UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENGINEERING AND THE ENVIRONMENT

Civil, Maritime and Environmental Engineering and Science

UK ports, extreme events and climate change: Legislative and adaptive perspectives

by

Esmé Frances Flegg

Thesis for the degree of Doctor of Philosophy

September 2018

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF ENGINEERING AND THE ENVIRONMENT

CIVIL, MARITIME AND ENVIRONMENTAL ENGINEERING AND SCIENCE

Thesis for the degree of Doctor of Philosophy

UK PORTS, EXTREME EVENTS AND CLIMATE CHANGE: LEGISLATIVE AND ADAPTIVE PERSPECTIVES

By Esmé Frances Flegg

UK trade relies heavily on the port sector, with 95% of trade by weight entering the country by ship. Port operations and infrastructure are affected by extreme weather and non-weather events. The severity of risks facing the UK port sector may become more complex with climate change. This thesis aims to assess the vulnerability to, effects of, and responses to extreme weather events affecting UK ports, and to determine how well the port sector is adapting to the future pressures and challenges of climate and climate change.

Historically, publically available records of extreme events that affected UK maritime zones (coastal areas, Exclusive Economic Zone and ports) are limited. A data archaeology study was undertaken by recording reported events from 1950-2014 as a scoping study to assess the importance of extreme events for ports compared to other maritime zones. A new severity scale allowed meaningful comparisons of events through recent decades. Severity of impacts from extreme events changed through time. Decreasing storm surge impacts were associated with improved technologies and behaviours, such as sea defences. Increased frequency of wind storm disruptions were associated with changing technologies, such as high-level cranes. Cautionary behaviours (e.g. pre-emptive port closures) reduced the occurrence of damaging events.

To resolve present-day port disruption, vessel activity data, was analysed for three ports over a two-year study period. Severe individual and cumulative minor events (not considered in the literature) had the most impacts on ports. Daytime events had more severe impacts as they occurred during periods of greater vessel and port activity, highlighting the complex interaction of port activity and extreme events. Ports need to focus resources on preparing for such events.

The climate change preparedness of the entire UK commercial port sector has not previously been considered. Future risk reduction was assessed through analyses of non-statutory Adaptation Reports. Preparedness for extreme weather and climate change was assessed through a questionnaire to all commercial ports. Questionnaire responses determined that ports are not well prepared for climate change, contrary to suggestions by multiple Government reports. There is a perception issue on port sector preparedness between the Government and port decision-makers, enhanced by the misreporting, through subtle framing, of current adaptation success (such as where normal upgrades are presented as adaptations). Port sector awareness of climate change risks and the number of ports putting in place adaptation measures is presently low, and differs between and within nations. Scottish ports are well prepared for current extreme weather risks, but their complacent perspective could be disadvantageous with climate change.

Many UK ports are unsure how climate change may affect their future operations, and would find additional guidance of great benefit. Port sector adaptation to climate change is limited by poor risk awareness, and a mismatch between port planning and climate change timescales. A three-part port planning timescale has been developed: infrastructure renewal, disaster preparedness, and port and environs planning. To begin filling gaps in port sector climate change preparedness a number of tools and techniques (e.g. adaptation legislation or risk summaries) have been identified. In coming decades the need for effective adaptation will become more pressing as climate change begins to affect their operations. This thesis has analysed port operations and adaptations in the UK and has developed a new framework for future activity.

Table of Contents

List of Tables

List of Figures

DECLARATION OF AUTHORSHIP

I, Esmé Frances Flegg declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Thesis title: UK ports, extreme events and climate change: Legislative and adaptive perspectives

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. Parts of this work have been published as:

Adam EF, Brown S, Nicholls R, Tsimplis MN (2016) A systematic assessment of maritime disruptions affecting UK ports, coastal areas and surrounding seas from 1950 to 2014 Nat Hazards 83:691-713 doi:10.1007/s11069-016-2347-4

Signed: ………………………………………….

Date: ………………………………………….

Acknowledgements

Firstly, grateful thanks must be extended to my brilliant supervisory team – Doctor Sally Brown, Professor Robert J. Nicholls and Professor Mikis Tsimplis. Their first class supervision, guidance and support has been invaluable. I am grateful to Southampton Marine and Maritime Institution, my funding body, for making this research possible.

