibility of the data. Again, a unique registration number is used to identify vessels similarly to the previous datasets. Effort and landings data was provided for the period of 2008-2016.

Table 3 defines all variables used in the later analysis. These are either taken or created from the datasets described above.

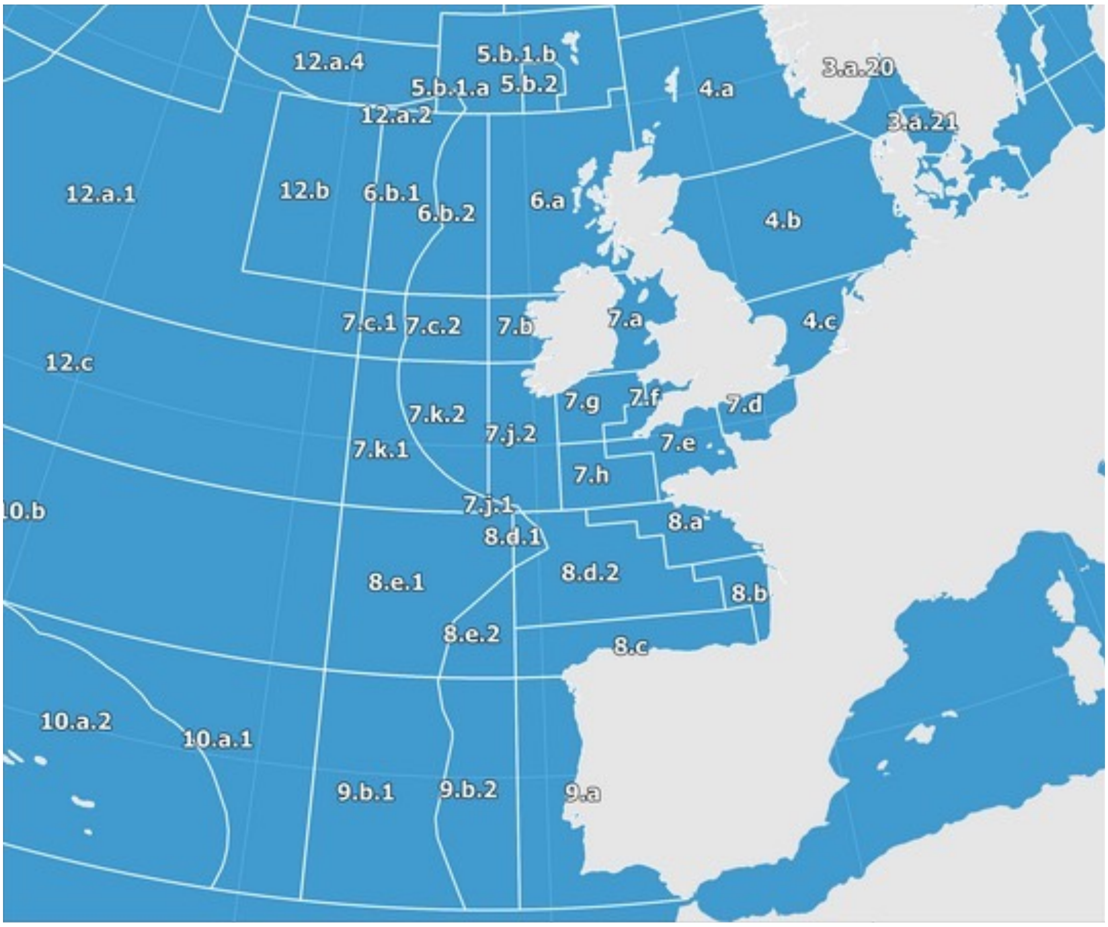
Table 3: Variable definitions

Variable (unit)	Code	Definition
Accident	Accident	Dummy variable for accidents. No differentiation between casualties with ships and occupational accidents.
Net profit (£)	Net profit	Operating profit less finance costs, depreciation and interest costs. Nominal values adjusted with a GDP deflator to reflect 2016 pound equivalence.
Value per unit of effort (£/kW days)	VPUE	Monthly value of landings divided by monthly fishing effort measured as kW days.
One past accident	Past accident=1	Dummy for having suffered one accident in the past.
Two or more past accidents	Past accident ≥ 2	Dummy for having suffered two or more accidents in the past.
Fishing effort (kW days)	kW days	Sum of product of engine power and time at sea in days.
Beam trawlers	Beam trawler	Gear type as per European Union's data collection framework (DCF)[1].
Demersal trawlers and demersal seiners	Demersal trawler/seiner	Gear type as per EU's DCF.
Dredgers	Dredger	Gear type as per EU's DCF.
Drift and fixed netters	Drift/fixed netter	Gear type as per EU's DCF.
Gears using hooks	Hooks	Gear type as per EU's DCF.
Vessels using polyvalent mobile gears	Polyvalent mobile	Gear type as per EU's DCF.
Vessels using polyvalent active gears	Polyvalent active	Gear type as per EU's DCF.
Pelagic seiners and purse seiners	Pelagic/purse seiner	Gear type as per EU's1 DCF.
Pelagic trawlers	Pelagic trawler	Gear type as per EU's DCF.
Vessels using pots and traps	Pots and traps	Gear type as per EU's DCF.
Summer	Summer	Dummy for the months of June, July and August.
Autumn	Autumn	Dummy for the months of September, October and November.
Winter	Winter	Dummy for the months of December, January and February.
Spring	Spring	Dummy for the months of March, April and May.
Year	2008-2016	Year dummy for 2008-2016.

[1] Available at https://datacollection.jrc.ec.europa.eu/wordef/fleet-segment-dcf.

In addition to the variables presented above, information on fishing areas is used as part of the later analysis. The fishing areas presented in Figure 5 below follow the definition of the International Council for the Exploration of Sea (ICES). Only the closest areas to the UK (4, 6, and 7 with all of their subareas) are used in the analysis.

Figure 5: ICES statistical fishing areas



Source: FAO Major Fishing Areas (2017).

Data on fishing areas is collected as part of activity data collection and is contained in the monthly effort and landings data provided by the MMO. However, in the analysis of the effect of net profit on accident likelihood, which utilises the Seafish economic performance dataset, fishing area is defined as the area where a vessel operated most frequently in a given year. Thus, a so-called ‘top area’ represents the fishing area of a given year. Moreover, top areas correspond to collections of ICES statistical areas. The definition of top areas used later is presented in table 4 below.

Table 4: Top area definition

Top area	ICES sub-area
North Sea	4a, 4b, 4c
VII Other	7.b, 7.c, 7.k, 7.h, 7.j
VIIA	7.a
VIIDE	7.d, 7.e
VIIFG	7.f, 7.g
West of Scotland	6.a, 6.b

To conclude, the dataset for analysing the effect of net profit on accident likelihood is generated by matching the MAIB dataset with the vessel accounts collected by Seafish, and the Seafish Fleet Economic Performance dataset for the period of 2008-2016. The dataset for the analysis of VPUE on accident likelihood is constructed by matching the MAIB dataset with monthly activity (effort and landings) data provided by the MMO. This dataset is also matched with the Seafish Fleet Economic Performance dataset for the purpose of using segmentation information. Not all accident observations from the MAIB dataset could be matched with the Seafish and MMO data, and hence, the total number of accidents in the samples used is smaller than what it was in reality. Moreover, the analysis of VPUE on accident likelihood exploits time dynamics, requiring the data to be converted into panel form. Since observations have to be uniquely identified, only one accident per vessel per month can be included in the dataset. This further reduces the accident variation by little in the sample used.

4 Method

4.1. Binary choice models

Since the interest of this study lies in a binary dependent variable taking on the values of one and zero indicating whether an accident occurred or not, logit and probit models are an appropriate model choice. Logit and probit models allow the construction of a probability model which enables analysing the effect of chosen variables on the accident likelihood of fishing vessels. In the following, the approach of Wooldridge (2012) is followed to derive logit and probit models.

We are interested in explaining the effect of chosen independent variables $\boldsymbol{x}$ on the probability that an accident happens

$$P(y=1|\boldsymbol{x})=G(\beta_0+\boldsymbol{x\beta}) \quad (1)$$

where y is the dependent accident variable taking on value one when an accident happens and zero otherwise. The response probability can be derived more generally from a latent variable formulation.

$$y^*=\beta_0+\boldsymbol{x\beta}+e, \quad y=1[y^*>0] \quad (2)$$

We assume that e is independent of $\mathbf{x}$ and that it has either a standard normal distribution or the standard logistic distribution. In either case e is symmetrically distributed around about zero, $1-G(-z)=G(z)$ for all real number z. Therefore,

$$P(y=1|\boldsymbol{x})=P(y^*>1|\boldsymbol{x}) =P[e>-(\beta_0+\boldsymbol{x\beta})|\boldsymbol{x}]=1-G[-(\beta_0+\boldsymbol{x\beta})]= G(\beta_0+\boldsymbol{x\beta}) \quad (3)$$

which is equal to the response probability in (1).

