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A systematic assessment of maritime disruptions affecting UK ports, coastal areas and surrounding seas from 1950 to 2014

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Abstract

Maritime disruptions can have severe negative implications. This study analysed maritime disruptions in UK ports, coastal areas and surrounding seas from 1950 to 2014, systematically assessing their scale, duration, extent and consequences. Disruptions are a single or sequence of hazardous events that negatively affect 'business as usual' conditions, ranging from minor to major disruption and even loss of life. To express this range a severity scale was developed and applied. A database of maritime disruptions and their severities was constructed using data archaeology, identifying 88 events, primarily caused by wind storms (36%), human error (23%), mechanical faults (14%) and storm surges (12%). All events other than human error or mechanical faults occurred between October and March (typically associated with autumn/winter storms and depressions), with 65% recorded between November and January. Maritime disruptions from weather events tended to have regional/national impacts; whereas human error or mechanical faults were usually locally severe. Since 2000 ports demonstrated more frequent disruption to wind storms due to mechanisation, increased delay and closure reporting, and refined health and safety regulations. Most frequently affected were the sea areas Fair Isle and Dover, and the Felixstowe and Dover ports. Through time, primary impacts shifted from extensive flooding and structural damage to financial impacts and disruption; associated with adaptation including implementation/upgrading of coastal defences, storm warning systems and legislation. Port and governmental bodies responded adaptively (e.g. Thames Barrier construction and development of automatic tracking systems). The UK's maritime disruption vulnerability has altered significantly since 1950 and continues to evolve.

Keywords Extreme events, UK, EEZ, coastal areas, ports, disruptions

1 Introduction

Maritime disruptions can have severe implications for the UK including damage to infrastructure, cargo and vessels, pollution, temporary port closure and the loss of life. These events have potential to cause long term repercussions for affected regions, through damage, interruptions to trade and even loss of life. Such disruptions are one or more hazardous events that have negative implications for 'business as usual' conditions. Both natural and anthropogenic drivers of disruptions are apparent and hence maritime disruption can have very different causes. Maritime disruptions are identified by their negative implications for the affected area(s). Whilst the focus of adverse conditions in the past has been due to extreme weather events, climate change now adds an additional factor of concern affecting port activities. Predicted climate change impacts include sea-level rise and changes in the nature, severity and frequency of extreme weather events. These events, as well as larger scale effects of climate change such as changes in food production, are expected to affect future economic and trade developments, although the severity and extent of impacts remain highly uncertain. Such impacts will likely challenge the continued success of safety and operational efficiency in ports, coastal areas and the EEZ through a combination of creeping change and sudden shocks, highlighting a need for development of robust adaptation and mitigation methods. As maritime disruptions are caused by both natural and human factors it is vital to assess the baseline of current occurrences, and identify the causes. This record can be used to aid investigation of projected implications of climate change, and the potential impacts of extreme weather events (as well as other possible drivers), for UK coastal areas.

The contribution of shipping to the UK's economy tripled between 2002 and 2008; in total the maritime sector comprises 2.1% of UK GDP (House of Commons 2014). Recent studies have found 95% of trade by volume and 75% by value enters the UK by shipping (Department for Transport 2012; HR Wallingford 2012). Increasing socio-economic reliance on shipping trade (Nicholls and Kebede 2012) poses an additional challenge by enhancing vulnerability, or the extent of disruption, to import delays, whilst busier ports and shipping routes heightens disruption risk arising from human error and mechanical faults. Between 2010 and 2030 sea trade within regions is expected to almost double (Lloyd's Register et al. 2015). Improvements in maritime safety regulations have acted to counteract this increased risk that arises from greater volumes of sea traffic. Global statistics of medium and large oil spills (>7 tonnes) have declined from an average of 78.8 events per year in the 1970s, to 7 events per year since 2010 (ITOPF 2015). Since the 1950s a number of changes have taken place in the UK shipping industry to accommodate increased trade volumes and greater vessel sizes. By 2006 containership lengths had increased from 135 to 397m, and vessel twenty-foot equivalent unit (TEU) capacities expanded from 500 to 14,000 (ABP 2010). This trend is particularly apparent from 1988 onwards when the first post-panamax containership began operations (Rodrigue et al. 2006). Such vessels, which include super-tankers, are unable to pass through the Panama Canal due to their size. In response to such developments, ports across the UK have undertaken upgrades to maintain their trade position; a trend that continues. Recent enhancements include an increase in the handling capacity of the port of Liverpool from 750,000 to 1.5 million TEU per year (Peel Ports 2014) and the opening of the first phase of a new deep water port on the Thames, London Gateway, in 2013 (DP World 2013). The largest shift in UK shipping trade involves the arrival of larger vessels carrying greater loads, rather than total changes in the number of vessels visiting UK ports.

The aim of the paper is to develop and analyse a database of maritime disruptions that have affected the UK from 1950 to 2014. The objectives are:

a) To develop a maritime disruptions database for the UK;
b) To define the different types of maritime disruption that are observed;
c) To analyse the occurrence of each type of maritime disruption by severity;
d) To critically assess temporal and spatial trends.

The paper is structured as follows: Section 2 comprises a literature review, Section 3 contains the methodology used, Section 4 refers to the results identified, the discussion is located in Section 5 and conclusions are brought together in Section 6.

2 Historical Maritime Disruptions

By volume 90% of global goods pass through the dominant trade nodes, ports (Ng and Liu 2010); a characteristic reflected in UK trade patterns. In 2010, the UK ranked second and fourth for European Union containerised imports and exports respectively (World Shipping Council 2015), where 80% of freight passing through its ports travelled to or from international destinations (Department for Transport 2014). In 2011 the UK's port sector provided 0.4% of employment and 0.5% of the country's total economic activity (Oxford Economics 2013). The UK has a strong coastal character, with regions dominated by ports, shipping, businesses, housing, tourism and a myriad of recreational activities and events.

Extreme events, such as wind storms or storm surges, become disruptions through two primary mechanisms: (1) the event strength overwhelms established defences or procedures, or (2) a sequence of circumstances weaken resilience before passing a tipping point.

Maritime disasters have been known to happen throughout history. The 1703 'Great Storm' directly caused approximately 8000 deaths (Lamb 2012); extensive flooding, primarily in the south and south-west (Brayne 2003), and the loss of around 300 vessels, including 12 Naval ships (Anon 1826). The magnitude of life lost places this disruption as one of the severest in UK recorded history, particularly in relative terms considering that the country's population was only about 5.2 million (Lee and Schofield 1981). The 1953 storm surge, which had devastating impacts for countries including UK, Belgium and the Netherlands had legacies including the Dutch Delta Plan and UK's Thames Barrier (Environment Agency 2012; Jonkman and Kelman 2005; Wadey et al. 2015a). Following the 2002 loss of the Tricolor and subsequent further shipping collisions a new vessel tracking system for the Dover Strait was implemented (BEAmer 2002). Many disruption events were not associated with responses for improvements or changes to regulations.

Less severe events, such as those that disrupt port operations, tend to be absorbed into day-to-day operations, highlighting port resilience (Osthorst and Manz 2012). Here resilience describes the ability of a region to resist extreme events without suffering devastating losses to infrastructure, commodities or lives (Mileti 1999). Such conditions arise naturally if the region is inherently invulnerable, or if adaptation options artificially enhance its robustness. Consequently exposure does not always translate into risk or damages (Nicholls et al. 2008).

Maritime disruptions are an important consideration for decision-makers in port, coastal areas and surrounding seas and must include an understanding of the risks posed by passing vessels, as well as those that berth within UK ports. This paper is designed to benefit this process by offering a new, consistent, data source on these damaging and disruptive events.

3 Methodology

Three distinct maritime zones were defined and analysed within this study:

- Ports refer to harbours, where facilities allow loading and unloading of goods and/or passengers to and from vessels;
- Coastal areas encompass the terrestrial region directly affected by the coast and ocean, such as areas protected by sea defences;
- The term surrounding seas refers in this paper to the Exclusive Economic Zone (EEZ) which extends a maximum of 200 nautical miles (370km) from the baseline, in many cases the low-water line, seawards (United Nations Convention on the Law of the Sea, 1982, Article 57).

This study covers the UK EEZ as defined in The Exclusive Economic Zone Order 2013 (SI3161/2013), but excludes from its scope estuaries, except when referring to estuaries within port boundaries. Note that minor UK ports were not included within the database, as records of disruptions for these areas are inconsistent; therefore analysing a database of extreme events on minor ports was beyond the feasible scope of the research. Major UK ports are listed in Appendix 2.

