Ocean & Coastal Management 130 (2016) 115–127

Contents lists available at ScienceDirect

Ocean & Coastal Management

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

The effect of extreme weather conditions on commercial fishing activities and vessel incidents in Atlantic Canada

Sara Rezaee*, Ronald Pelot, Alireza Ghasemi

Dalhousie University, Industrial Engineering Department, Halifax, NS B3J2X4, Canada

A R T I C L E I N F O

Article history:
Received 15 December 2015
Received in revised form
25 May 2016
Accepted 27 May 2016

Keywords:
Fishing vessel incidents
Fishing vessel activity
Extreme weather conditions
Random Parameters
Negative Binomial Regression
Zero-Inflated Negative Binomial Regression
Fractional Logit Regression

A B S T R A C T

Extreme weather factors, a key aspect of the commercial fishing operating environment, can present danger to fish harvesters and fishing vessels. The extreme environmental conditions in Atlantic Canada, most often associated with the passage of extratropical cyclones and icy waters, can be characterized using wind speed, precipitation, air and sea surface temperature, Laplacian of pressure, and ice presence over the study area. This research aims to identify the extreme weather conditions that may affect fishing activity levels and fishing incidents. Negative Binomial Regression, Zero-Inflated Negative Binomial Regression, Fractional Logit Regression, and Random Parameters Negative Binomial Regression were applied to recognize patterns in historical fishing activity levels, incident data, and extreme weather factors in Atlantic Canada. The results suggest that there is a strong relationship between the studied weather factors and fishing activity levels overall (extreme weather conditions usually result in decreased fishing activity levels in the study area). Furthermore, different weather factors can have different effects on various vessel sizes. Wind speed is a significant factor in determining fishing activity levels for vessels smaller than 45 feet; but activity levels of vessels larger than 45 feet are only affected by ice presence. There are correlations between harsh weather factors and fishing incidents with respect to activity levels. More specifically, incident rates (*i.e.* number of fishing incidents over fishing activity levels) increase with low air temperature, ice presence, strong winds, and high Laplacian of pressure. These results can help mariners and fisheries management to make more informed decisions with respect to fishing safety.

1. Introduction

Working in the fishing industry is one of the most hazardous occupations in the world. Fish harvesters are 52.4 times more likely to have a fatal incident at work compared to other occupations in Great Britain (Roberts, 2002). Fishing is also one of the most dangerous occupations in Canada with a fatality rate of 1.15 per 1000 persons, which is almost equivalent to the top-listed risk occupations of forestry workers. In addition to the high risk of fatality, fish harvesters are also at risk of a wide range of non-fatal injuries during their work at sea (Murray et al., 1997).

Mariners consider the most dangerous fishing situations to be associated with weather-related factors (bad weather/poor forecasts), vessel characteristics (such as size and stability), and lack of safety equipment (Safecatch Report, 2006). There is an extensive literature investigating different risk factors in fishing incidents. In the majority of them, the weather conditions are part of the study. Results of a report prepared by the National Research Council of Canada and the Canadian Coast Guard in 2005 showed that there have been more than 1000 incidents in Canadian waters due to icing since 1970 (Kubat and Timco, 2005). Chatterton (2008) demonstrates that seasonal darkness, cold water, high speed winds, icing, fatigue and short fishing seasons are the most important factors in icing-related accidents for the vessels over 79 ft long. Wu et al. (2005, 2009), Wu (2008) applied classification tree-based modelling to study the historical patterns of fishing vessel incidents and weather factors in Atlantic Canada. The results showed that the most dominant factor is the amount of exposure of vessels (*i.e.* fishing activity levels or number of fishing trips in the study area), and when the activity variable was excluded from the model, wave height became the most significant factor. Rezaee et al. (2016) used Logistic Regression to reveal the underlying relationships between extratropical cyclone weather factors and severity

* Corresponding author.
E-mail address: Sara.Rezaee@dal.ca (S. Rezaee).

http://dx.doi.org/10.1016/j.ocecoaman.2016.05.011

level of fishing incidents, showing that wind speed, ice presence, sea surface temperature, and Laplacian of pressure are critical factors in the prediction of the severity levels of fishing incidents. Severity levels in this study were defined as severe (*i.e.* a vessel or a person is threatened by imminent danger that requires immediate assistance) and non-severe (*i.e.* any reported incident, which is not classified as severe, is considered as non-severe) (CCG, 2000; 2001). The results suggested that incidents related to different fishery types might be affected by different weather conditions. Jin et al. (2001); Jin and Thunberg (2005); Niclasen et al. (2010); and Wang et al. (2005) also investigated the key factors in fishing incidents and suggested that harsh weather conditions (*e.g.* high winds, high waves, and heavy precipitation) are significant environmental factors in their occurrences.

This research aims to investigate the relation between commercial fishing activity levels, incidents, and extreme weather conditions, as well as other weather factors. Extreme weather conditions in this research refer to extratropical cyclones that occur in the middle latitudes of the Earth and are characterized by strong winds, precipitation and temperature changes. Extratropical cyclones can be at any intensity (*i.e.* from weak to very strong). Various criteria (*e.g.* changes in sea level pressure (Serreze and Barrett, 2008) or vorticity (Hodges, 1999) have been used in the related literature to identify and track extratropical cyclones.