In the probit model G is the standard normal cumulative distribution function, and in the logit model G is the logistic function. Both models limit the response probabilities strictly between zero and one for all values of parameters and independent variables.

Probit and logit estimators are estimated by maximum likelihood. Finally, the choice between using a logit or a probit model depends on whether the error terms of a model to be estimated are assumed to follow a standard logistic or standard normal distribution. In practice, both models tend to produce very similar marginal effects and both will be estimated for the purpose of this study.

Before describing the constructed models, it is important to note how partial effects are calculated. The partial, or marginal, effect of continuous independent variables on the response probability $p(\boldsymbol{x}) = P(y=1|\boldsymbol{x})$ is obtained by taking a partial derivative,

$$\frac{\partial p(\boldsymbol{x})}{\partial x_j} = g(\beta_0 + \boldsymbol{x\beta})\beta_j, \quad \text{where} \quad g(z) = \frac{dG}{dz}(z). \qquad (4)$$

In the case of discrete independent variables, the partial effect of changing x_k from zero to one is simply

$$G(\beta_0+\beta_1+\beta_k) - G(\beta_0+\beta_1). \qquad (5)$$

Compared to a simple linear probability model estimated by ordinary least squares, partial effects in logit and probit models depend on the value of **x.** To circumvent the reliance of partial effects on the chosen values of **x** , I report average partial effects (APE) also known as average marginal effects (AME) in the results section. They overcome the issue of value specific partial effects by averaging individual partial effects estimated at values specific to each observation across the sample.

4.2. Model development

Two separate accident probability models are specified for analysing the effect of economic performance on accident likelihood. In the first, the main variable of interest is net profit. Higher net profit is hypothesised to lower the accident likelihood of a vessel. However, the sign of the relationship between net profit and accident likelihood could be positive as well. As described in Section 2, profitability does not only enable vessel owners to spend on safety improving measures such as preventative maintenance and training, but higher profitability could also be achieved by cutting costs on such areas of spending. In addition to net profit, vessel age, effort, fishing gear, fishing area and year dummies for 2008-2016 are included in the model to be estimated. Vessel age is expected to increase a vessel's accident likelihood. Vessel effort is expected to increase accident likelihood, as more time spent at sea increases exposure to risks. Different gear types and fishing areas are expected to have both negative and positive effects on vessels' accident probabilities. The selection of covariates follows the approach of Jin et al. (2002) and Jin and Thunberg (2005). The model[2] to be estimated is presented below.

$$P(accident=1|\boldsymbol{x}) = \Phi\ (\beta_0 + \beta_1\ net\ profit + \beta_2\ kw\ days + \beta_3\ age + \beta_{4i}\ gear\ type + \beta_{5i}\ fishing\ area + \beta_{6i}\ year) \qquad (6)$$

The main variable of interest in the second model specification is value per unit of effort (VPUE). According to Davies et al. (2015) "value achieved from time spent at sea is a central driver of fishing decisions and fishing behaviors" (p. 1). Commercial fishing operations aim to maximize the value from time spent at sea, and VPUE is an important indicator of economic performance (Davies et al., 2015). Thus, higher VPUE is expected to decrease a vessel's accident likelihood.

Similarly to net profit, VPUE is taken to be an indicator of healthy economic performance which enables fishermen to spend resources on necessary costs as well as accident preventative measures. The panel form of the dataset used for the estimation of the second model also enables the use of lagged dependent variables. Hence, the

[2] In the logit model specification the standard normal cumulative distribution function Φ is replaced by the logistic function Λ. Using the subscript i in the coefficients of dummy variables (gear type, fishing area, year) is used to denote more than one coefficient for a certain group of variables.

influence of past accidents on current accident likelihood can be analysed. Past accidents are expected to have a positive effect on accident likelihood. Other control variables included in the second model specification are similar to the first specification. A dummy variable for the season is included in the model, allowing to control for potential seasonal patterns in the occurrence of accidents. The second model to be estimated is presented below.

$$P(accident=1|\boldsymbol{x}) = \Phi\ (\beta_0 + \beta_1\ VPUE + \beta_{2i}\ past\ accident + \beta_3\ age + \beta_{4i}\ gear\ type + \beta_{5i}\ fishing\ area + \beta_{6i}\ season + \beta_{7i}\ year) \quad (7)$$

Data used for the estimation of both model specifications contains vessels that occur multiple times in the datasets. The first dataset contains nine years, and hence nine time periods. Any one vessel appears 1-9 times in the dataset, and hence the panel is not balanced. The second dataset spans over 108 months (9 years). Vessels appear 1-108 times in the dataset. Due to the panel nature of the datasets, the probit and logit models derived at the beginning of this section are estimated as pooled models. In other words, the panel structure of the data is ignored and the data is treated as a cross-section. Wooldridge (2011) derives a useful result, implying that if a model is dynamically complete,

$$P(y_{it} = 1 /\ \boldsymbol{x}_{it},\ y_{i,t-1},\ \boldsymbol{x}_{i,t-1}...) = P(y_{it} = 1 /\ \boldsymbol{x}_{it}) \quad (8)$$

all the usual statistics from a probit or logit that pools observations treating the sample as an independent cross-section are valid. Moreover, dynamic completeness implies the absence of serial correlation which is an essential condition for consistent inference. Dynamic completeness was tested for according to a simple one-degree-of-freedom test specified in Wooldridge (2012). However, the null hypothesis of dynamic completeness was rejected for both model specifications. Thus, to account for serial correlation in the error terms a robust variance matrix is needed. The pooled estimator using asymptotic standard errors is consistent and $\sqrt{N}$-asymptotically normal without any other assumptions than identification and standard-regularity conditions given that T is fixed and $N \rightarrow \infty$.

Pooled estimators using clustered standard errors were chosen over logit and probit models developed for panel data. Not only can binary choice models for panel data be computationally difficult to estimate (Wooldridge, 2012) but they are also usually designed to be used with balanced panels. Unfortunately, both datasets utilized for this study are only weakly balanced.

Tables 5 and 6 below present summary statistics for the data used for the estimation of both model specifications. Inactive vessels were dropped from the sample. Moreover, if monthly total days at sea or value of landings (variables used for constructing the VPUE variable) were negative or missing, a vessel was excluded from the analysis. Lastly, to be able to use categorical variables as regressors in a probit or logit regression, there has to be variation within all categories. In other words, if there were fishing areas or gear types with only non-accidents, these had to be dropped from the analysis.

The models are estimated separately for three different vessel length groups; <15m, 15-24m and >24m. The length group classification follows from different legal safety requirements and regulations for vessels of different lengths. Separate estimation instead of using dummy variables to indicate the different groups was decided for due to a recognition that effects of independent variables on the accident likelihood are not likely to be monotonous between vessels' of different sizes. Lastly, results reported in the following section contain low activity vessels in the samples. Lawrence, Moran Quintana and Motova (2016) define low activity vessels as "any vessel that recorded a total value of landings under £10'000 in the year considered". Results with samples excluding low activity vessels are not presented in the main body of the text, but they are contained in full in the appendix.