To allow meaningful comparisons between events over time, a severity criteria was developed. The typology developed was validated and tested against the database (the structure was designed to be flexible and allow wider application than the UK). Severity was classified by ranking financial and social implications separately. Events were classed between 1 (least severe) to 5 (most severe) (Table 1), and an average taken to define overall severity:

1. Least severe – e.g. <3 hours delay to vessels due to rough conditions.
2. Low severity – e.g. superficial or minor damage to a vessel or oil platform.
3. Moderate severity – e.g. small oil spill (<7 tonnes).

4. High severity – e.g. flooding requiring evacuation of buildings.
5. Most severe – e.g. severe port damage. Most severe events were further subdivided: (i) a single criterion listed in Table 1 is met; (ii) two listed criteria are met; (iii) all three listed criteria are met.

In the context of this study the impact and costs of deaths associated with accidents were classed according to the Fatal Accidents Act 1976 and Accidental death and dismemberment coverage (AD&D). Bereavement damages are currently a fixed sum of £12,980 per person; historical values are available, and were applied to the appropriate time periods to assess the financial implications of such losses on a regional or national scale. Additionally, organisations such as Maersk Line offer AD&D as standard to their employees. The value of such coverage varies by company; for example BP covers AD&D up to $1 million dollars per person, or double their base pay, whichever is less (BP 2015). These definitions were used to aid valuation of societal losses arising from disruptions, rather than focusing on the sensitive and emotive impacts of recorded deaths. For ease of analysis and understanding of severity, financial implications of each event were converted to pounds sterling equivalent to January 1st 2014.

The analysis is based on a critical assessment of the literature and media sources, building on the methodology used by Ruocco et al. (2011). The primary data sources used were newspapers and online news reports[1], supplemented by white papers, Commons Sittings transcripts (http://hansard.millbanksystems.com/) and official reports from the *AAIB* (Air Accidents Investigation Branch) and *MAIB* (Marine Accidents Investigation Branch). Such reports provided detailed information regarding the causes and severities of maritime disruption events. Data sources were analysed for each day from January 1st 1950 to December 31st 2014; a maritime disaster was recorded within the database if a situation(s) or circumstance(s) resulted in negative implications.

A data bias arising from the increase in Internet-based media was identified after the mid-1990s. Previously only severe maritime disruptions, or those of interest to the target audience, tended to be reported within newspapers. Data relating to port closures or delays were also not as available prior to the 1990s. These biases gave the impression that the total number of maritime disruptions had increased per year since the mid-1990s. Records of Level 1 and 2 events are at lower confidence, as it is almost certain that not all of these events are resolved within the database. Hence the database focused on Level 3, 4 and 5 events where we are more confident of their representativeness.

The quality of the database constructed is reliant on the standard of the data sources; to reduce this issue multiple data sources were used where possible. This study only took into account disruptions that were recorded within news articles and/or additional data sources as having negative implications. It is assumed that there are additional events that were not recorded, or those which are not available for public use.

To identify maritime disruptions reports from digital news archives keywords were used. For example words and phrases used to identify potential reports of storm surges included:

Storm surge(s); flooding/flood(s); coastal; sea defences/ wall; breach; waves; rough sea(s); tidal.

Where possible multiple data sources were used to validate the accuracy of the report of a disruption event. Evidence sampling was primarily sourced from documentary evidence which is fragmentary in nature. It must be noted that a bias is almost certainly present within the database as reporting of lesser events is sporadic, particularly prior to the development of digital news reporting. For each identified maritime disruption the following information was recorded: location (coastal areas, EEZ, port) scale, frequency, type, duration, extent, recovery time, impacts and outcome(s). This data, when used in conjunction with the developed severity scale, aided determination of how vulnerability differed between regions. The severity of events that affected multiple locations were assessed for each region separately. The overall severity of the disruption was taken as the highest value recorded across the affected location(s).

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[1] Primary data sources containing records of maritime disruptions: BBC, Belfast Telegraph, Bournemouth Echo, East Anglian Daily Times, Ipswich Star, Irish Independent, ITV News, South Wales Argus, The Argus, The Daily Mail, The Daily Mirror, The Daily Post, The Grimsby Telegraph, The Guardian, The Herald, The Independent, The Irish Emigrant, The Irish Independent, The Scotsman, The Southern Daily Echo, The Shetland Times and The Telegraph. A full list is located in Appendix 1.

The recorded occurrence of storm surge events was validated against the SurgeWatch database, which provides a record of UK coastal flooding events since 1915 (Haigh et al. 2015).

Each event was classified by its primary type – the main cause of damage or disruption (secondary types are detailed in Appendix 1). Two distinct disruption groups were identified; those that arise from a single cause, such as human error, or composite events, where damage was caused by multiple sources, such as a combined wind storm and storm surge (Wisner et al. 2004). This classification clearly identified which aspects of composite events had the most severe impacts. Sequential disruptions, such as wind storms arising from separate fronts (even if they occurred only days apart), were recorded as distinct events.

4 Results

Maritime disruptions and their severities

The analysis identified 88 events caused by seven primary mechanisms between 1950 and 2014.

1. Human error (in ports, boats, offshore platforms – and aircraft servicing them) – poor or untimely decisions or actions which directly result in a disruption event; for example not taking suitable precautions to avoid collision with a vessel.
2. Mechanical – or structural – fault (occurring in a port or on board a vessel, offshore platforms or aircraft servicing installations) – a fault or weakness in the structure or operation of a vessel of installation which directly results in a disruption event; for example an offshore platform collapsing due to its structure not being robust enough for the known sea conditions.
3. Poor visibility – where visibility is reduced to such an extent that operations cannot safely continue, or leads to a collision occurring.
4. Rough seas – where wave heights are great enough to disrupt the progress of a vessel or cause damage to a vessel or structure.
5. Snow and ice – in recent years usually associated with health and safety regulations; where conditions disrupt port operations by being unsafe to operate equipment such a cranes or precluding truck access from the neighbouring road network.
6. Storm surge – atmospheric and/or wind conditions lead to a rising of the sea level which causes coastal flooding, and damage, which can penetrate far inland. Such events include wave run-up events and those characterised primarily by coastal flooding.
7. Wind storm – strong gusts and mean wind conditions that disrupt normal working conditions through damage or risk of danger.

In many of these events more than a single mechanism operates (Table 2). Events were classed according to the primary cause of disruption. Maritime disruptions arising from weather related events tended to have impacts on regional or national scales, whereas those events resulting from human error or mechanical faults usually had effects felt most severely on a local scale. The impacts of cumulative events were also considered, which refers to an interlinked series of events that act to cause multiple waves of damage to a region, vessel or structure.

Appendix 1 lists the events, including primary and secondary disruption types and the maritime zones affected, with a summary in Table 3. The records of maritime disruptions were dominated by wind storms, human error and mechanical faults, which comprise over 70% of events. Excluding disruptions resulting from human error or mechanical faults all events occur between October and March, with the greatest number (65%) between November and January showing the importance of the autumn and winter season. Rough seas was the most common secondary disruption type, and occurred less frequently as a primary event cause.

Storm surges tended to affect the coastal areas through breaching of sea defences and flooding, whilst human error primarily resulted in damage to a vessel, platform, aircraft or environmental pollution. Events were identified as being highly individualised, with very few events repeating the same specific impacts. In nine cases events had implications which also affected other European countries in a maritime context. If terrestrial disruptions, damage or death were included this number would be significantly higher. Events affecting multiple countries were primarily identified as wind storms or storm surges, including the January 1953 storm surge that also severely impacted The Netherlands and Belgium, and the October 2013 storm surge that affected Belgium, Germany, Denmark and The Netherlands, where the port of Rotterdam was closed for a day. To highlight the individual nature of each maritime disruption three case studies are included in Appendix 3.

Before 1995 no Level 1 or 2 events were recorded (Figure 1); this characteristic reflects the bias in reporting already discussed. From 2000 onwards the frequency of Level 5 disruptions was found to increase, dominated by wind storms which primarily affected ports. A range of severities were found to be present for each of the seven disruption mechanisms. Events arising from human error and wind storms showed the greatest diversity in severity, ranging from Level 1 to Level 5.

Three of the severest events to affect the UK: the 1953 storm surge, and the losses of the MV Braer and MSC Napoli, in 1993 and 2007, respectively, remain in the public memory (Table 4), illustrating the strong legacy of their impacts. Events such as these are often used as media case studies in the wake of disruptions; for example the 1953 storm surge was used as a comparison in news reports when describing the UK's winter 2013 storms (BBC 2013). Impacts common to these events include the loss of vessel(s) and at least partial cargo. Other outcomes included structural damage to ports and buildings, deaths, loss of trade arising from disruption and port closures (particularly affecting just-in-time deliveries) and environmental pollution. These severest events also had the longest-term impacts or greatest implications for society, government and affected businesses.