Thanks must also be extended to my examiners – Doctor Jonathan Simm, Doctor Simon Blainey and Professor Ian Townend.

I am indebted to the work of Professor Austin Becker of the University of Rhode Island whose past research on global port climate change adaptation has acted as a vital starting point for my research direction.

The support of my family has been instrumental in letting me pursue my PhD – thank you for everything. You know that I can never thank you enough for the million ways you have helped make this possible. In particular, I must thank my cousin Robin whose discussions have helped greatly improve the clarity of my research. To my “sister” Charlotte – thank you for being my rock.

Thank you also to my friends and colleagues both within and beyond the University for your laughter, support and smiles. In particular to PhD students Amy Welch, Sien Van der Plank, Salma Sabour and Jose Alejandro Pinto for being my coastal partners in crime.

Lastly, to my little Godson Noah – thank you for teaching me that playing trains and watching Peppa Pig makes any day better. Let’s go find some muddy puddles to splash in.

Chapter 1: Introduction

1.1 Background

UK ports are global economic hubs (Loh and Van Thai, 2014) and transport gateways (Chhetri et al., 2013) that include a wide range of businesses (Zanuttigh, 2011) including transport, fishing, logistics, cargo management, energy companies, shipping agents, goods production systems and recreational activities (Becker et al., 2014; Becker et al., 2013; Wang et al., 2007). UK trade is heavily reliant on a number of its major ports, with 51 of its 162 commercial ports handling 98% of its total traffic by weight (Department for Transport, 2015) (Figure 1.1). The socio-economic benefits of the UK port industry is significant, providing 0.4% of total employment (one in every 270 jobs) and contributes £7.9 billion to the UK's GDP (Oxford Economics, 2015). Ports are under immense pressure to contend with increasing vessel size and traffic.

Imports and exports are dominated by shipping rather than transport by air or through the Channel Tunnel which connects to mainland Europe. 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). UK ports are of key importance for the trading system globally in 2014, 129 countries were recorded as either loading goods destined for UK ports, or receiving UK exports (Department for Transport, 2016b). Shipping is a responsive industry, constantly fluctuating in response to changes in supply and demand on a global scale (Burton et al., 2002).

Globalisation has produced a lifestyle where items used for daily functionality are imported by vessels from across the globe (Chhetri et al., 2013; Inoue, 2012), and is accompanied with an assumption that goods are always available. Ports and the vital trade services they provide tend only to become visible in the public eye if disruption occurs, whereas the continuous seamless flow of cargo (Chhetri et al., 2015) remains unobserved. Imported goods are of vital importance to the survival of the UK's economic and societal health, as the nation is far from self-sustaining in terms of either food or commodities. In recent decades the UK has become more reliant on imported foods to sustain its growing population, a figure now estimated at 50% of all foods consumed (ESRC, 2012; FSA, 2007).