Table 5: Summary statistics for model specification 1

	<15m					15-24m					>24m				
	Count	Mean	SD	Min	Max	Count	Mean	SD	Min	Max	Count	Mean	SD	Min	Max
Accident	2346	0.038	0.192	0	1	1172	0.113	0.316	0	1	759	0.117	.322	0	1
Net profit	2346	24605	36000	-106102	404567	1172	57609	114499	-451386	1183218	744	479965	1284878	-767512	9685921
kW days	2346	15348	14246	15	122031	1172	61945	32956	1074	222268	759	179416	147420	1788	1252332
Age	2346	22.48	13.66	0	83	1172	26.41	13.36	0	74	759	24.42	12.55	1	62
Drift/fixed netter	2346	0.088	0.283	0	1	1172	0.021	0.145	0	1	759	0	0	0	0
Dredgers	2346	0.074	0.261	0	1	1172	0.099	0.299	0	1	759	0.092	0.290	0	1
Demersal trawler/seiner	2346	0.222	0.416	0	1	1172	0.740	0.439	0	1	759	0.544	0.498	0	1
Pots and traps	2346	0.515	0.500	0	1	1172	0.073	0.261	0	1	759	0	0	0	0
Hooks	2346	0.060	0.238	0	1	1172	0	0	0	0	759	0	0	0	0
Polyvalent active	2346	0.011	0.103	0	1	1172	0	0	0	0	759	0	0	0	0
Beam trawler	2346	0.030	0.171	0	1	1172	0.067	0.249	0	1	759	0.199	0.399	0	1
Pelagic trawler	2346	0	0	0	0	1172	0	0	0	0	759	0.165	0.371	0	1
North Sea	2346	0.396	0.489	0	1	1172	0.536	0.499	0	1	759	0.582	0.493	0	1
VII Other	2346	0	0	0	0	1172	0.005	0.071	0	1	759	0.120	0.325	0	1
VIIA	2346	0.098	0.297	0	1	1172	0.112	0.315	0	1	759	0.032	0.175	0	1
VIIDE	2346	0.195	0.396	0	1	1172	0.067	0.249	0	1	759	0.128	0.334	0	1
VIIFG	2346	0.071	0.257	0	1	1172	0.020	0.139	0	1	759	.0132	0.114	0	1
West of Scotland	2346	0.240	0.427	0	1	1172	0.261	0.439	0	1	759	0.125	0.331	0	1
2008	2346	0.074	0.262	0	1	1172	0.101	0.301	0	1	759	0.116	0.320	0	1
2009	2346	0.072	0.259	0	1	1172	0.114	0.318	0	1	759	0.125	0.331	0	1
2010	2346	0.074	0.262	0	1	1172	0.087	0.282	0	1	759	0.112	0.316	0	1
2011	2346	0.075	0.264	0	1	1172	0.098	0.298	0	1	759	0.123	0.328	0	1
2012	2346	0.122	0.328	0	1	1172	0.125	0.330	0	1	759	0.121	0.327	0	1
2013	2346	0.133	0.340	0	1	1172	0.114	0.318	0	1	759	0.088	0.284	0	1
2014	2346	0.153	0.361	0	1	1172	0.125	0.331	0	1	759	0.096	0.295	0	1
2015	2346	0.165	0.371	0	1	1172	0.131	0.337	0	1	759	0.120	0.325	0	1
2016	2346	0.131	0.337	0	1	1172	0.105	0.307	0	1	759	0.099	0.299	0	1

Table 6: Summary statistics for model specification 2

	15-24m					>24m				
Variable	Count	Mean	SD	Min	Max	Count	Mean	SD	Min	Max
Accident	42188	0.010	0.010	0	1	19255	0.012	0.108	0	1
VPUE lag	40226	7.574	4.905	0	123.65	17718	9.153	7.789	0	190.92
Past accident=1	42188	0.215	0.411	0	1	19255	0.230	0.421	0	1
Past accident ≥ 2	42188	0.090	0.285	0	1	19255	0.118	0.322	0	1
Age	42188	29.97	13.07	0	77	19255	26.71	12.92	0	88
Beam trawler	42188	0.049	0.215	0	1	19255	0.174	0.380	0	1
Demersal trawler/seiner	42188	0.720	0.449	0	1	19255	0.588	0.492	0	1
Dredger	42188	0.133	0.339	0	1	19255	0.139	0.345	0	1
Drift/fixed netter	42188	0.025	0.156	0	1	19255	0.034	0.181	0	1
Hooks	42188	0	0	0	0	19255	0.052	0.222	0	1
Pelagic/purse seiner	42188	0.0001	0.012	0	1	19255	0.001	0.023	0	1
Pots and traps	42188	0.074	0.261	0	1	19255	0.012	0.110	0	1
27.4.a	42188	0.245	0.430	0	1	19255	0.387	0.487	0	1
27.4.b	42188	0.128	0.335	0	1	19255	0.137	0.343	0	1
27.4.c	42188	0.013	0.112	0	0	19255	0.007	0.085	0	1
27.6.a	42188	0.230	0.458	0	1	19255	0.082	0.275	0	1
27.6.b	42188	0.003	0.059	0	0	19255	0.023	0.150	0	1
27.7.a	42188	0.206	0.405	0	1	19255	0.044	0.205	0	1
27.7.c	42188	0	0	0	0	19255	0.015	0.121	0	1
27.7.d	42188	0.008	0.090	0	1	19255	0.051	0.221	0	1
27.7.e	42188	0.057	0.232	0	1	19255	0.110	0.313	0	1
27.7.f	42188	0.016	0.124	0	1	19255	0.009	0.096	0	1
27.7.g	42188	0.013	0.114	0	1	19255	0.009	0.096	0	1
27.7.h	42188	0.009	0.092	0	1	19255	0.048	0.213	0	1
27.7.j	42188	0.002	0.047	0	1	19255	0.061	0.239	0	1
27.7.k	42188	0	0	0	0	19255	0.016	0.124	0	1
Summer	42188	0.252	0.434	0	1	19255	0.247	0.431	0	1
Autumn	42188	0.248	0.432	0	1	19255	0.258	0.437	0	1
Winter	42188	0.247	0.431	0	1	19255	0.254	0.435	0	1
Spring	42188	0.253	0.435	0	1	19255	0.242	0.428	0	1
2008	42188	0.123	0.328	0	1	19255	0.119	0.324	0	1
2009	42188	0.121	0.326	0	1	19255	0.117	0.322	0	1
2010	42188	0.116	0.321	0	1	19255	0.118	0.323	0	1
2011	42188	0.108	0.310	0	1	19255	0.113	0.317	0	1
2012	42188	0.105	0.307	0	1	19255	0.106	0.307	0	1
2013	42188	0.110	0.312	0	1	19255	0.106	0.307	0	1
2014	42188	0.107	0.309	0	1	19255	0.107	0.309	0	1
2015	42188	0.105	0.307	0	1	19255	0.108	0.310	0	1
2016	42188	0.105	0.306	0	1	19255	0.106	0.308	0	1

5 Results

Results from model specification 1 analysing the effect of net profit on accident likelihood are presented first. As a technical note on the results, only marginal effects from logit and probit estimations are presented since the model coefficients are informative only for the sign of an effect. It has been confirmed, however, that all presented marginal effects have the same sign as the estimated model coefficients. Marginal effects are average marginal effects as defined in Section 4. Goodness of fit measures referring to the logit and probit regressions estimated by maximum likelihood are presented at the bottom panel of the regression tables. Various pseudo R^2 measures have been suggested for binary response models, and the pseudo R^2 reported in this paper follows the definition of McFadden. Percentage correctly predicted, a commonly used goodness of fit measure for logit and probit models is not reported here since it is downward biased for the less frequent outcome in an unbalanced sample, and mainly reflects the outcome shares (Cramer, 1999). It is good to note that goodness of fit in binary response models is not as important as the statistical and economic significance of the explanatory variables (Wooldridge, 2011). Results from a linear probability model are reported for comparison.

5.1. Net profit and accident likelihood

Table 7 below presents the marginal effects for fishing vessels less than 15 metres in length. The coefficient for net profit is not statistically significant, implying that profitability does not have an effect on the accident likelihood of small vessels. According to the probit and logit models, a unit increase in kW days leads to an increase of 0.000066 percentage points in accident probability. This finding is intuitive as vessels with higher effort in terms of kW days spend more time at sea making them more prone to suffering an accident. However, the average accident probability in the sample is 0.038, and hence the marginal increase of 0.000066 percentage points is practically insignificant. According to the probit model vessels using hooks are 3.95

percentage points more likely to suffer an accident compared to fixed/drift netters, the base category. However, this finding does not agree with the LPM and logit models. Lastly, accident likelihood was lower in 2012, 2014 and 2015 compared to 2008.