All maritime disruptions had financial implications from the small scale, such as loss of business due to delays, through to large-scale environmental clean-up operations and compensation schemes. Assessment of insured losses resulting from maritime disruptions showed that wind storms comprise 4 of the 5 most expensive events recorded, and was a secondary cause of impacts for the 1953 storm surge (Table 5). Financial impacts were not used to directly calculate severity; instead these impacts were assessed through damage (including contamination from oil spills), disruption and loss of trade affecting the maritime zone and businesses operating within maritime regions (such as offices located within port boundaries).

Differences in vulnerability between ports, coastal areas and EEZ

Disruptions affected ports most frequently: 60% of the 88 recorded events, compared to 39% and 32% for the coastal areas and EEZ respectively (Figure 2)[2]. Offshore infrastructure is unevenly distributed around the UK's EEZ, with a focus on the North Sea oil field, associated with a particularly high concentration of oil and gas terminals along the coastal areas (Brown et al. 2014). Therefore, conditions liable to cause disruptions could have occurred in other shipping zones without resulting in negative impacts. Similarly, a peak in disruptions involving vessels was identified in the shipping zone which includes the Dover Strait, reflecting a region where shipping is concentrated. Almost one quarter of events affected multiple zones, and 11 events affected all three regions. The most common event types depended on the zone of investigation (Table 6). For example ports are particularly vulnerable to wind storms (Figure 2). Disruptions affecting coastal areas primarily resulted in flooding or damage to coastal defences. The greatest number of Level 5 events affected the region from Gibraltar Point to North Foreland on the East Coast (Table 7). Although ports were affected by the most events, this did not mean that this zone experienced a greater percentage of more severe disruptions; compared to the EEZ the percentage of Level 5 events were lower.

The severest events, such as the 1953 storm surge, tended to affect each maritime zone differently. For example, rough seas in the EEZ, a secondary characteristic, caused the sinking of the MV Princess Victoria, whereas the storm surge itself affected ports and coastal areas resulting in severe flooding, evacuation of residents, damage to buildings and 475 deaths. Secondary impacts from rough seas were recorded during two-thirds of storm surge events, causing vessel delays or closures to ports beyond the influence of the surge.

A common primary disruption type, wind storms, were associated with secondary impacts arising from rough seas and storm surge (Appendix 1) in 63% of recorded events. Disruptions attributed to human error in ports or EEZ increased during periods of poor visibility, despite the presence of disruption prevention tools such as sonar or ship tracking systems. The cause of such incidents were detailed in official documentation, such as MAIB reports, as poor judgement rather than a direct consequence of potentially hazardous weather conditions.

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[2] Percentages exceed 100% as events that affected multiple areas were recorded multiple times.

Only one of the five severest UK maritime disruptions affected multiple maritime zones – the exceptional 1953 storm surge, which impacted ports, coastal areas and EEZ. The other four events exclusively affected a single zone - the EEZ – involving environmental pollution and the loss of vessels, cargo and crew.

Spatial differences in vulnerability to maritime disruption types

The distribution of maritime disruptions in terms of frequency, severity and primary cause varies greatly across the UK's coastal areas, ports and EEZ. Events were recorded across most of the shipping zones surrounding the UK, and impacts were recorded at 18 of the UK's 47 major ports (for a port list see Appendix 3). Regions of the UK most frequently impacted by maritime disruptions were the south-east (Gibraltar Point, Lincolnshire to North Foreland, Kent) and south-west coast (Lyme Regis to St. David's Head, Pembrokeshire) inshore regions, Fair Isle and Dover sea areas, and the ports of Dover and Felixstowe. These ports demonstrated the greatest vulnerability, being impacted by 17 events each (Figure 3). The third most vulnerable port, Belfast, recorded only 6 events. The specific regions of the UK affected by the most disruptions, despite being impacted by a range of event severities, tend to also endure the most severe events most frequently. Overall, ports are affected by the most events, almost double that of the EEZ, but a higher frequency of Level 5 events was recorded in the EEZ.

Changes in the impacts, and nature of, maritime disruptions since 1950

The frequency and severity of maritime disruption event types have shifted since 1950. Level 5 event frequency showed an increase since the 2000s (Figure 4), reflecting increased media reporting and improvements to operational health and safety guidelines. This shift has arisen from changing occurrences of Level 5(i) events, whereas 5(ii) and 5(iii) events have fluctuated.

From the mid-1960s an increase in disruptions recorded in the EEZ was identified following the installation of offshore platforms, providing an additional source of vulnerability. Storm surge events declined in severity through time, likely reflecting improved preparedness, warnings and defences. Between 1970 and 2014 the percentage of events classed as Level 5 reduced from 50% to 33%. In contrast the frequency of wind storms events recorded has demonstrated an increase since the 1990s. An average of 1 event per decade was recorded between 1950 and 2000. From 2007 disruptions arising from wind storms occurred with a return period of less than one year, with the greatest frequency, 6 events, in 2013 (Figure 5). Of the wind storm events recorded only one disruption, in 2005, was classed as Level 1 or 2; this suggests that the UK is either only vulnerable to more severe wind storms, or that wind storms tend to have moderate to severe implications. An assessment of the UK's vulnerability to such events will be detailed later.

5 Discussion

Natural maritime disruptions affecting the UK are strongly dictated by weather conditions, as would be expected. During autumn and winter months UK maritime weather can be more severe, typically characterised by an increased frequency of depressions and storms; consequently 65% of natural events were recorded between November 1st and January 31st. Instances of human error and mechanical faults also increase as adverse conditions enhance strain on equipment, and poorer operating conditions (e.g. limited visibility or rougher seas) occur more frequently. Few recorded disruptions occurred simply as a primary type; instead they were associated with secondary causes which also resulted in damage or disruption. This highlights how a number of disruption types are interrelated, whilst illustrating variance in vulnerability. Wind storms, storm surges and rough seas are often recorded together, with wind storms most frequently recorded as the primary disruption type. Recognising the different vulnerabilities for each disruption type can inform decision makers on the advisable adaptive actions (Boulter et al. 2013), whilst also highlighting periods of potentially greater damage likelihood. It must be accepted that the causes of disruption detailed in this database are not exhaustive, and consequently in future years additional sources of negative implications may be recorded; this is an acknowledged sampling issue.

A number of maritime disruptions had strong legacies, or impacts that have permanently altered behaviour in the maritime sector, having impacts that range from the local to the international scale. Important examples include:

- October 26th-27th 2002 wind storm – Queen's Harbour Master Portsmouth altered regulations whereby in winds exceeding 45 knots large vessels must have two tugs available, and large ferries are not allowed to operate in winds above 55 knots (MAIB 2003)
- December 14th 2002 human error (multiple collisions between vessels) – Development of an automatic tracking system for all vessels in the Dover Strait (BBC 2002a; BBC 2002b). This system was implemented to aid collision avoidance and general navigation by creating a real time map of vessel locations.
- January 31st to February 1st 1953 storm surge – Developments include the Thames Barrier and associated river defences (£634 million in 2014), £20 million investment in sea defences to protect greater London (£498.7 million in 2014) (Jonkman and Kelman 2005; Lumbroso and Vinet 2011), and investments for nationally improving sea defences and building a nationwide tidal gauge network.

Ports were affected most frequently by disruption events; after 2000 a greater occurrence of more severe events occurred. This arose from a number of factors: increased reporting of delays and closures (such as blogs, and forums), stricter port health and safety operational guidelines and the increased use of larger cranes which are more vulnerable to high winds. Events identified were more often disruptive rather than resulting in extensive damage and lives lost (Figure 6). The EEZ was mainly affected by most severe events, so are considered resistant to lesser potential disruptive events and more vulnerable to circumstances such as the loss of an offshore platform or vessel. Coastal areas were affected by 34 events, with wind storms and storm surges causing the most, and severest, events for the zone. Since the 1990s the number of events recorded per year has increased, particularly for ports. This likely arose from increased reporting of lesser events following the development of digital news reporting. Online news offers readers access to events locally relevant, as well as providing a greater breadth of news articles (Maier 2010).

The range of disaster types, severities and impacts identified highlights the challenges posed for decision-makers to achieve effective adaptation. The majority of events recorded did not affect coastal areas, ports and EEZ in combination, highlighting the spectrum of disruption events experienced by the UK. All disruptions that affected multiple zones were Level 3 or greater, indicating that more severe events can potentially have wider reaching implications.