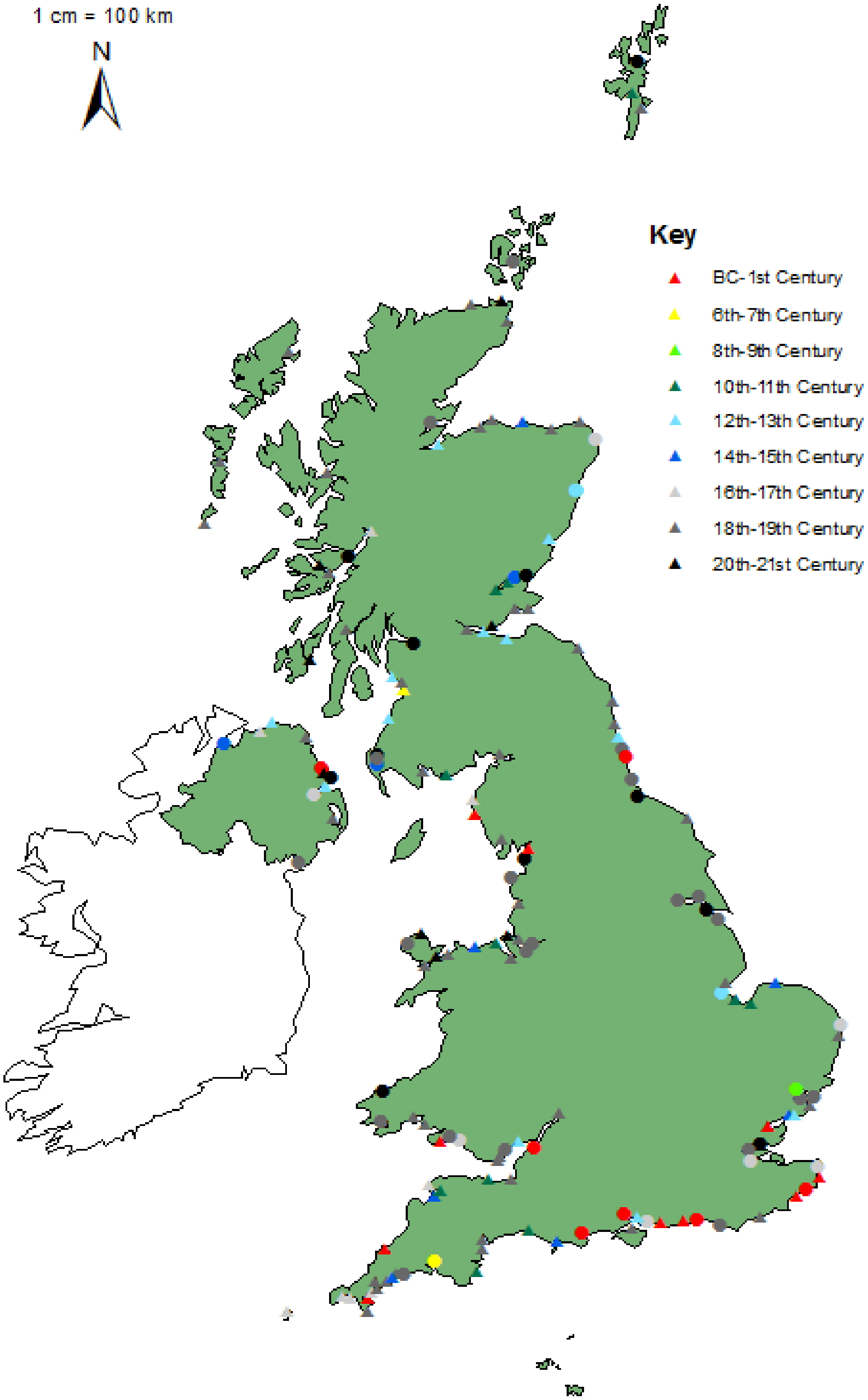


Figure 1.1: Map of the UK's 162 commercial ports and the centuries they began operating according to Department for Transport (2016a) data. Major commercial ports (circles) move at least 1 million tonnes of cargo per annum, and minor commercial ports (triangles) less than 1 million tonnes of cargo per annum. See Appendix G for a list of all commercial ports.

1.2 Justification of study

1.2.1 The history of the UK port sector and surrounding coastal areas

Records of UK port development extend back over 2500 years, and range from those ports first thought to be used around 500BC (Dover port) through to those that opened for trade in recent years (e.g. London Gateway in 2015) (Figure 1.1). Almost half (47%) of the current 162 commercial ports began operating since the 19th Century, reflecting the boom in trade from the extensive British Empire. The locations of more recently developed ports were selected according to developing trade links (such as major towns and cities and the presence of nearby road and rail infrastructure), the positions of quarries and mines, and population densities.