Table 7: Marginal effects for fishing vessels <15m

	LPM Accident		PROBIT Accident		LOGIT Accident	
Net profit	0.00000015	(<0.000)	0.00000011	(<0.000)	0.00000011	(<0.000)
kW days	0.00000072**	(<0.000)	0.00000066**	(<0.000)	0.00000066**	(<0.000)
Age	0.0006*	(<0.000)	0.0006*	(<0.000)	0.0006*	(<0.000)
Dredgers	-0.0097	(0.028)	-0.0098	(0.030)	-0.0109	(0.032)
Demersal trawler/seiner	0.0004	(0.020)	-0.0025	(0.024)	-0.0031	(0.025)
Pots and traps	-0.0280	(0.019)	-0.0293	(0.022)	-0.0299	(0.023)
Hooks	-0.0324	(0.020)	-0.0395*	(0.024)	-0.0396	(0.025)
Polyvalent active	-0.0006	(0.044)	0.0039	(0.058)	0.0031	(0.063)
Beam trawler	0.0105	(0.033)	0.0033	(0.033)	0.0063	(0.037)
VIIA	-0.0019	(0.015)	-0.0056	(0.015)	-0.0044	(0.016)
VIIDE	-0.0084	(0.013)	-0.0099	(0.011)	-0.0091	(0.012)
VIIFG	0.0174	(0.019)	0.0209	(0.024)	0.0232	(0.027)
West of Scotland	0.0009	(0.011)	0.0000	(0.011)	0.0006	(0.012)
2009	-0.0191	(0.027)	-0.0193	(0.024)	-0.0198	(0.026)
2010	-0.0019	(0.027)	-0.0010	(0.026)	-0.0031	(0.026)
2011	-0.0320	(0.025)	-0.0293	(0.023)	-0.0319	(0.024)
2012	-0.0389*	(0.023)	-0.0383*	(0.021)	-0.0400*	(0.023)
2013	-0.0033	(0.025)	0.0001	(0.024)	-0.0042	(0.026)
2014	-0.0455**	(0.022)	-0.0451**	(0.020)	-0.0469**	(0.022)
2015	-0.0378*	(0.022)	-0.0364*	(0.021)	-0.0393*	(0.022)
2016	-0.0174	(0.025)	-0.0153	(0.024)	-0.0178	(0.025)
Constant	0.0520**	(0.025)				
N	2346		2346		2346	
Pseudo R^2	0.020		0.060		0.060	
Log-likelihood			-358.77		-358.72	

Cluster-robust standard errors in parentheses [* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$]

Table 8 presents the results for vessels between 15-24 metres in length. According to all three models net profit has a statistically significant effect on accident probability. According to the probit model specification, a unit increase (1000£) in net profit leads to a 0.000023 percentage point reduction in accident likelihood. However, the mean accident probability in the sample for the medium length vessels is 0.113, rendering the marginal decrease in accident probability by net profit insignificant despite statistical significance.

Table 8: Marginal effects for fishing vessels 15-24m

	LPM Accident		PROBIT Accident		LOGIT Accident	
Net profit	-0.00000021**	(<0.000)	-0.00000023**	(<0.000)	-0.00000023**	(<0.000)
kW days	0.00000108*	(<0.000)	0.00000096**	(<0.000)	0.00000095**	(<0.000)
Age	0.0003	(0.001)	0.0002	(0.001)	0.0002	(0.001)
Dredgers	0.1874	(0.129)	0.0836*	(0.050)	0.0816	(0.051)
Demersal trawler/seiner	0.1721	(0.123)	0.0656*	(0.035)	0.0587*	(0.034)
Pots and traps	0.3250**	(0.127)	0.2292***	(0.062)	0.2249***	(0.063)
Beam trawler	0.2371**	(0.115)	0.1435**	(0.063)	0.1390**	(0.064)
VII Other	0.2405	(0.161)	0.2855	(0.221)	0.2745	(0.240)
VIIA	-0.0276	(0.032)	-0.0334	(0.032)	-0.0339	(0.033)
VIIDE	0.0363	(0.057)	0.0241	(0.051)	0.0191	(0.047)
VIIFG	0.3303***	(0.120)	0.3606**	(0.147)	0.3619**	(0.156)
West of Scotland	0.0237	(0.029)	0.0178	(0.027)	0.0183	(0.028)
2009	0.0609	(0.040)	0.0591	(0.038)	0.0594	(0.038)
2010	-0.0237	(0.036)	-0.0159	(0.033)	-0.0223	(0.033)
2011	0.0411	(0.040)	0.0415	(0.040)	0.0378	(0.042)
2012	0.0798**	(0.038)	0.0805**	(0.037)	0.0749*	(0.038)
2013	-0.0502	(0.032)	-0.0437	(0.031)	-0.0497	(0.031)
2014	-0.0028	(0.035)	-0.0022	(0.034)	-0.0038	(0.035)
2015	0.0633*	(0.037)	0.0705*	(0.037)	0.0667*	(0.037)
2016	0.0010	(0.038)	0.0047	(0.036)	-0.0001	(0.037)
Constant	-0.1702	(0.131)				
N	1172		1172		1172	
Pseudo R^2	0.059		0.079		0.079	
Log-likelihood			-379.91		-379.81	

Cluster-robust standard errors in parentheses [* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$]

Similarly to small vessels, higher effort in terms of kW days increases the likelihood to suffer an accident. However, the effect is negligible in light of the sample mean accident probability. Observing the second column with results from the probit regression, vessels using pots and traps are 22.92 percentage points more likely to suffer an accident compared to the comparison group of fixed/drift netters. Beam trawlers have a 14.35 percentage points higher accident likelihood than fixed/drift netters. Accident likelihood in the fishing area VIIFG is 36.06 percentage higher compared to the North Sea. Finally, accident likelihood for vessels 15-24 metres in length was higher 2012 and 2015 compared to 2008.

The results for the large boats, more than 24 metres in length are presented in table 9 below. According to the logit and probit models, a unit increase in net profit decreases accident likelihood by 0.000004 percentage points. The effect is negligible in practice.

Table 9: Marginal effects for fishing vessels >24m

	LPM Accident		PROBIT Accident		LOGIT Accident	
Net profit	-0.00000001	(<0.000)	-0.00000004*	(<0.000)	-0.00000004*	(0.002)
kW days	0.00000032*	(<0.000)	0.00000026**	(0.002)	0.00000026**	(0.002)
Age	0.0026	(0.002)	0.0022	(0.002)	0.0023	(0.000)
Demersal trawler/seiner	-0.0172	(0.070)	-0.0091	(0.060)	-0.0051	(0.062)
Beam trawler	-0.0986	(0.076)	-0.0682	(0.054)	-0.061	(0.055)
Pelagic trawler	-0.0799	(0.085)	-0.0589	(0.066)	-0.057	(0.065)
VII Other	0.0805	(0.060)	0.0724	(0.058)	0.0698	(0.059)
VIIA	0.0051	(0.089)	0.0151	(0.073)	0.0131	(0.071)
VIIDE	0.1065**	(0.052)	0.0951*	(0.051)	0.0936*	(0.051)
VIIFG	0.1934	(0.177)	0.1861	(0.180)	0.1966	(0.186)
West of Scotland	0.0453	(0.042)	0.0480	(0.045)	0.0565	(0.048)
2009	0.0863	(0.054)	0.0897*	(0.053)	0.0842*	(0.054)
2010	0.0383	(0.050)	0.0356	(0.048)	0.0362	(0.049)
2011	0.0428	(0.043)	0.0485	(0.043)	0.0467	(0.044)
2012	0.0592	(0.045)	0.0685	(0.046)	0.0650	(0.047)
2013	-0.0185	(0.045)	-0.0122	(0.046)	-0.0143	(0.047)
2014	0.0369	(0.054)	0.0539	(0.056)	0.0454	(0.057)
2015	-0.0233	(0.041)	-0.0188	(0.042)	-0.0215	(0.042)
2016	-0.0449	(0.045)	-0.0272	(0.043)	-0.0307	(0.430)
Constant	-0.0095	(0.109)				
N	744		744		744	
Pseudo R^2	0.061		0.084		0.085	
Log-likelihood			-245.88		-245.71	

Cluster-robust standard errors in parentheses [* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$]

Despite statistical significance, the practical importance of the coefficient of kW days is insignificant as well. According to the probit and logit models, accident probability in the fishing area VIIA is higher compared to the North Sea and accident likelihood was higher in 2009 compared to 2008.

The hypothesis that higher net profit leads to lower accident probability is confirmed for medium and large fishing vessels. However, as discussed the practical significance of this finding is negligible. The magnitude of the effect of net profit on accident likelihood is minor compared to that of gear type, fishing area or even year. Results from estimations using a sample excluding low activity vessels are almost identical to the results presented above for all length groups. The results with a limited sample are presented in appendix A.

5.1. Value per unit of effort and accident likelihood

Results for the effect of VPUE on accident likelihood are presented only for vessels belonging to the medium or large length groups due to concerns over the credibility of data for small vessels. As explained in Section 3, vessels less than 10 metres are not required to submit logbooks and landings declarations. Therefore, effort data for these vessels are mainly estimates from sales notes and figures from voluntarily submitted logbooks. Thus, using estimated effort data for the construction of the VPUE variable can render the results for small vessels unreliable. The results for vessels less than 15 metres in length are presented in appendix B only.

Model specification 2 was estimated using actual VPUE and VPUE lagged by one or two months. VPUE lagged by one month led to the best model fit and was thus included in the final model specification. Neither VPUE in the current month or VPUE lagged by two months were statistically significant.