The most common cause of maritime disruption differed dependent on the region under investigation. Coastal area and port disruptions most commonly arose from wind storms, with less frequent mechanical fault, human error and storm surge events. The Fair Isle sea areas, south-west and west coasts were principally affected by wind storms, implying the presence of distinct storm tracks across the UK (Bengtsson et al. 2006). Debate continues regarding whether climate change will enhance storminess (IPCC 2012; Ulbrich et al. 2008); any changes would have implications for the frequency and severity of events such as wind storms and storm surges affecting the UK. Felixstowe, an east coast port, is vulnerable to wind storms passing across the North Sea, recording more frequent events than sheltered ports such as those located in Southampton and London. The south-west UK coast was affected most frequently by storm surge events, reinforcing the threat of storms approaching from the North Atlantic and North Sea. The shipping zone Dover, including the Dover Strait, is most vulnerable to human error events, reflecting the pressures of the busy shipping lane. Whereas the port of Dover, which caters primarily for passenger transport, was also affected by a high frequency of primarily wind storm events. Its passenger vessels do not sail if conditions are too rough or if secure docking is not possible. Disruptions affecting French ports such as Calais, to which ports such as Dover are strongly connected, can also cause delays to passenger transport. Disruptions affecting the UK's eastern EEZ region, extending southwards in the North Sea, were dominated by mechanical faults, a result of the oil field and associated offshore platforms; therefore the vulnerability of these installations is not expected to greatly alter under climate change.

A slight increase in the number of disruptions recorded from the mid-1960s to 1990s is attributed to the discovery of North Sea oil, subsequent installation of drilling platforms and associated risks of this new technology, with 50% of events recorded in the EEZ in the 1960s and 1980s involving offshore platforms. This presented an additional potential source of maritime disruption, including risks faced by sea or air craft transporting crew to and from offshore structures. The earliest disruption was recorded in December 1965 following the collapse and subsequent loss of the first UK offshore platform, Sea Gem (Burke 2013). A decline in both the number of oil spills recorded in the EEZ and the percentage of those classed as large (over 700 tonnes) has been observed in recent decades. In the 1970s 54% of 245 incidents were classed as large spills compared to 8% of 35 incidents in the 2000s (ITOPF 2015). Statistics such as these illustrate how the resilience and safety of vessels is continuing to be improved.

The nature of the UK's vulnerability to maritime disruptions since 1950 has changed alongside shifts in industry, legislation and understanding of the impacts of extreme events. Since 1950, sea level has risen about 10cm around the UK (Woodworth et al. 2009); coastlines along the English Channel are estimated to be slightly lower at around 8cm (Wahl et al. 2013). Increasing baseline sea level poses additional challenges for those improving protection against storm surges and associated flooding. Flood event frequency has not increased despite rising sea levels (Ruocco et al. 2011), as increased recognition of coastal flooding risk from storm surges and the advantages of sea defences have resulted in upgraded coastal protection (Nicholls et al. 2013). Instances where defences were upgraded following an event include after the 1953 East Coast Flood and the December 1981 storm surge event (Appendix 1). Serious events were found to generate a 'window of opportunity' for improvements (Hall et al. 2012; Tompkins et al. 2010). The benefit of such schemes were highlighted following the winter storms of 2013, during which water levels higher than 1953 were recorded in locations including Lowestoft and Great Yarmouth (Met Office 2014; Spencer et al. 2015; Wadey et al. 2015a). These events resulted in large scale disruption, and major financial implications, but the flood impacts were less severe than the East Coast Flood of January 1953. Coastal and terrestrial damage was significantly lower, and only one life was lost. This increased resilience arose following multiple improvements including enhanced sea defences, including the Thames Barrier, and a tidal warning system (Lumbroso and Vinet 2011; Met Office 2014). However, such developments do not provide an impervious protection for coastal businesses and residents, and some losses continue. On the 5th December 2013 a storm surge resulted in flooding of the port of Immingham and related damage of port facilities (ABPmer 2014; Wadey et al. 2015b). In November 2005 parts of Hayling Island, Hampshire were flooded by unusual long period swell waves, despite the earlier installation of improved defences (Ruocco et al. 2011). On several occasions swell originating from the Atlantic Ocean has resulted in flooding and sea defence damage along the south English coast. Swell has longer wave lengths than those of waves produced by storms, increasing their likelihood of overtopping sea defences (Palmer 2011). In February 2014 a sea wall collapse at Dawlish, Devon, resulting in partial washing away of the main railway line to south-west England (BBC 2015). Taking two months to rebuild at a cost of £35 million, there were reports of much larger, but uncertain indirect losses due to reduce passenger travel (BBC 2015). Hence, these examples highlight the continued need to assess vulnerability and to determine the causes of events and the extent of protection required. Therefore, threats from severe events which have potentially major implications remain. Disruptions such as this illustrate the need to continue enhancing defences. It is vital for decision-makers to begin acting in anticipation, rather than in response, to storm events through techniques such as raising of ports, and coastal area protection. Measures including higher quality defences are anticipated to reduce, but not eradicate, storm surge disruption risks.

Changes in wave fields, such as the presence and occurrence frequency of large waves can have negative implications for offshore structures, vessels and coastal defences. For the UK, wave fields are strongly influenced by the NAO index, and have displayed significant variability between 2000 and 2009 (Feng et al. 2014). Changes in significant wave heights (SWH) are debated; some research suggests SWH in the North Atlantic Ocean have increased since 1900 leading to a rougher wave climate, and is associated with rising wind speeds (Bertin et al. 2013; Dodet et al. 2010), whereas other groups such as WASA conclude that storm and surge in Europe has shown no significant change since 1900 (WASA Group 1998). The role of climate in terms of the frequency and strength of disruptive events remains uncertain, requiring further investigation.

An increase in the frequency of Level 5(i) events was identified as primarily resulting from greater wind storm disruption occurrences. Ports have become more vulnerable to wind storms as a consequence of increased mechanisation and that some equipment, such as quay cranes, have specific safe wind speed operating guidelines (TT Club et al. 2011). In recent years progress has been towards more stringent health and safety measures in such conditions (BSI 2013). Improved prediction of disruptions resulting from storm surges, snow and ice or wind storms allows for pre-emptive closures of ports to reduce the risks posed by weather hazards. Despite the best use of prediction methods, it is likely that a percentage of closures occur prior to events that would not have caused damage to the port, or at least not to the same financial scale as the implications of the closure. Enhanced communication of ports with shippers and truck operators increase awareness of closures, damage and delays, introducing a data bias. For example during the winter of 2013, when multiple wind storms occurred (affecting much of the UK including Southern and Eastern England, Wales, and Northern Ireland), details of closures were available from a number of sources including port websites and logistics suppliers (Cosco 2013).

Wind storms were associated with secondary implications including storm surges and rough seas (Appendix 1). These events primarily affected ports, with wind damage tending to be the severest of the combined causes, reflecting their vulnerability to this disruption type (Edmond and Maggs 1978). A recent study by TT Club et al. (2011) found that 29% of asset claims in ports and terminals were weather related, with 10% arising from windstorms affecting quay cranes alone. The prevalence of disruptions arising from mechanical faults and human error which tend to occur most frequently in the EEZ have also increased. However, when compared against the number of operational oil and gas installations (283 in December 2014), an increase in resilience is identified (Department of Energy and Climate Change 2014). Events arising from mechanical faults do not represent declining standards of operating vessels, aircraft or drilling platforms. Similarly, increased occurrence of disruptions from human error are not indicative of declining performance safety or qualification standards of those working in UK maritime zones, as justified by stricter regulatory documents produced by bodies of authority such as the HSE and port operators . Instead they represent increased activity, including enhanced used of drilling platforms and greater vessel traffic travelling through UK waters and ports. Since 1950 UK ports have changed in multiple ways in terms of the nature and method of their operations, this is reflected in their shifting vulnerabilities to disruptive events.

This study has provided details of both the nature and scale of maritime disruptions that have affected the UK, and how they have shifted since the 1950s. The database produced during this study has highlighted a number of key points of current vulnerability alongside positive actions, such as improved sea defences, that has significantly reduced previous areas of weakness to disruption events. It is clear, however, that the UK remains vulnerable to disruptions, and must continue to take action to reduce the impacts it endures. Further research of interest would be to assess whether UK storm pathways have shifted since 1950 with changing cyclonic weather conditions, beyond NAO variability (Hurrell et al. 2003), and consequently whether the regions primarily affected by wind storms have altered. The scope of the study does not fully take into account activities that are delayed from starting due to disruptions; analysis of such aspects would aid building a fuller picture of the implications of maritime disruptions. Continued collection of systematic data detailing UK maritime disruptions will further aid understanding of the UK's areas of vulnerability and available actions to increase resilience.

6 Conclusions

A database of UK maritime disruptions from 1950 to 2014 was constructed primarily using newspaper and digital news records. Disruptions were found to arise from seven primary sources: (1) human error, (2) mechanical fault, (3) poor visibility, (4) rough seas, (5) snow and ice, (6) storm surge and (7) wind storms, adding complexity to the methods of adapting and defending against future events. 88 recorded events were identified and classified from severities of 1 (minor impacts) to 5 (major impacts). The most commonly recorded events were wind storms, human error and mechanical faults, totalling over 70% of the records; whilst rough seas were recorded most commonly as secondary impacts. A strong seasonal distribution in events was identified; with 65% of natural events occurring between November and January. The most severe events recorded, as determined by the classification scale (Table 2) include the dramatic 1953 East Coast Flood and the breakups of the vessels *MV Braer* and MSC Napoli in 1993 and 2007, respectively.