The normal successful operation of ports can be disrupted or delayed by a number of types and issues that are often beyond their control. Throughout history the UK has been affected by extreme events, which are weather or non-weather events that are unusually severe, unseasonal in nature or occur without warning. The 1703 “Great Storm” had multiple devastating impacts for the nation including the loss of an estimated 8000 lives (Lamb, 2012), 300 vessels (Anon, 1826) including 12 Naval ships, and extensive flooding, particularly in the south and south-west of England (Brayne, 2003). In the 18th Century the UK’s population was only around 5.2 million (Lee and Schofield, 1981) compared to 66 million in 2017. The relative magnitude of life lost places this extreme event as one of the most severe recorded events in the nation’s history. In 1953, a powerful storm surge affected multiple countries (including the UK, Belgium and the Netherlands) causing 475 deaths in the UK and the loss of 24,000 homes, and resulted in a number of protective legacies including the Dutch Delta Plan and the UK Thames Barrier (Environment Agency, 2012; Jonkman and Kelman, 2005; Wadey et al., 2015b). Non-weather events, such as human error, can be harder to prepare for due to their unpredictable nature. In 1967 the Torrey Canyon ran aground, dispersing its cargo of more than 100,000 tonnes of crude oil into the sea. The outcomes of this event were very costly as over £3 million compensation was paid out to those affected within the UK and France (Bureau of Maritime Affairs Monrovia, 1967).

1.2.2 Risks facing the UK port sector

The current and future risks facing the UK port sector are both diverse and complicated. The main current challenges that are contended with on a frequent basis are extreme weather events (such as storms – see Sections 1.2.3 and 1.2.4), non-weather events (such as human error or industrial action), supply chain and “just-in-time” delivery issues and business risks (such as competition between ports).

The risks that ports face are not expected to remain consistent through time due to expected temporal changes in business and supply needs as well as the in nature and occurrence of extreme events. Changing public demands for goods is likely to affect port operations and productivity in future decades. Extreme weather events and climate change are two issues of different time-scales which will, in the future, have complicated challenges for ports. Extreme weather events are short-term potentially disruptive or damaging conditions that occur at a particular location. An area’s climate refers to average conditions experienced over a long-term period (in excess of 30 years). With climate change these average baseline conditions are predicted to shift.

Extreme weather events have the potential to be more complicated to contend with compared to non-weather events. Predicted future changes in extreme weather events are particularly challenging as they cannot be directly controlled, but risks can be reduced through effective adaptation measures (see Section 2.4.2). Climate change is predicted to both alter and create new risks for the UK port sector through changing baseline conditions (such as sea-level and mean/extreme temperatures) and is likely to impact both the frequency and severity of many extreme weather event types, although the specifics, and extent, of many of these changes remain uncertain (Stott et al., 2016).

It is critical that ports respond to the risks they face but it is unclear, both historically and in the present-day, what these risks are. The likely impacts of many extreme weather and climate change risks for the UK port sector are beginning to be identified (DEFRA, 2013). It is vital that ports respond to these risks through coping strategies and adaptations to reduce future losses in trade or reductions in their viability due to periods of disruption or damage.

1.2.3 The UK’s busiest ports and their baseline flood risk

Ten of the UK’s 162 commercial ports (seven in England, two in Wales and one in Northern Ireland) handle two thirds (67%) of total UK shipping trade (Department for Transport, 2016b) (Figure 1.2). These ports represent the diverse range of trades and operations carried out by UK ports including passenger services (ferries and cruise vessels), the movement and processing of cargo (including food, fuel, vehicles and technology), energy generation and on-site businesses. These ports are the busiest in the UK in terms of the tonnage of goods and/or the number of