Table 10 presents the results for medium length vessels.

Table 10: Marginal effects for fishing vessels 15-24m

	LPM Accident		PROBIT Accident		LOGIT Accident	
VPUE lag	-0.0002**	(<0.000)	-0.0002**	(<0.000)	-0.0002**	(<0.000)
Past accident=1	0.0019	(0.001)	0.0018	(0.001)	0.0019	(0.001)
Past accident ≥ 2	0.0064**	(0.003)	0.0060**	(0.002)	0.0059**	(0.002)
Age	-0.0001	(<0.000)	-0.0001	(<0.000)	-0.0001	(<0.000)
Demersal trawler/seiner	-0.0026	(0.005)	-0.0030	(0.004)	-0.0032	(0.004)
Dredger	-0.0000	(0.005)	-0.0002	(0.004)	-0.0003	(0.004)
Drift/fixed netter	0.050	(0.006)	0.0049	(0.006)	0.0048	(0.005)
Pelagic/purse seiner	0.3157***	(0.003)	0.2535***	(0.031)	0.2260***	(0.044)
Pots and traps	0.0044	(0.004)	0.0036	(0.003)	0.0033	(0.003)
27.4.b	0.0013	(0.002)	0.0013	(0.002)	0.0014	(0.002)
27.4.c	-0.0021	(0.006)	-0.0020	(0.004)	-0.0020	(0.004)
27.6.a	0.0020	(0.002)	0.0019	(0.002)	0.0019	(0.002)
27.6.b	0.0166*	(0.010)	0.0147*	(0.009)	0.0146*	(0.009)
27.7.a	-0.0025	(0.002)	-0.0029*	(0.002)	-0.0028*	(0.002)
27.7.d	0.0041	(0.006)	0.0030	(0.004)	0.0025	(0.004)
27.7.e	0.0061	(0.005)	0.0051	(0.004)	0.0049	(0.004)
27.7.f	0.0073	(0.007)	0.0050	(0.005)	0.0048	(0.005)
27.7.g	-0.0042	(0.005)	-0.0031	(0.003)	-0.0028	(0.003)
27.7.h	0.0062	(0.008)	0.0047	(0.007)	0.0043	(0.006)
27.7.j	-0.0030	(0.012)	-0.0015	(0.008)	-0.0015	(0.007)
Autumn	0.0008	(0.001)	0.0010	(0.001)	0.0009	(0.001)
Winter	-0.0012	(0.001)	-0.0010	(0.001)	-0.0011	(0.001)
Spring	0.0000	(0.001)	0.0002	(0.001)	0.0001	(0.001)
2009	0.0007	(0.002)	0.0008	(0.002)	0.0007	(0.002)
2010	-0.0012	(0.002)	-0.0011	(0.002)	-0.0013	(0.002)
2011	0.0012	(0.002)	0.0011	(0.002)	0.0011	(0.002)
2012	0.0027	(0.002)	0.0027	(0.002)	0.0025	(0.002)
2013	-0.0015	(0.002)	-0.0014	(0.002)	-0.0016	(0.002)
2014	-0.0038*	(0.002)	-0.0035*	(0.002)	-0.0037*	(0.002)
2015	-0.0022	(0.002)	-0.0019	(0.002)	-0.0021	(0.002)
2016	-0.0012	(0.002)	-0.0010	(0.002)	-0.0012	(0.002)
Constant	0.0133**	(0.005)				
N	40226		40226		40226	
Pseudo R^2	0.003		0.021		0.021	
Log-likelihood			-2181.89		-2182.02	

Cluster-robust standard errors in parentheses [* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$]

According to the results from all three models, a unit increase in VPUE decreases accident likelihood by 0.02 percentage points. Thus, a one unit increase in VPUE in the past month leads to a reduction in accident likelihood in the current month. The results in table 10 also indicate that having suffered two or more accidents in the past increases current accident likelihood by 0.59-0.64 percentage points depending on the model used for estimation. Interestingly, the effect of having suffered one accident is not statistically significant. Finally, accident probability is higher for pelagic/purse seiners compared to the comparison category of beam trawlers, accident likelihood is higher in area 27.6.b compared to the reference area 27.4.a and accident likelihood was lower in 2014 relative to 2008.

Table 11 contains the final results for large vessels. The effect of lagged VPUE on accident likelihood is not significant for large vessels. Moreover, past accidents are not a statistically significant determinant for the likelihood to suffer an accident. This finding is likely to result from large vessels' smaller frequency of past accidents compared to medium or small vessels. Stricter safety regulations for larger vessels are likely to play a role in preventing reoccurring accidents. Moreover, the financial resources of larger vessels could dampen the effect of past accidents by ensuring that necessary repairs and maintenance following an accident can be undertaken.

The hypothesis that an increase in VPUE decreases accident likelihood is confirmed for vessels with overall length 15-24m. Interestingly, only the lagged value of VPUE had a statistically significant effect on accident likelihood. This finding does intuitively make sense, however. If a vessel has only extracted low value for the time spent at sea in the previous month, the objective to maximize value in the following month becomes more pronounced. The following section will discuss this finding in more detail. Results with a sample excluding low activity vessels are presented in appendix B.

Table 11: Marginal effects for fishing vessels >24m

	LPM Accident		PROBIT Accident		LOGIT Accident	
VPUE lag	-0.0001	(<0.000)	-0.0001	(0.000)	-0.0001	(<0.000)
Past accident=1	0.0035	(0.002)	0.0035	(0.002)	0.0034	(0.002)
Past accident ≥ 2	0.0079	(0.006)	0.0081	(0.006)	0.0085	(0.006)
Age	-0.0001	(<0.000)	-0.0000	(0.000)	-0.0001	(<0.000)
Demersal trawler/seiner	-0.0060	(0.004)	-0.0062	(0.005)	-0.0070	(0.005)
Dredgers	0.0014	(0.004)	0.0007	(0.004)	0.0001	(0.005)
Drift/fixed netter	-0.0040	(0.006)	-0.0040	(0.007)	-0.0054	(0.006)
Hooks	0.0015	(0.005)	0.0018	(0.007)	0.0010	(0.007)
Pelagic/purse seiner	0.0854	(0.094)	0.0964	(0.103)	0.0964	(0.106)
Pots and traps	-0.0109*	(0.006)	-0.0109*	(0.006)	-0.0119*	(0.006)
27.4.b	-0.0077***	(0.003)	-0.0077***	(0.003)	-00082***	(0.003)
27.4.c	-0.0092	(0.008)	-0.0079	(0.006)	-0.0084	(0.006)
27.6.a	0.0002	(0.004)	0.0001	(0.004)	0.00004	(0.005)
27.6.b	0.0084	(0.007)	0.0091	(0.008)	0.0093	(0.008)
27.7.a	0.0127	(0.008)	0.0104	(0.007)	0.0103	(0.007)
27.7.c	-0.0077	(0.005)	-0.0091	(0.005)	-0.0094	(0.006)
27.7.d	-0.0024	(0.005)	-0.0027	(0.004)	-0.0029	(0.004)
27.7.e	-0.0031	(0.004)	-0.0033	(0.004)	-0.0038	(0.004)
27.7.f	0.0030	(0.012)	0.0013	(0.011)	0.0011	(0.011)
27.7.g	-0.0073	(0.006)	-0.0083	(0.006)	-0.0082	(0.006)
27.7.h	-0.0056	(0.005)	-0.0054	(0.005)	-0.0062	(0.005)
27.7.j	-0.0060*	(0.003)	-0.0070*	(0.004)	-0.0075*	(0.004)
27.7.k	-0.0092**	(0.005)	-0.0103**	(0.004)	-0.0102**	(0.005)
Autumn	-0.0003	(0.002)	-0.0006	(0.002)	-0.0004	(0.002)
Winter	0.0015	(0.003)	0.0014	(0.003)	0.0013	(0.003)
Spring	-0.00004	(0.002)	-0.0003	(0.002)	-0.0001	(0.002)
2009	0.0031	(0.004)	0.0028	(0.004)	0.0029	(0.005)
2010	0.0006	(0.004)	0.0001	(0.004)	0.0002	(0.004)
2011	0.0001	(0.004)	0.0006	(0.004)	0.0005	(0.005)
2012	-0.0017	(0.004)	-0.0024	(0.004)	-0.0023	(0.005)
2013	-0.0058*	(0.003)	-0.0063*	(0.004)	-0.0063*	(0.003)
2014	-0.0049	(0.004)	-0.0054	(0.004)	-0.0055	(0.004)
2015	-0.0074*	(0.004)	-0.0074*	(0.004)	-0.0077*	(0.004)
2016	-0.0083**	(0.004)	-0.0088**	(0.004)	-0.0087**	(0.004)
Constant	0.0204***	(0.006)				
N	17718		17718		17718	
Pseudo R^2	0.005		0.032		0.032	
Log-likelihood			-1090.68		-1090.36	

Cluster-robust standard errors in parentheses [* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6 Discussion

The results presented in the previous section demonstrate that the relationship between fishing vessels' economic performance and likelihood to suffer an accident is not unambiguous. First, the effect of economic performance depends on the chosen indicator. Second, interpreting the effects is challenging. As concluded in the brief literature review in Section 2, high net profits can enable vessel owners to spend more on pre-emptive maintenance or other safety improving measures thereby decreasing the accident likelihood of a vessel. Moreover, vessel owners and fishermen operating profitable vessels could value safety more to be able to continue to earn high profits leading them to make decisions and take actions that decrease accident likelihood. On the other hand, increases in net profit can also be achieved by cutting costs at the expense of safety. The results of this paper indicated that increases in net profit lead to a lower accident likelihood. The magnitude of the effect, however, was insignificant in practice. Regardless, further research needs to be conducted to gain a better understanding of the different direct and indirect channels through which net profit influences accident likelihood of fishing vessels.