Fisheries in Atlantic Canada are spatially distributed inshore, mid-shore, and offshore. The main target species are shrimp, groundfish, herring, seal, crab, lobster, tuna, salmon, scallop, and sea urchin. Many vessels are used for multispecies fishing. Lobster fishing vessels are generally smaller than 45′ and herring fishing vessels are larger than 65′, but fishing vessels related to other species can be at varied sizes. Fisheries management in Atlantic Canada is based on three main systems: Individual Quota (allowable catch by weight for a given period of time), limited traps, and competitive (fishing for a given period of time) and it varies for different fishing locations (DFO, 2008).

The main objective of this study is to determine if fishing activity levels, fishing incidents, and fishing incident rates are significantly related to any or all of: wind speed, air and sea surface temperature, ice presence, amount of precipitation, and/or Laplacian of pressure. Note that based on the cited literature, fishing activity levels and incident rates can be related to the various patterns of environmental conditions (*e.g.* high winds and low air temperature, low sea surface temperature and presence of ice, strong storms contacting heavy rain, *etc.*); therefore, the aforementioned hypotheses are not mutually exclusive and accepting one doesn't mean rejecting the others.

Fishing safety is a complex dynamic system which requires a multi-criteria decision making approach to better understand and improve the system. This research aims to contribute to such an approach and help various stakeholders such as the Canadian Coast Guard (CCG), Transport Canada (TC), Department of Fisheries and Ocean (DFO), and other marine activity decision makers to make more informed safety decisions. The effect of weather conditions on fishing vessels can vary based on many factors, and understanding these variations will help to improve the overall fishing safety. Fish harvesters can also be provided with better information about the potential consequences of certain weather conditions so they can prepare better for, or even avoid, risky conditions.

2. Material and methods

2.1. Material

2.1.1. Data sources

Study scope: The study area for this research encompasses Atlantic Canadian Waters from 40° to 60° N latitude, and 73° 20′ to 45° 50′ W longitude over the years 2005–2010. Fishing activity levels, fishing incidents, and weather data were gathered and organized into an integrated format. Close examination of the data revealed that there were inconsistencies in the incident data collection process during year 2007 (*i.e.* Canadian Coast Guard didn't collect a full dataset in that year due to changes in data collection forms and format); therefore, 2007 was excluded from the analysis. The entire study area is overlaid by a series of grid squares of size 2.5° by 2.5°. This resolution is chosen to ensure the presence of at least one weather point in each grid. Consequently there are 88 grid squares that cover the study area of which thirteen are entirely on land, yielding 75 usable grids for the analysis. Over the five year study period, the combination of grid cells and days thus yields $365 \times 5 \times 75 = 136{,}875$ potential samples, referred to as grid-days. Fig. 1 shows the gridded study area.

Fishing Activity Data: Vessel Monitoring System (VMS) datasets were used as an indicator of fishing activities. VMS is a satellite-based, near real-time, positional tracking system, which allows Department of Fisheries and Oceans (DFO) to monitor fisheries. The use of VMS allows fishing vessel positions to be transmitted to DFO at pre-determined intervals depending on the VMS unit and fishery type and it varies from minutes to hours. This information is relayed to a monitoring center where data are analyzed and archived. This research uses a subset of VMS data within the study area, providing information for each unique (anonymized) vessel identifier, its latitude and longitude, time of the day, speed, and vessel length.

Matching fishing activity data with grid-days was carried out in two steps. First VMS data were processed to connect data points for each trip and calculate trip tracks (*i.e.* a track comprises a combination of line segments from starting point in one grid to ending point in the same or another grid through the intervening grids). Fig. 2 shows the spatial distribution of these tracks over the study period (*i.e.* 136,875 grid-days). The next step is to count the number of line segments in each grid-day as an indicator of fishing vessels presence in that grid on the specific day and assign it to the related grid-day. Throughout the paper, term "number of fishing trips" will be used to point out to fishing activity levels in each grid.

Fishing Incident Data: When a vessel encounters a problem in Canadian waters and calls the Search and Rescue (SAR) Joint Rescue Coordination Center (CCG and Department of National Defence), a record is generated in the SISAR (Search and Rescue Program Information Management System) database and the most available and suitable SAR resources are sent to the location of the reported incident. The SISAR database includes detailed information about these reported incidents such as time and location, fishery type, type of vessel, type of incident, and severity level (life loss and/or total vessel loss) (CCG, 2012).

In this study, the term 'incident' refers to a record in the SISAR database. Due to the quality of the database, it was not possible to separate records according to the primary causal factor (*e.g.* harsh weather, engine failure, *etc.*), therefore all incidents have been included in the study regardless of their primary cause.

The total number of fishing Incidents over the 5 years (*i.e.* 2005, 2006, 2008, 2009, and 2010) within our area of interest is equal to 3148. Table 1 shows the temporal distribution of fishing incidents over the study period.

To match incident data with grid-days, the number of incidents in each grid-day was counted and assigned to the related grid-day (3148 Incidents that occurred over 136,875 grid-days). The number of incidents by grid-day in the dataset varies from 0 to 7. Table 2 shows the frequency of each number of incidents in the dataset.

Weather Data: Weather factors included in this study were chosen based on literature and personal communications with experts. Datasets with the finest available spatial and temporal