Events were most frequently recorded affecting the Fair Isle and Dover sea areas, south-east and south-west coasts, and the major ports Dover and Felixstowe. Both of these ports were identified as being particularly vulnerable to wind storms which affected progress of vessels and transportation of goods. Their location, towards the east coast, resulted in disruptions arising from wind storms passing across the North Sea.

Maritime disruption frequency has increased through time, most probably due to improved reporting of less severe events, rather than increased event occurrence. This is reflected by an increase in the records of Level 1 and 2 events following the development of Internet-based reporting. Reductions in storm surge impact severities are attributed to improved sea defences and warning systems. Comparisons between the significant death and destruction caused by the 1953 East Coast Flood, where 475 people lost their lives, to the similar event in 2013 where disruption was the primary outcome and only a single life was lost demonstrates this. This illustrates the need to continue improving maritime sector legislation and service quality to reduce the vulnerability of the maritime sector to disruption events. Increased occurrence of human error and mechanical fault events was identified; reflecting increased activity and operational pressures in UK ports and EEZ. Also changing foci of trade, tourism and industrialisation since 1950 acts to modify the impacts, and extent, of maritime disruptions.

The maritime environment is under increasing pressure to improve safety and disruption prevention measures as risk has increased alongside the rising number of operating vessels and installations. The increased vulnerability of ports to wind storms is a by-product of mechanisation, and the use of pre-emptive closures in association with health and safety regulations. Further study could be conducted to develop our understanding of the specific impacts of maritime disruptions on UK ports. This study is particularly important in assessment of how disruptions have had implications on a regional scale, developing our understanding of how coastal areas may be affected by climate change in the future. The current database could also be refined by liaising with port operators to determine whether past disruption was viewed as disruptions, or just accepted as a 'fact of life' and incorporated into schedules and profit margins. The method used within this research could be applied to develop comparable severity scales to analyse maritime disruptions that have affected other countries, and to compare vulnerabilities between nations.

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8 References

ABP (2010) Port of Southampton Master Plan 2009-2030.
ABPmer (2014) Ensuring flood resilience: An overview of 5/6 December 2013 UK storm surge vol 1400/30.
Anon (1826) Eddystone Lighthouse vol 150. Knight and Lacey,
BBC (2002a) £30m cargo 'lost' as ship sinks. http://news.bbc.co.uk/1/hi/world/europe/2576179.stm. Accessed 7 January 2015
BBC (2002b) Ship sinks after Channel collision. http://news.bbc.co.uk/1/hi/world/europe/2575009.stm. Accessed 7 January 2015
BBC (2013) Lethal storm and tidal surge sees thousands out of homes. http://www.bbc.co.uk/news/uk-25220224. Accessed 23 October 2014
BBC (2015) Dawlish rail line: closure 'costs economy up to £1.2bn'. http://www.bbc.co.uk/news/uk-england-devon-31140192. Accessed 5 February 2015
BEAmer (2002) Supplementary report to the inquiry into the collision between the car carrier Trocolor and the container vessel Kariba.
Bengtsson L, Hodges KI, Roeckner E (2006) Storm tracks and climate change Journal of Climate 19:3518-3543
Bertin X, Prouteau E, Letetrel C (2013) A significant increase in wave height in the North Atlantic Ocean over the 20th century Global and Planetary Change 106:77-83 doi:http://dx.doi.org/10.1016/j.gloplacha.2013.03.009
Boulter SL, Palutikof J, Karoly DJ, Guitart D (2013) Natural disasters and adaptation to climate change. Cambridge University Press,
BP (2015) Accidental death & dismemberment (AD&D) coverage. http://hr.bpglobal.com/LifeBenefits/Sites/Core/BP-Life-benefits/Employee-benefits-handbook/Basic-life-and-accidental-death---dismembermen/How-the-plan-works/Accidental-death--amp;-dismemberment-(AD-amp;D)-co.aspx. Accessed 12 November 2015
Brayne M (2003) The Greatest Storm: Britain's night of destruction November 1703. The History Press,
Brown S, Hanson S, Nicholls RJ (2014) Implications of sea-level rise and extreme events around Europe: a review of coastal energy infrastructure Climatic Change 122:81-95
BSI (2013) Code of practice for the safe use of cranes. Inspection, maintenance and thorough examination. Cargo handling and container cranes.
Burke L (2013) The Sea Gem: A story of material failure Journal of Undergraduate Engineering Research and Scholarship
Cosco (2013) Port of Felixstowe weather warning. http://www.coscon.co.uk/news/port-of-felixstowe-weather-warning/. Accessed 23 October 2014

Department for Transport (2012) National Policy Statement for Ports. The Stationary Office, London
Department for Transport (2014) UK Port Freight Statistics: 2013. The Stationary Office, London
Department of Energy and Climate Change (2014) Table of current UKCS installations.
Dodet G, Bertin X, Taborda R (2010) Wave climate variability in the North-East Atlantic Ocean over the last six decades Ocean Modelling 31:120-131 doi:http://dx.doi.org/10.1016/j.ocemod.2009.10.010
DP World LG (2013) Britain's new gateway to global trade DP World London Gateway port. http://www.londongateway.com/media-page/press-releases/britains-new-gateway-global-trade-dp-world-london-gateway-port/. Accessed 28th July 2015
Edmond ED, Maggs RP (1978) How Useful are Queue Models in Port Investment Decisions for Container Berths? The Journal of the Operational Research Society 29:741-750 doi:10.2307/3009265
Environment Agency (2012) Thames Estuary 2100: Managing flood risk through London and the Thames estuary.
The Exclusive Economic Zone Order, (2013). United Kingdom
Feng X, Tsimplis MN, Quartly GD, Yelland MJ (2014) Wave height analysis from 10 years of observations in the Norwegian Sea Continental Shelf Research 72:47-56 doi:http://dx.doi.org/10.1016/j.csr.2013.10.013
Haigh ID et al. (2015) A user-friendly database of coastal flooding in the United Kingdom from 1915–2014 Scientific Data 2:150021 doi:10.1038/sdata.2015.21
Hall JW, Brown S, Nicholls RJ, Pidgeon NF, Watson RT (2012) Proportionate adaptation Nature Clim Change 2:833-834
House of Commons (2014) Transport Committee: Forging ahead? vol HC 630. The Stationary Office,
HR Wallingford (2012) Climate change risk assessment for the transport sector.
Hurrell JW, Kushnor Y, Ottersen G, Visbeck M (2003) The North Atlantic Oscillation: Climate significance and environmental impact vol 134. Geophysical Monograph. American Geophysical Union,
IPCC (2012) Managing the risks of extreme events and disasters to advance climate change adaptation.
ITOPF (2015) Oil tanker spill statistics 2014.
Jonkman SN, Kelman I Deaths during the 1953 North Sea storm surge. In: Proceedings of the Solutions to Coastal Disasters Conferences, American Society for Civil Engineers, Charleston, South Carolina, 8-11 May 2005.
Lamb HH (2012) Weather, Climate and Human Affairs: A Book of Essays and Other Papers. Routledge Revivals,
Lee RD, Schofield RS (1981) Volume 1: 1700-1860 vol 1. The Economic History of Britain since 1700. Cambridge University Press,
Lloyd's Register, QinetiQ, Strathclyde Uo (2015) Global Marine Trends 2030.
Lumbroso DM, Vinet F (2011) A comparison of the causes, effects and aftermaths of the coastal flooding of England in 1953 and France in 2010 Natural Hazards and Earth System Science 11:2321-2333 doi:10.5194/nhess-11-2321-2011
MAIB (2003) Report on the investigation of the collision between Pride of Portsmouth and HMS St. Albans Portsmouth Harbour 27 October 2002. Southampton
Maier S (2010) Are the news fit to post? Comparing news content on the web to newspapers, television and radio Journalism and Mass Communication Quarterly 87:548-562
Met Office (2014) The recent storms and floods in the UK. Exeter
Mileti D (1999) Disasters by Design: A Reassessment of Natural Hazards in the United States. Joseph Henry Press,
Ng AKY, Liu JJ (2010) The port and maritime industries in the post-2008 world: Challenges and opportunities Research in Transportation Economics 27:1-3
Nicholls R et al. (2008) Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates OECD Environment Working Papers:63 doi:10.1787/011766488208
Nicholls RJ, Kebede AS (2012) Indirect impacts of coastal climate change and sea-level rise: The UK example Climate Policy 12:S28-S52
Nicholls RJ, Townend IH, Bradbury AP, Ramsbottom D, Day SA (2013) Planning for long-term coastal change: Experiences from England and Wales Ocean Engineering 71:3-16
Osthorst W, Manz C (2012) Types of cluster adaptation to climate change. Lessons from the port and logistics sector of Northwest Germany Maritime Policy & Management: The flagship journal of international shipping and port research 39:227-248 doi:10.1080/03088839.2011.650724
Oxford Economics (2013) The economic impact of the UK Maritime Services Sector: Ports. Oxford
Palmer T (2011) Energetic swell waves in the English Channel. University of Southampton
Peel Ports (2014) Liverpool 2. http://www.peel.co.uk/projects/liverpool2. Accessed 19 November 2015
Rodrigue J-P, Comtois C, Slack B (2006) The geography of transport systems. Routledge,