The findings indicated that the effect of lagged VPUE on the accident likelihood of vessels between 15 and 24 metres in length is negative meaning that a higher VPUE in the previous month Ieads to a lower accident likelihood in the current month. Again, this effect could be realised through multiple channels. Firstly, low value per unit of effort could be an indication of operational problems related to gear or crew for example. Poorly maintained gear or inexperienced crew members could potentially have a negative effect on the amount of catch and thereby the total value per unit of effort landed. However, value per unit of effort is also affected by catch prices and a host of other factors that were not controlled for in this study. Another possible explanation for the effect of VPUE on accident likelihood is risk-taking behaviour. Fishermen who have extracted low value per unit of effort in the previous month could be more likely to engage in risky behaviour when faced with financial pressures of having to cover vessel and operational costs after a month of low value. However, no research exploring the connection between risk-taking behaviour of fishermen and low VPUE has been published, and hence the discussion of the topic should be judged accordingly.

In addition to conducting further research on the effect of net profit and VPUE on accident likelihood, results could be improved by employing estimation techniques that can take individual vessel-level unobserved heterogeneity into account. As explained in Section 4, pooled estimators were chosen for the purpose of this study due to the unbalanced panel structure of the data and the computational difficulty of panel estimators for binary choice models. However, logit and probit models with unobserved effects are becoming more popular, and methods for unbalanced panels are being developed increasingly (Albarran, Carrasco & Carro, 2015). Addressing potential unobserved heterogeneity between vessels could influence the estimation results.

Insights for modeling the accident probability of fishing vessels can also be derived from the estimation of highway accidents. Like fishing vessel accidents "it is impossible to have access to all of the data that could potentially determine the likelihood of a highway accident or its resulting injury severity" (Mannering, Shankar & Bhat, 2016). The researchers suggest that the problem of unobserved heterogeneity, which, if correlated with regressors, can potentially lead to biases or inconsistencies in parameter estimates, can be addressed with statistical methods such as random parameter models and latent-class models. Further research should explore the potential of using such methods in the context of fishing vessels. These methods, however, also still need continuing advances in techniques and computational power (Mannering et al., 2016).

7 Conclusion

The purpose of this research commissioned by Seafish in assistance with the Marine Accident Investigation Branch was to determine whether there is a link between the economic performance of fishing vessels and their likelihood to suffer an accident. The findings on the effect of net profit and value per unit of effort on accident likelihood varied between the small, medium and large fishing vessels. Moreover, the interpretation of the results was hindered due to a lack of published research addressing the role of economic performance, particularly that of net profit and VPUE on the likelihood to suffer an accident. However, as discussed in the previous section, more advanced estimation techniques could improve the results and further research into the direct and indirect influences of economic performance on safety at sea should be undertaken. Reiterating the introduction, economic pressures are, after all, potentially one of greatest driving forces in the fishing industry (MAIB, 2008).

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9 Appendix

Appendix A

Table A1: Marginal effects for fishing vessels less than 15m, excluding low activity vessels

	LPM Accident		Probit Accident		Logit Accident	
Net profit	0.000000	(0.000)	0.000000	(0.000)	0.000000	(0.000)
Age	0.000600*	(0.000)	0.000582*	(0.000)	0.000614*	(0.000)
kW days	0.000001	(0.000)	0.000001*	(0.000)	0.000001*	(0.000)
Dredger	-0.014191	(0.031)	-0.014854	(0.034)	-0.015325	(0.037)
Demersal trawler/seiner	-0.004010	(0.023)	-0.007019	(0.027)	-0.007029	(0.029)
Pots and traps	-0.034264	(0.022)	-0.036108	(0.026)	-0.035887	(0.027)
Hooks	-0.047297**	(0.022)	-0.055016**	(0.026)	-0.054139**	(0.028)
Polyvalent active	-0.008527	(0.045)	-0.006082	(0.059)	-0.006187	(0.064)
Beam trawler	0.004231	(0.036)	-0.002481	(0.037)	0.000861	(0.041)
VIIA	-0.002206	(0.017)	-0.005381	(0.016)	-0.003997	(0.017)
VIIDE	-0.011963	(0.015)	-0.012874	(0.012)	-0.011562	(0.013)
VIIFG	0.020963	(0.022)	0.025430	(0.028)	0.026974	(0.031)
WoS	0.000550	(0.012)	-0.000216	(0.012)	0.000303	(0.013)
2009	-0.016615	(0.028)	-0.017241	(0.026)	-0.017903	(0.027)
2010	0.000846	(0.028)	0.001177	(0.027)	-0.000914	(0.028)
2011	-0.031497	(0.025)	-0.0296460	(0.024)	-0.032106	(0.025)
2012	-0.038400*	(0.023)	-0.038144*	(0.023)	-0.039727*	(0.024)
2013	-0.002442	(0.026)	-0.000549	(0.026)	-0.004348	(0.027)
2014	-0.045709**	(0.022)	-0.045646**	(0.021)	-0.047387**	(0.023)
2015	-0.036361	(0.022)	-0.035554*	(0.022)	-0.038472*	(0.023)
2016	-0.013082	(0.026)	-0.011293	(0.025)	-0.013874	(0.027)
Constant	0.060030**	(0.028)				
Observations	2120		2120		2120	
Pseudo R-squared	0.019		0.055		0.055	
Log-likelihood			-349.112		-349.081	

Cluster-robust standard errors in parentheses [* p<0.10, ** p<0.05, *** p<0.01]

Table A2: Marginal effects for fishing vessels 15-24m, excluding low activity vessels

	LPM Accident		Probit Accident		Logit Accident	
Net profit	<-0.000000**	(<0.000)	<-0.000000**	(<0.000)	<-0.000000**	(<0.000)
Age	0.000308	(0.001)	0.000229	(0.001)	0.000242	(0.001)
kW days	0.000001*	(<0.000	0.000001**	(<0.000)	0.000001*	(<0.000)
Dredgers	0.187605	(0.129)	0.083776*	(0.050)	0.081660	(0.051)
Demersal trawler/seiner	0.172273	(0.122)	0.065768*	(0.035)	0.058842*	(0.034)
Pots and traps	0.326710**	(0.127)	0.230803***	(0.062)	0.226217***	(0.063)
Beam trawler	0.236700**	(0.115)	0.143166**	(0.063)	0.138644**	(0.064)
VII OTHER	0.240616	(0.161)	0.285454	(0.220)	0.274689	(0.239)
VIIA	-0.028231	(0.032)	-0.033959	(0.032)	-0.034411	(0.032)
VIIDE	0.036485	(0.057)	0.024217	(0.051)	0.019311	(0.047)
VIIFG	0.330261***	(0.119)	0.360495**	(0.146)	0.361666**	(0.154)
WoS	0.023327	(0.029)	0.017596	(0.027)	0.018130	(0.028)
2009	0.061748	(0.041)	0.059946	(0.038)	0.060223	(0.039)
2010	-0.022423	(0.036)	-0.015029	(0.033)	-0.021436	(0.033)
2011	0.041007	(0.040)	0.041416	(0.040)	0.037770	(0.042)
2012	0.079641**	(0.038)	0.080316**	(0.037)	0.074820*	(0.038)
2013	-0.050484	(0.032)	-0.043832	(0.031)	-0.049800	(0.031)
2014	-0.003030	(0.035)	-0.002344	(0.034)	-0.003976	(0.035)
2015	0.063672*	(0.037)	0.070878*	(0.037)	0.067059*	(0.038)
2016	0.000833	(0.038)	0.004635	(0.036)	-0.000266	(0.037)
Constant	-0.169481	(0.131)				
Observations	1169		1169		1169	
Pseudo R-squared	0.059		0.054		0.054	
Log-likelihood			-379.589		-379.500	