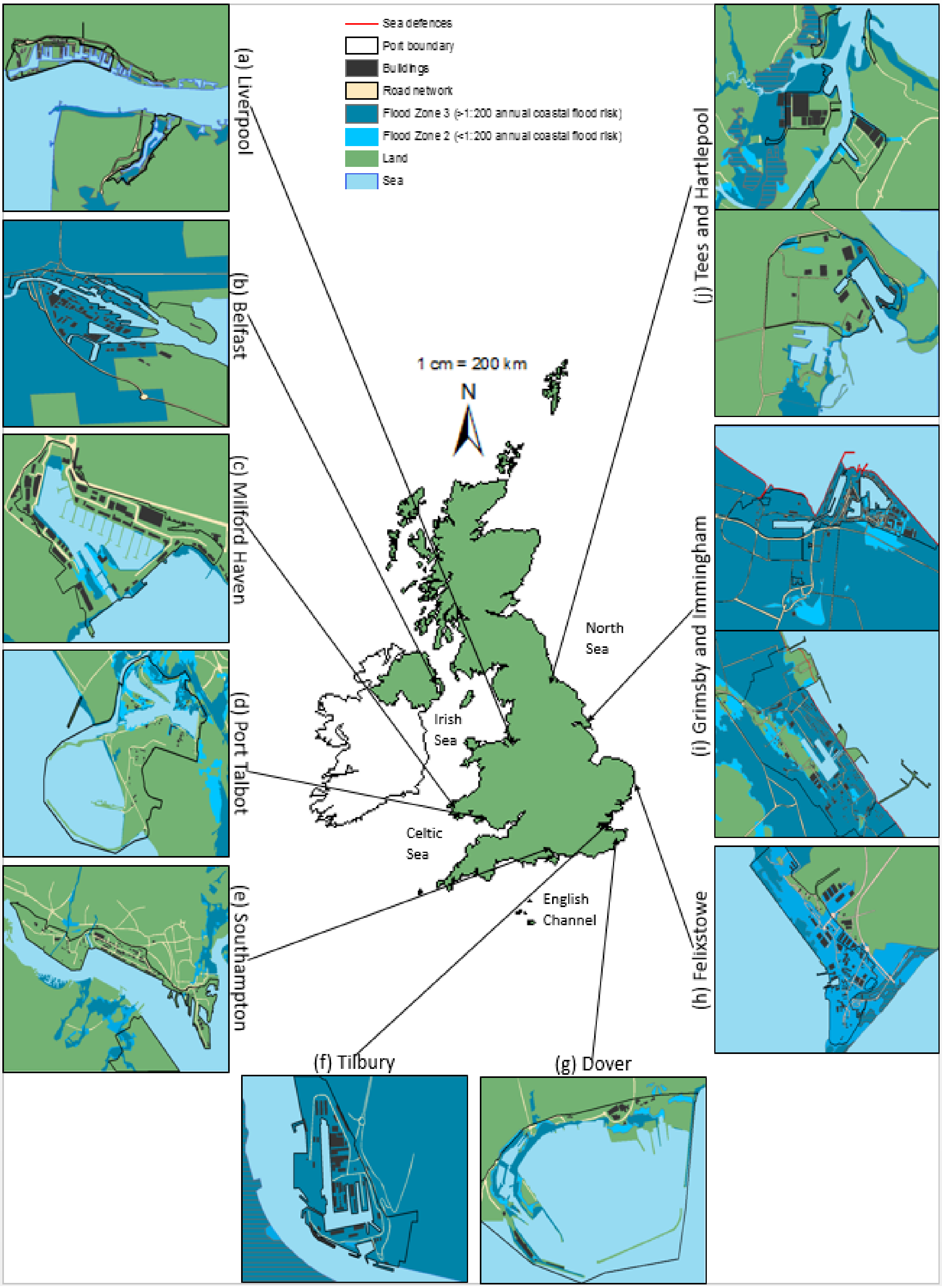


Figure 1.2: Maps of present-day flood risk for the UK's 10 busiest commercial ports/port clusters (data source: Environment Agency (2016)): Belfast, Dover, Felixstowe, Grimsby, Hartlepool, Immingham, Liverpool, Milford Haven, Port Talbot, Southampton, Tees and Tilbury. Flood zone 2 refers to a 1:200-1:1000 annual coastal flood risk, and Flood zone 3 is a greater than 1:200 annual flood risk. Inset figures are at a scale of 1:10,000,000.

passengers moving through the port annually. The history of the UK's busiest ports is highly diverse with the timing and nature of each development reflecting their individual original purposes for trade and connectivity.