Ruocco AC, Nicholls RJ, Haigh ID, Wadey MP (2011) Reconstructing coastal flood occurrence combining sea level and media sources: a case study of the Solent, UK since 1935 Natural Hazards 59:1773-1796 doi:10.1007/s11069-011-9868-7

Spencer T, Brooks SM, Evans BR, Tempest JA, Möller I (2015) Southern North Sea storm surge event of 5 December 2013: Water levels, waves and coastal impacts Earth-Science Reviews 146:120-145 doi:http://dx.doi.org/10.1016/j.earscirev.2015.04.002

Tompkins EL, Adger WN, Boyd E, Nicholson-Cole S, Weatherhead K, Arnell N (2010) Observed adaptation to climate change: UK evidence of transition to a well-adapting society Global Environmental Change 20:627-635 doi:http://dx.doi.org/10.1016/j.gloenvcha.2010.05.001

TT Club, ICHCA International, Port Equipment Manufacturers Association (2011) Recommended minimum safety specifications for quay container cranes.

Ulbrich U, Pinto JG, Kupfer H, Leckebusch GC, Spangehl T, Reyers M (2008) Changing Northern Hemisphere Storm Tracks in an Ensemble of IPCC Climate Change Simulations Journal of Climate 21:1669-1679 doi:10.1175/2007JCLI1992.1

United Nations Convention on the Law of the Sea, 1982, Article 57.

Wadey MP, Brown JM, Haigh ID, Dolphin T, Wisse P (2015a) Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions Natural Hazards and Earth System Sciences Discussions 3:44

Wadey MP et al. (2015b) A comparison of the 31 January – 1 February 1953 and 5 – 6 December 2013 coastal flood events around the UK Frontiers in Marine Science 2 doi:10.3389/fmars.2015.00084

Wahl T et al. (2013) Observed mean sea level changes around the North Sea coastline from 1800 to present Earth-Science Reviews 124:51-67 doi:http://dx.doi.org/10.1016/j.earscirev.2013.05.003

WASA Group (1998) Changing Waves and Storms in the Northeast Atlantic? Bulletin of the American Meteorological Society 79:741-760 doi:10.1175/1520-0477(1998)079<0741:CWASIT>2.0.CO;2

Wisner B, Blaikie P, Cannon T, Davis I (2004) At Risk: Natural hazards, people's vulnerability and disasters. Routledge,

Woodworth PL, Teferle FN, Bingley RM, Shennan I, Williams SDP (2009) Trends in UK mean sea level revisited Geophysical Journal International 176:19-30 doi:10.1111/j.1365-246X.2008.03942.x

World Shipping Council (2015) Trade Statistics. http://www.worldshipping.org/about-the-industry/global-trade/trade-statistics. Accessed 10 March 2015

Table 1 Interrelation of disruption mechanisms.

	Human error	Mechanical fault	Poor visibility	Rough Seas	Snow and ice	Storm surge	Wind storm
Human error	✓	✓	✓				✓
Mechanical fault		✓					
Poor visibility			✓				
Rough seas				✓			✓
Snow and ice				✓	✓		✓
Storm surge				✓	✓	✓	✓
Wind storm	✓	✓		✓	✓	✓	✓

Table 2 Severity scale of maritime disruptions affecting coastal areas, ports and territorial waters and the criteria relevant to each category.

Criteria	**Region(s) affected**			**Severity Scale**				
	Coastal areas	Ports	Territorial waters	1	2	3	4	5
Rough coastal conditions causing slight delays (<3 hours) in progress of vessels		✓	✓	✓				
Overtopping in the immediate coastal area	✓			✓				
Offshore platform, vessel or aircraft sustained superficial or minor damage (requiring repairs but able to continue normal operations); assistance required (e.g. from tugs or lifeboats); minor injuries and those requiring first aid	✓	✓	✓		✓			
Delay to service (e.g. progress of passenger ferry or inability to dock not exceeding 15 hours)		✓	✓		✓			
Overtopping extends beyond immediate coastal area; minor damage to sea defences	✓				✓			
Moderate damage to vessel, offshore platform or aircraft; minor environmental damage (e.g. small oil spill <7 tonnes - Ornitz & Champ, 2002)	✓	✓	✓			✓		
Service delays between 15 and 24 hours or cancellations to passenger services (e.g. ferries)		✓	✓			✓		
Localised breaching of sea defences and minor flooding	✓					✓		
Cargo damage or small-scale loss; major injury requiring hospitalisation or singular fatality	✓	✓	✓				✓	
Service delays exceeding 24 hours; major damage to vessel, offshore platform or aircraft		✓	✓				✓	
Damage to port or harbour (including infrastructure); port partially functioning or closed for <3 hours		✓					✓	
Severe breaching of sea-defences resulting in flooding/evacuation of homes and or businesses (>50 buildings)	✓						✓	
Major environmental damage (e.g. extensive oil spill >7 tonnes); vessel, offshore platform or aircraft sinks or is irreparably damaged; cargo severely damaged or lost; multiple fatalities	✓	✓	✓					✓
Port closed for prolonged periods (>3 hours); port severely damaged		✓						✓
Destruction of sea defences/loss of natural defences (e.g. beaches) and/or extensive flooding resulting in destruction of buildings or infrastructure	✓							✓

Table 3 Number of maritime disruptions caused by each of the eight identified mechanisms since 1950

Primary Cause	**Event classification**	**Number of recorded events**					
		Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Total**
Anthropogenic	Human error	1	4	1	5	9	20
	Mechanical fault	1	1			9	11
Natural	Poor visibility					1	1
	Rough seas			1		4	5
	Snow & ice			1	1	3	5
	Storm surge			3	4	4	11
	Wind storm		1	7	10	17	35

Table 4 Record of the timing, type and key impacts of the most severe maritime disruptions to have affected the UK since 1950

Date(s) of Event	**Primary event Classification**	**Key Impacts (for sources see Appendix 1)**
January 31st – February 1st 1953	Storm surge	Multiple vessels sank (including Princess Victoria car ferry); loss of, and damage to 24,000 homes, 200 businesses; 475 died; Felixstowe docks severely damaged
November 17th 1953	Human error	Steamer Vittoria Claudia sank; mineral oil cargo lost; entire crew of 20 died
January 5th & 10th 1993	Wind storm	MV Braer broke up and lost cargo; 84700 metric tons of light crude oil spilled
January 17th-19th 2007	Wind storm	MSC Napoli beached following hull breach; 302 tonnes light fuel oil spilt; Dover, Dublin and Felixstowe ports were also closed

Table 5 Insured losses resulting from the five most expensive maritime disruptions since 1950 (nb. losses from 1953 are total, i.e. classing damages to buildings or other properties as irreparable, as many businesses and houses were uninsured at that time; losses are calculated at 2014 values)

Date	Event classification	Insured losses (2014 values – for sources see Appendix 1)
January 25th 1990	Wind storm	£4 billion
October 15th – 16th 1987	Wind storm	£3.46 billion
January 31st – February 1st 1953	Storm surge	£1.2 billion (absolute)
January 2nd – 4th 1976	Wind storm	£816 million
January 17th – 19th 2007	Wind storm	£484 million

Table 6 The most common maritime disruption types per zone and the percentage of events classed as Level 5.

Zone	Most common disruption type(s)	Percentage that are Level 5 events
Coastal areas	Wind storm Storm surge	31% 44%
EEZ	Mechanical fault Wind storm	82% 70%
Ports	Wind storm	33%

Table 7 The number of recorded Level 3 to Level 5 maritime disruptions affecting coastal areas since 1950

UK Coastal Area Regions	Level 3	Level 4	Level 5
Cape Wrath to Rattray Head (including Orkney)	1		
Rattray Head to Berwick upon Tweed			
Berwick upon Tweed to Witby	1		
Witby to Gibraltar Point		3	2
Gibraltar Point to North Foreland		3	5
North Foreland to Selsey Bill	1	2	3
Selsey Bill to Lyme Regis	1	1	3
Lyme Regis to Land's End (including Isles of Scilly)		3	3
Land's End to St. David's Head (including Bristol Channel)	1	2	1
St. David's Head to Great Orme Head (including St. George's Channel)		3	1
Great Orme Head to Mull of Galloway	1	2	1
Isle of Man			
Lough Foyle to Carlingford Lough	1	1	
Mull of Galloway to Mull of Kintyre (including Firth of Clyde and North Channel)		1	
Mull of Kintyre to Ardnamurchan Point			1
The Minch		1	
Ardnamurchan Point to Cape Wrath			
Shetland Isles			
The Channel Islands			1

Figure 1 The severities of maritime disruptions recorded since 1950.