Cluster-robust standard errors in parentheses [* p<0.10, ** p<0.05, *** p<0.01]

Table A3: Marginal effects for fishing vessels over 24m, excluding low activity vessels

	LPM Accident		Probit Accident		Logit Accident	
Net profit	<-0.000000	(<0.000)	<-0.000000**	(<0.000)	<-0.000000**	(<0.000)
Age	0.002645	(0.002)	0.002283	(0.002)	0.002362	(0.002)
kW days	<0.000000*	(<0.000)	<0.000000**	(<0.000)	<0.000000***	(<0.000)
Demersal trawler/seiner	-0.014015	(0.071)	-0.004903	(0.060)	0.000425	(0.062)
Beam trawler	-0.101310	(0.075)	-0.069319	(0.054)	-0.062083	(0.054)
Pelagic trawler	-0.077712	(0.085)	-0.056163	(0.066)	-0.053699	(0.065)
VII OTHER	0.083630	(0.060)	0.076193	(0.058)	0.074362	(0.060)
VIIA	0.004688	(0.089)	0.014927	(0.072)	0.012433	(0.070)
VIIDE	0.108801**	(0.052)	0.098001*	(0.052)	0.097231*	(0.053)
VIIFG	0.246224	(0.183)	0.254044	(0.186)	0.274056	(0.184)
WoS	0.045614	(0.042)	0.048393	(0.045)	0.057047	(0.047)
2009	0.085089	(0.053)	0.088004*	(0.052)	0.082184	(0.054)
2010	0.038153	(0.050)	0.035412	(0.048)	0.035960	(0.049)
2011	0.042717	(0.043)	0.048351	(0.043)	0.046458	(0.044)
2012	0.063022	(0.045)	0.072655	(0.046)	0.070084	(0.047)
2013	-0.018784	(0.045)	-0.012517	(0.046)	-0.014725	(0.047)
2014	0.036377	(0.054)	0.053330	(0.056)	0.044591	(0.057)
2015	-0.024517	(0.041)	-0.019830	(0.042)	-0.023202	(0.042)
2016	-0.047172	(0.046)	-0.028960	(0.043)	-0.033195	(0.043)
Constant	-0.013410	(0.109)				
Observations	743		743		743	
Pseudo R-squared	0.062		0.086		0.087	
Log-likelihood			-245.2909		-245.049	

Cluster-robust standard errors in parentheses [* p<0.10, ** p<0.05, *** p<0.01]

Appendix B

Table B1: Marginal effects for fishing vessels less than 15m

	LPM Accident		Probit Accident		Logit Accident	
VPUE lag	-0.000005*	(<0.000)	-0.000017*	(0.<000)	-0.000016*	(0.<000)
Past accident=1	0.006007***	(0.001)	0.005985***	(0.001)	0.006046***	(0.001)
Past accident >2	0.011658***	(0.002)	0.011322***	(0.002)	0.011257***	(0.002)
Age	0.000024**	(0.000)	0.000026***	(0.000)	0.000027***	(0.000)
Demersal trawler/seiner	-0.002996*	(0.002)	-0.003222*	(0.002)	-0.002927*	(0.002)
Dredger	-0.000846	(0.002)	-0.000976	(0.002)	-0.000680	(0.002)
Drift/fixed netter	-0.003901**	(0.002)	-0.004067**	(0.002)	-0.003764**	(0.002)
Hooks	-0.005307***	(0.002)	-0.005486***	(0.002)	-0.005200***	(0.002)
Mobile polyvalent	-0.002702	(0.003)	-0.002522	(0.004)	-0.002332	(0.004)
Pots & traps	-0.004078**	(0.002)	-0.004241**	(0.002)	-0.003909**	(0.002)
27.4.b	0.001736***	(0.000)	0.001719***	(0.<000)	0.001821***	(0.<000)
27.4.c	0.000741	(0.001)	0.000834	(0.001)	0.000951	(0.001)
27.6.a	0.000746*	(<0.000	0.000788*	(0.<000)	0.000865*	(0.<000
27.7.a	0.001060*	(0.001)	0.001029*	(0.001)	0.001147**	(0.001)
27.7.d	-0.000191	(<0.000)	-0.000188	(0.<000)	-0.000087	(0.001)
27.7.e	0.001551***	(<0.000)	0.001511***	(0.<000)	0.00157***	(0.001)
27.7.f	0.002233***	(0.001)	0.002417***	(0.001)	0.002583***	(0.001)
27.7.g	0.004354***	(0.002)	0.004478***	(0.002)	0.004760***	(0.002)
Autumn	0.000205	(<0.000)	0.000175	(0.<000)	0.000204	(0.<000)
Winter	-0.000518	(<0.000)	-0.000455	(0.<000)	-0.000487	(0.<000)
Spring	0.000423	(<0.000)	0.000421	(0.<000)	0.000397	(0.<000)
2009	0.000075	(0.001)	-0.000025	(0.001)	-0.000019	(0.001)
2010	0.000643	(0.001)	0.000504	(0.001)	0.000493	(0.001)
2011	-0.001804***	(0.001)	-0.002038***	(0.001)	-0.002156***	(0.001)
2012	-0.000687	(0.001)	-0.000865	(0.001)	-0.001010	(0.001)
2013	-0.000048	(0.001)	-0.000351	(0.001)	-0.000453	(0.001)
2014	-0.001867***	(0.001)	-0.002110***	(0.001)	-0.002139***	(0.001)
2015	-0.003145***	(0.001)	-0.003141***	(0.001)	-0.003256***	(0.001)
2016	-0.001922***	(0.001)	-0.002077***	(0.001)	-0.002171***	(0.001)
Constant	0.006189***	(0.002)				
Observations	247087		247087		247087	
Pseudo R-squared	0.002		0.037		0.037	
Log-likelihood			-6022.68		-6021.57	

Cluster-robust standard errors in parentheses [* p<0.10, ** p<0.05, *** p<0.01]

Table B2: Marginal effects for fishing vessels less than 15m, excluding low activity

	LPM Accident		Probit Accident		Logit Accident	
VPUE lag	-0.000001	(<0.000)	-0.000004	(<0.000)	-0.000003	(<0.000)
Past accident=1	0.005646***	(0.001)	0.005651***	(0.001)	0.005726***	(0.001)
Past accident>2	0.010868***	(0.002)	0.010640***	(0.002)	0.010607**	(0.002)
Age	0.000027**	(<0.000)	0.000029**	(<0.000	0.000030**	(<0.000)
Demersal trawler/seiner	-0.003166*	(0.002)	-0.003261*	(0.002)	-0.002971	(0.002)
Dredger	-0.000901	(0.002)	-0.000975	(0.002)	-0.000651	(0.002)
Drift/fixed netter	-0.003799**	(0.002)	-0.003831*	(0.002)	-0.003567*	(0.002)
Hooks	-0.005546***	(0.002)	-0.005620***	(0.002)	-0.005353***	(0.002)
Mobile polyvalent	-0.003239	(0.003)	-0.003205	(0.004)	-0.002971	(0.004)
Pots & traps	-0.004239**	(0.002)	-0.004339**	(0.002	-0.004016**	(0.002)
27.4.b	0.001692***	(0.001)	0.001649***	(0.001)	0.001767***	(0.001)
27.4.c	0.001142	(0.001)	0.001191*	(0.001	0.001310*	(0.001)
27.6.a	0.000715	(<0.000)	0.000682	(0.001)	0.000778	(0.001)
27.7.a	0.001237*	(0.001)	0.001141*	(0.001)	0.001270**	(0.001)
27.7.d	-0.000371	(0.001)	-0.000447	(0.001)	-0.000326	(0.001)
27.7.e	0.001807***	(0.001)	0.001683***	(0.001)	0.001750***	(0.001)
27.7.f	0.002330***	(0.001)	0.002355**	(0.001)	0.002573***	(0.001)
27.7.g	0.005353**	(0.002)	0.005206***	(0.002)	0.005586***	(0.002)
Autumn	0.000462	(<0.000)	0.000420	(<0.000)	0.000459	(<0.000)
Winter	-0.000502	(<0.000)	-0.000463	(<0.000)	-0.000487	(<0.000)
Spring	0.000251	(<0.000)	0.000265	(<0.000)	0.00024	(<0.000)
2009	0.000083	(0.001)	-0.000029	(0.001)	-0.000019	(0.001)
2010	0.000644	(0.001)	0.000502	(0.001)	0.000472	(0.001)
2011	-0.002157***	(0.001)	-0.002438***	(0.001)	-0.002572***	(0.001)
2012	-0.000777	(0.001)	-0.000996	(0.001)	-0.001162	(0.001)
2013	-0.000176	(0.001)	-0.000500	(0.001)	-0.000634	(0.001)
2014	-0.002095***	(0.001)	-0.002371***	(0.001)	-0.002413***	(0.001)
2015	-0.003291***	(0.001)	-0.003295***	(0.001)	-0.003446***	(0.001)
2016	-0.002259***	(0.001) -	0.002454***	(0.001)	-0.002536***	(0.001)
Constant	0.006484***	(0.002)				
Observations	194689		194689		194689	
Pseudo R-squared	0.002		0.035		0.035	
Log-likelihood			-5113.871		-5112.643	