Risks from coastal flooding due to extreme weather events are an important issue for UK ports, particularly when taking into consideration sea-level rise. Current rates for sea-level rise in the UK are of the order of 3mm per annum (Environment Agency, 2012), although future changes to this rate remains uncertain. To date sea-level rise has been larger in the south of the UK where land is subsiding, and less for the north where isostatic rebound is occurring (Jenkins et al., 2009). This challenge is further complicated as the baseline, or current, flood risk is individual to each port (Figure 1.2). Ports located on the east coast of England, which is exposed to storm surges that travel across the North Sea, had the greatest overall baseline flood risk (Figure 1.2), i.e. the likelihood and anticipated severity of a flood risk for a particular area. These ports, including Felixstowe and Immingham, represented those ports most likely to experience flooding across their land according to Environment Agency flood risk maps (Environment Agency, 2016). In many cases ports at risk of flooding have, and are, putting in place defence strategies, such as raising the heights of sea defences and dock gates, to increase their resilience to future flood events.

1.2.4 Winter 2013/14 and the cost for the UK port sector

Winter 2013/14 was the stormiest on record for the UK (Matthews et al., 2014), reflecting a period of sustained mean stormy conditions, flooding, and 12 distinct wind storm events between mid-December 2013 and mid-February 2014 (Kendon, 2014). For England and Wales as a whole, damage experienced due to flooding was estimated at £1,300 million, with damages to the UK port sector estimated at £1.8 million (Chatterton et al., 2016). In addition to direct damages caused by flooding, additional financial losses were associated with delays to services, where ports temporarily suspended operations to reduce the likelihood of additional damage to infrastructure or equipment, or injury to staff and passengers. The extended period of stormy conditions resulted in delays of 60 days for the construction of Peel Ports Liverpool2 terminal development (Liverpool Echo, 2014). A total of 99.3% of damages due to flooding alone were caused by coastal flooding, and the remaining 0.7% of damages arose from fluvial or groundwater flooding (Chatterton et al., 2016).

Twenty-one UK ports (1 major, 6 minor and 14 non-commercial ports) in Cornwall, Devon, East Yorkshire, Hampshire, Suffolk, Norfolk, West Sussex and Cambridgeshire received grants from the government following flood damage during the winter storms. Immingham and Portsmouth ports also sustained damage, but these expenses were covered by the port businesses themselves (Department for Transport and Rt Hon Patrick McLoughlin MP, 2014; Fenn, 2017) (Figure 1.3). Direct economic damage experienced by Immingham port is estimated to be in the region of £10 to £15 million. The outcomes of the winter storms included direct damages and an additional estimated cost of around £40 million caused by disruption to port operations and on-site businesses (Chatterton et al., 2016).

The damage and disruption experienced during this period of particularly stormy conditions highlights the importance of preparing the UK ports for the challenges and pressures associated with extreme events and climate change.

1.3 Aim and objectives

Any disruption or damage to port operations can have severe, and potentially long-lasting impacts on individual ports, and even for the UK's economy and productivity. With future sea-level rise, and changes in the nature and severity of extreme weather events (due to potential changes in storm tracks, rainfall patterns and temperature extremes), the challenges for ports will increase. Hence, it is critical that the challenges ports face both now, and in future decades, are well understood to enable timely and effective adaptation to protect their operations against damage or disruption.

The scope of this thesis has been developed to address these important issues in the context of the UK commercial port sector. This research aims to assess the vulnerability to, effects of, and responses to extreme weather events affecting UK ports, and to determine how well the port sector is adapting to the pressures and challenges of climate and climate change.

The study objectives are:

1. To determine the historic nature, and extent, of impacts of extreme weather and non-weather events on UK ports and the use of coping mechanisms as responses to disruptions,
2. To examine disruptions to dock-side port operations due to extreme weather and non-weather events under present conditions,
3. To assess how well UK port infrastructure and operations are prepared for the current and future challenges of extreme weather and climate change,
4. To propose measures for enhancing the adaptation preparedness of the UK port sector for climate change.