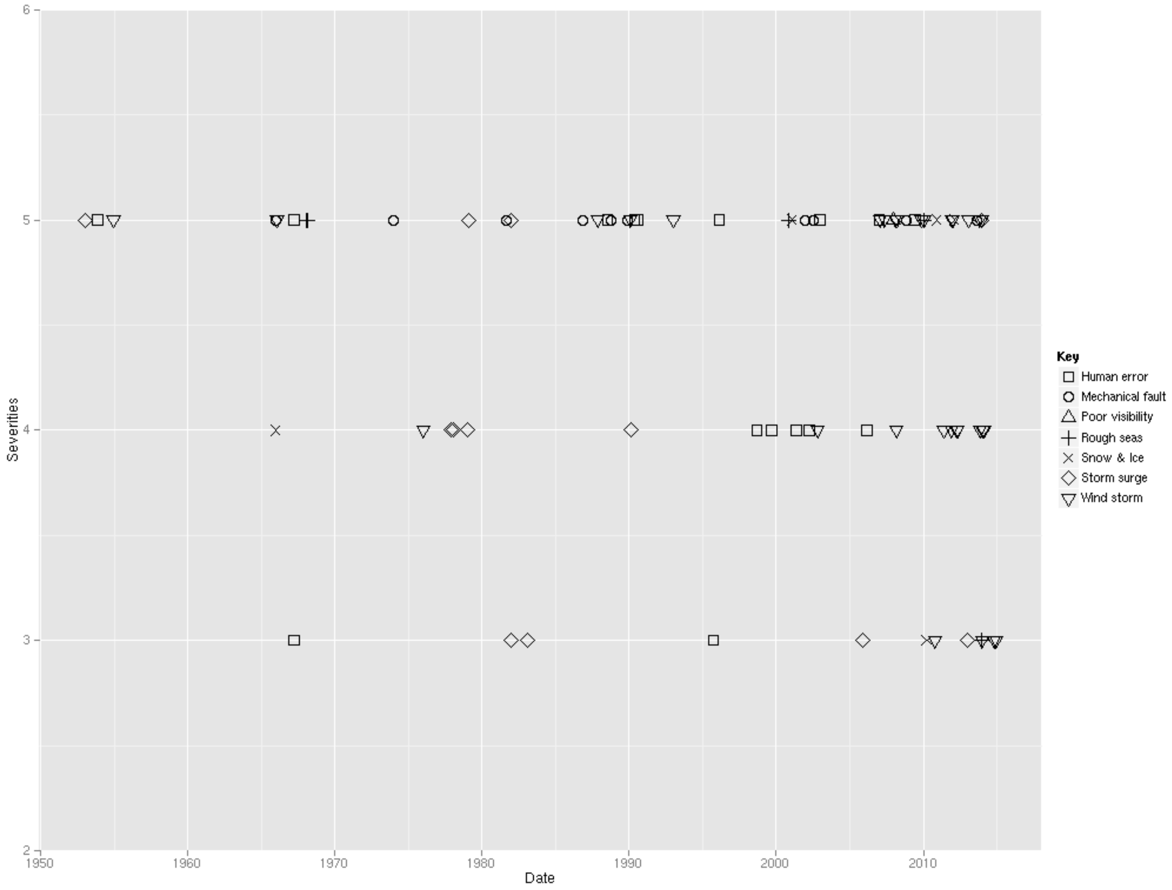

Figure 2 Relative frequencies of disruption events per type and maritime zone. Events that affected more than one zone are recorded multiple times. (a) Coastal areas, (b) EEZ, (c) Ports.

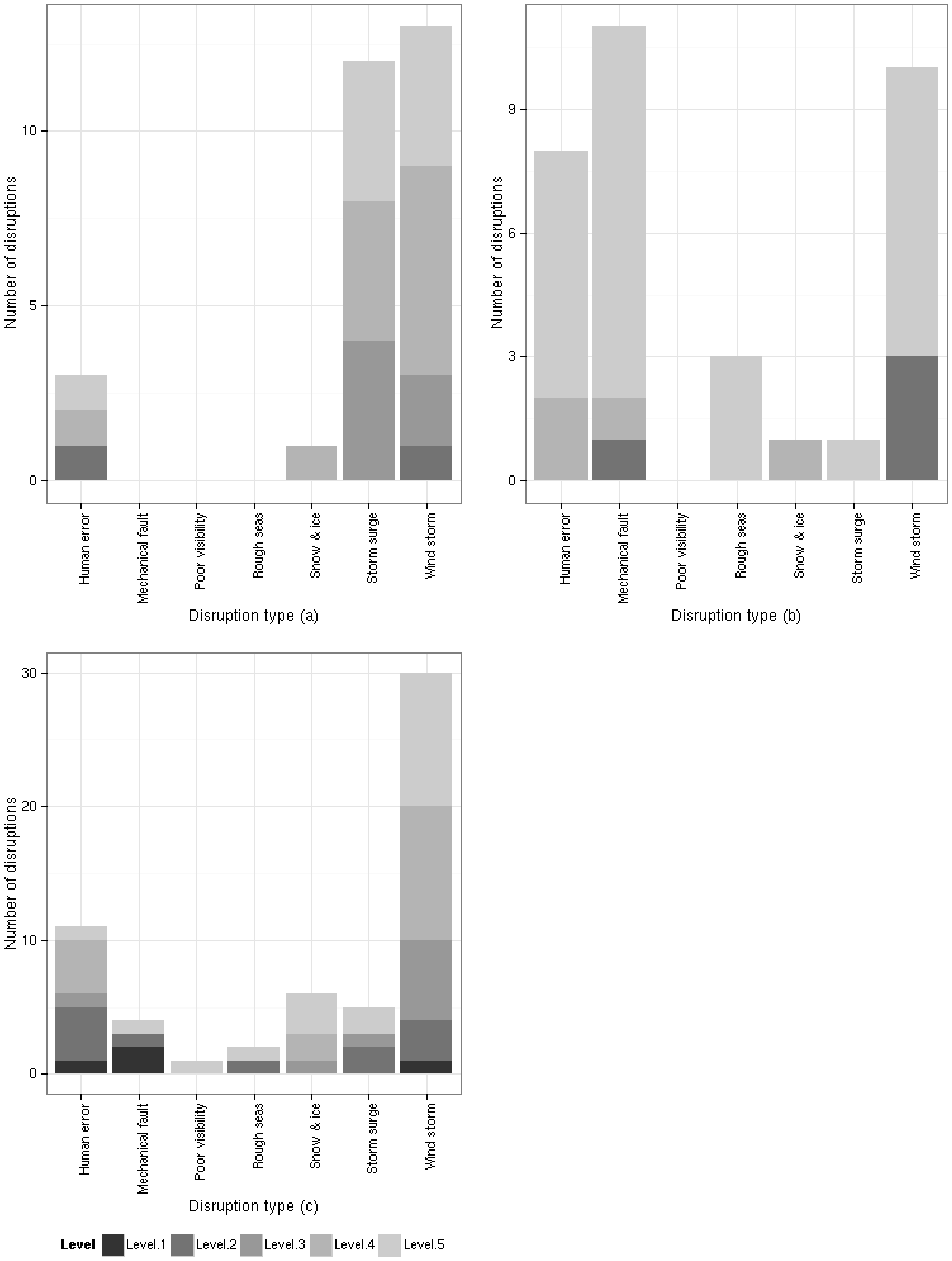

Figure 3 Number of recorded maritime disruptions affecting sea areas (block colours) and ports (circles) since 1950 for Level 3, Level 4, Level 5 and All Events (nb. All events includes Levels 1 to 5). Please note that the Republic of Ireland is excluded from this study.