Cluster-robust standard errors in parentheses [* p<0.10, ** p<0.05, *** p<0.01]

Table B3: Marginal effects for fishing vessels 15-24m, excluding low activity vessels

	LPM Accident		Probit Accident		Logit Accident	
VPUE lag	-0.000196**	(<0.000)	-0.000202	(<0.000)	-0.000216*	(<0.000)
Past accident=1	0.001727	(0.001)	0.001555	(0.001)	0.001703	(0.001)
Past accident>2	0.006417**	(0.003)	0.005973**	(0.002)	0.005944**	(0.002)
Age	-0.000068	(<0.000)	-0.000071*	(<0.000)	-0.000068	(<0.000)
Demersal trawler/seiner	-0.002537	(0.005)	-0.002986	(0.004)	-0.003148	(0.004)
Dredger	0.000143	(0.005)	-0.000032	(0.004)	-0.000262	(0.004)
Drift/fixed netter	0.005104	(0.006)	0.005043	(0.006)	0.004940	(0.005)
Pelagic/purse seiner	0.315719***	(0.003)	0.251194***	(0.031)	0.223014***	(0.044)
Pots & traps	0.004565	(0.004)	0.003738	(0.003)	0.003385	(0.003
27.4.b	0.001661	(0.002)	0.001673	(0.002)	0.001771	(0.002)
27.4.c	-0.001529	(0.006)	-0.001457	(0.004)	-0.001473	(0.004)
27.6.a	0.002189	(0.002)	0.002071	(0.002)	0.002144	(0.002)
27.6.b	0.016625*	(0.010)	0.014339*	(0.008)	0.014205*	(0.008)
27.7.a	-0.002051	(0.002)	-0.002481	(0.002)	-0.002451	(0.002)
27.7.d	0.004320	(0.006)	0.003195	(0.004)	0.002629	(0.004)
27.7.e	0.006388	(0.005)	0.005366	(0.004)	0.005127	(0.004)
27.7.f	0.007562	(0.007)	0.005324	(0.005)	0.005081	(0.005)
27.7.g	-0.003969	(0.005)	-0.002837	(0.003)	-0.002567	(0.003)
27.7.h	0.006315	(0.008)	0.004724	(0.007)	0.004352	(0.006)
27.7.j	-0.002793	(0.012)	-0.001195	(0.008)	-0.001240	(0.007)
Autumn	0.000720	(0.001)	0.000877	(0.001)	0.000791	(0.001)
Winter	-0.001539	(0.001)	-0.001325	(0.001)	-0.001387	(0.001)
Spring	0.000020	(0.001)	0.000225	(0.001)	0.000112	(0.001)
2009	0.000768	(0.002)	0.000876	(0.002)	0.000777	(0.002)
2010	-0.000908	(0.002)	-0.000832	(0.002)	-0.000991	(0.002)
2011	0.001477	(0.002)	0.001429	(0.002)	0.001432	(0.002)
2012	0.002953	(0.002)	0.002933	(0.002)	0.002810	(0.002)
2013	-0.001455	(0.002)	-0.001323	(0.002)	-0.001518	(0.002)
2014	-0.003727*	(0.002)	-0.003468*	(0.002)	-0.003647*	(0.002)
2015	-0.001851	(0.002)	-0.001584	(0.002)	-0.001831	(0.002)
2016	-0.000902	(0.002)	-0.000721	(0.002)	-0.000872	(0.002)
Constant	0.013230**	(0.005)				
Observations	40192		40192		40192	
Pseudo R-squared	0.003		0.022		0.022	
Log-likelihood			-2161.901		-2162.095	

Cluster-robust standard errors in parentheses [* p<0.10, ** p<0.05, *** p<0.01]

Table B4: Marginal effects for fishing vessels over 24m, excluding low activity vessels

	LPM		Probit		Logit	
	Accident		Accident		Accident	
VPUE lag	-0.000064	(<0.000)	-0.000102	(<0.000)	-0.000103	(<0.000)
Past accident=1	0.003556	(0.002)	0.003534	(0.002)	0.003474	(0.002)
Past accident>2	0.007984	(0.006)	0.008240	(0.006)	0.008621	(0.006)
Age	-0.000067	(<0.000)	-0.000053	(<0.000)	-0.000053	(0.000)
Demersal trawler/seiner	-0.005674	(0.004)	-0.005964	(0.005)	-0.006679	(0.005)
Dredger	0.001156	(0.004)	0.000564	(0.004)	-0.000087	(0.005)
Drift/fixed netter	-0.004074	(0.005)	-0.003937	(0.007)	-0.005293	(0.007)
Hooks	0.001499	(0.005)	0.001836	(0.007)	0.000962	(0.007)
Pelagic/purse seiner	0.085984	(0.094)	0.098512	(0.104)	0.099618	(0.109)
Pots & traps	-0.010617*	(0.006)	-0.010668*	(0.006)	-0.011586*	(0.006)
27.4.b	-0.007628***	(0.003)	-0.007575**	(0.003)	-0.008027**	(0.003)
27.4.c	-0.008840	(0.008)	-0.007713	(0.006)	-0.008193	(0.006)
27.6.a	0.000254	(0.004)	0.000218	(0.004)	-0.000002	(0.005)
27.6.b	0.008469	(0.007)	0.009190	(0.008)	0.009361	(0.008)
27.7.a	0.011731	(0.008)	0.009642	(0.007)	0.009464	(0.007)
27.7.c	-0.007597	(0.005)	-0.009071*	(0.005)	-0.009336*	(0.006)
27.7.d	-0.002094	(0.004)	-0.002476	(0.004)	-0.002687	(0.004)
27.7.e	-0.002995	(0.004)	-0.003269	(0.004)	-0.003738	(0.004)
27.7.f	0.0029078	(0.012)	0.001260	(0.011)	0.001039	(0.011)
27.7.g	-0.007434	(0.006)	-0.008271	(0.006)	-0.008173	(0.006)
27.7.h	-0.005626	(0.005)	-0.005415	(0.005)	-0.006122	(0.005)
27.7.j	-0.005957*	(0.003)	-0.006923*	(0.004)	-0.007401*	(0.004)
27.7.k	-0.009277**	(0.005)	-0.010245**	(0.004)	-0.010173**	(0.005)
Autumn	-0.000529	(0.002)	-0.000806	(0.002)	-0.000589	(0.002)
Winter	0.001489	(0.003)	0.001404	(0.003)	0.001344	(0.003)
Spring	-0.000044	(0.002)	-0.000296	(0.002)	-0.000124	(0.002)
2009	0.003017	(0.004)	0.002737	(0.005)	0.002797	(0.005)
2010	-0.000023	(0.004)	-0.000508	(0.004)	-0.000512	(0.004)
2011	0.000006	(0.004)	-0.000669	(0.004)	-0.000696	(0.005)
2012	-0.001839	(0.004)	-0.002548	(0.004)	-0.002560	(0.005)
2013	-0.005950*	(0.003)	-0.006416*	(0.004)	-0.006520*	(0.004)
2014	-0.005064	(0.004)	-0.005554	(0.004)	-0.005685	(0.005)
2015	-0.007545*	(0.004)	-0.007541*	(0.004)	-0.007936*	(0.004)
2016	-0.008568**	(0.004)	-0.008944**	(0.004)	-0.008899**	(0.004)
Constant	0.0198950***	(0.006)				
Observations	17709		17709		17709	
Pseudo R-squared	0.004		0.031		0.032	
Log-likelihood			-1087.10		-1086.83	

Cluster-robust standard errors in parentheses [* p<0.10, ** p<0.05, *** p<0.01]