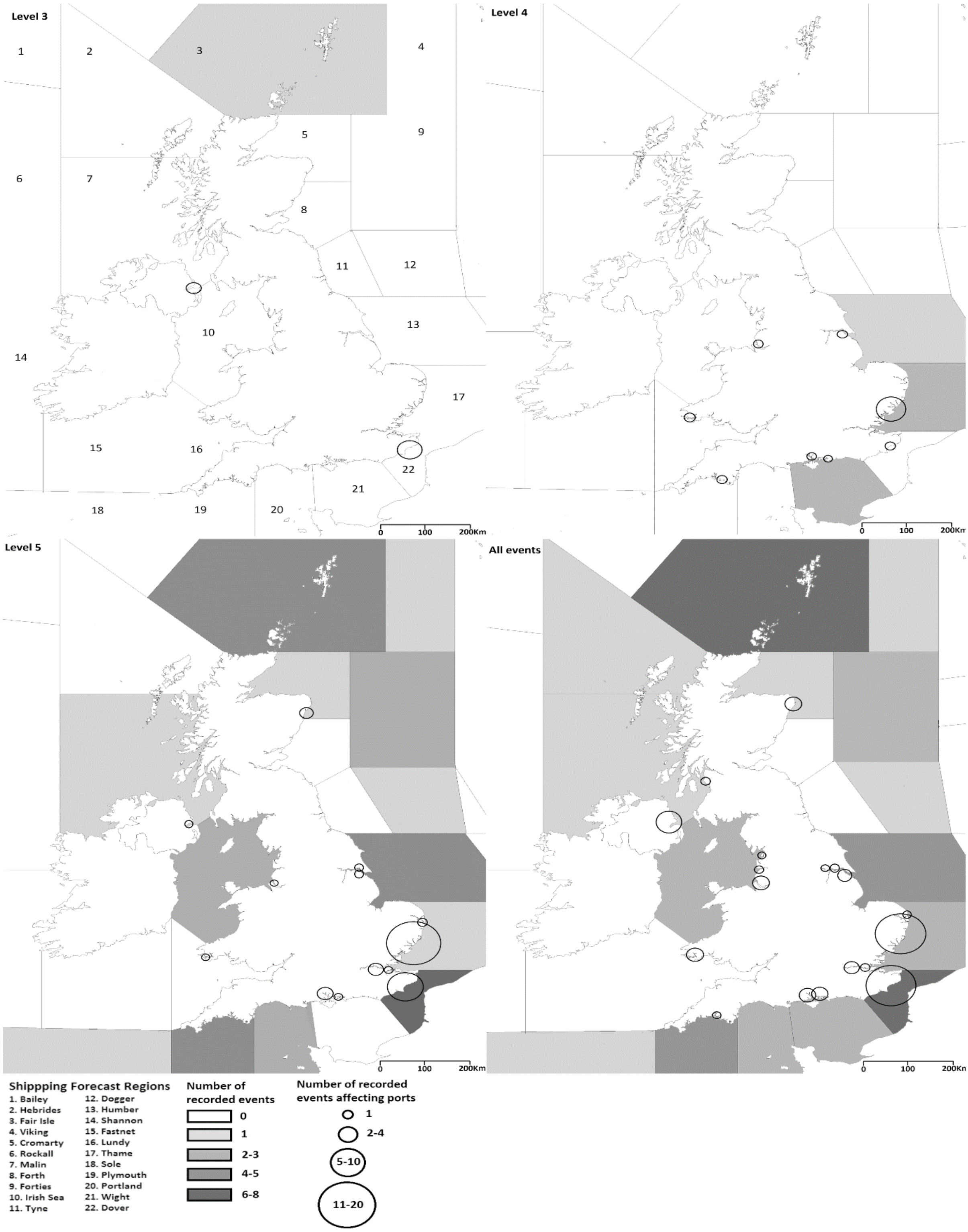

Figure 4 The decadal frequency of Level 5 events that affected the UK since 1950. Events are further subdivided into the following categories: 5(i), 5(ii) and 5(iii).

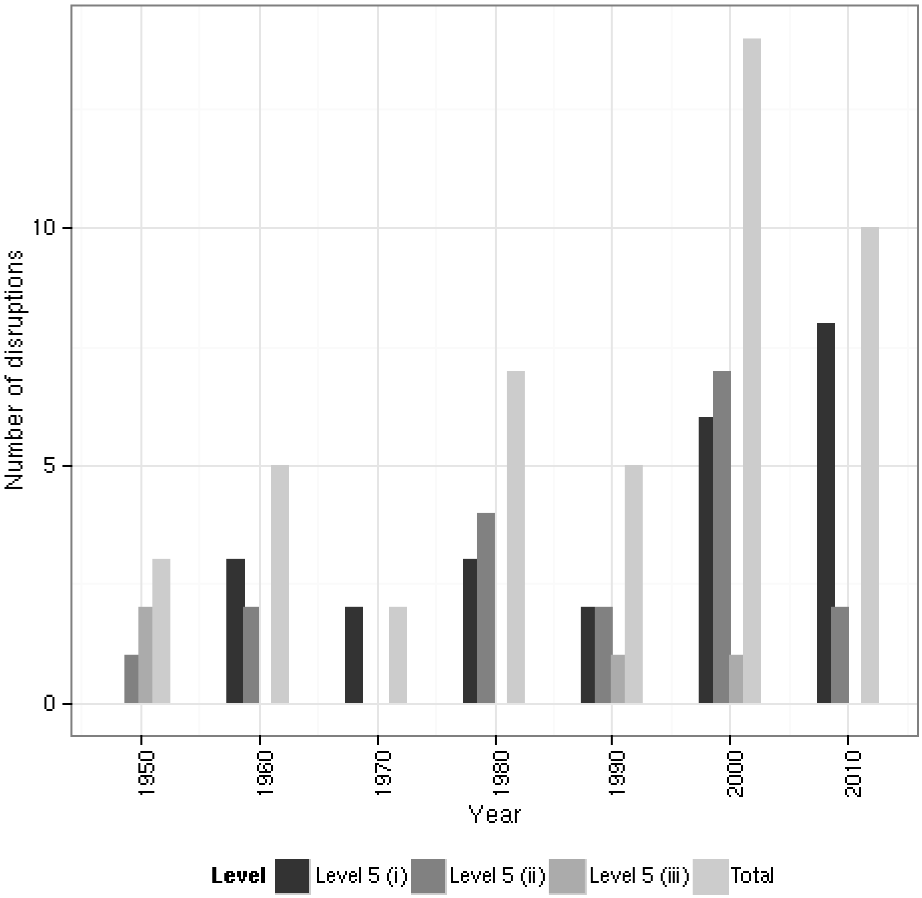

Figure 5 The annual frequency of maritime disruptions caused by wind storms.

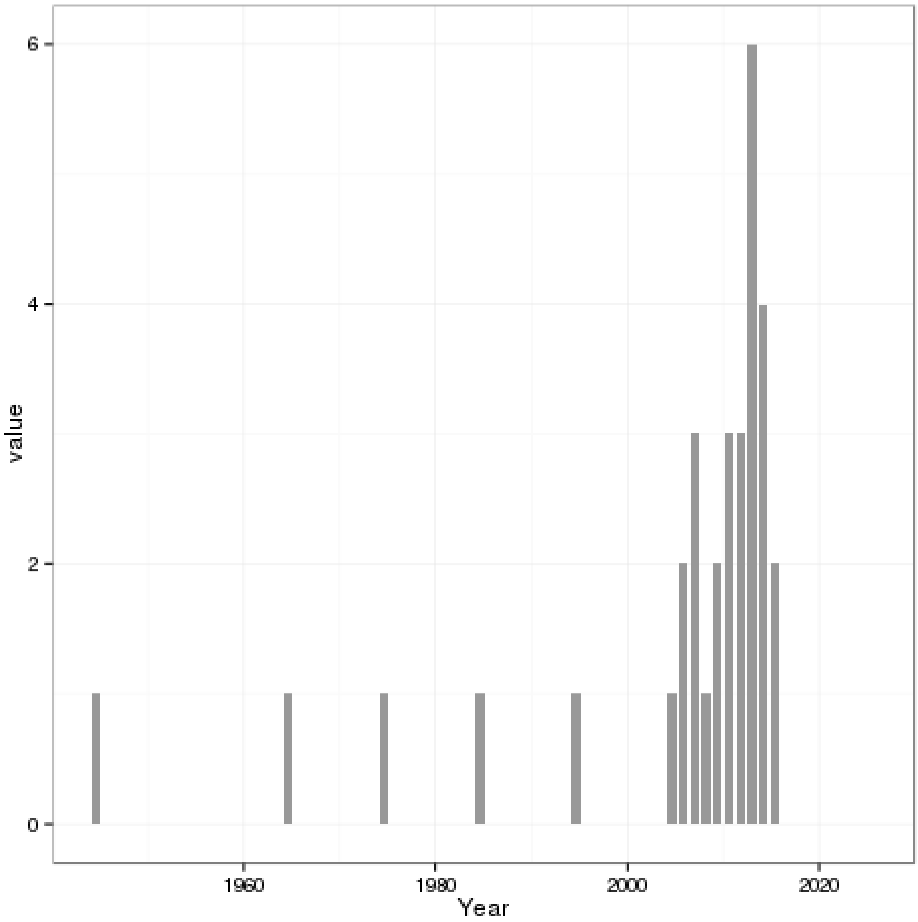

Figure 6 The number of deaths caused by maritime disruptions since 1950.