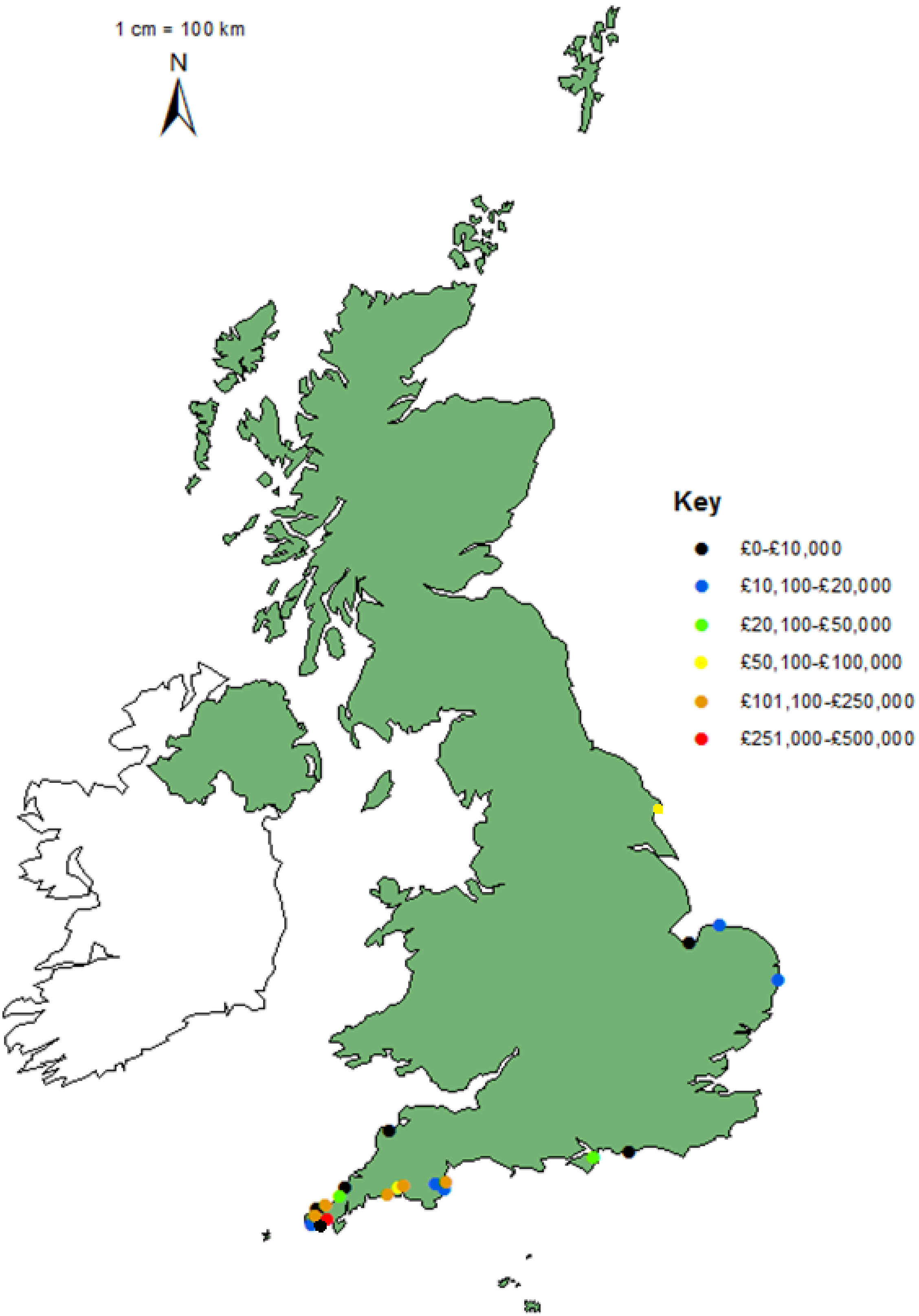


Figure 1.3: Map of UK ports who received financial grants and allocated funding from the Government for damage repairs following the winter 2013/14 storms.

The framework of this research (see Figure 1.4) is structured as follows:

Driver → Pressure → State → Impact → Response

1.4 Thesis structure

This thesis has eight chapters:

- Chapter 2 details the importance and vulnerabilities of the UK port sector, and challenges posed by extreme weather events and climate change. Port climate change adaptation and legislation are detailed, and a critical review of international studies that have assessed the effects that climate change will have for ports is detailed,
- Chapter 3 details the results of a data archaeology scoping study of historic extreme weather and non-weather events that have affected UK maritime regions,
- A new proxy for identifying periods of port disruption are described in Chapter 4 through a two-year assessment of three UK ports,
- Chapter 5 assesses the preparedness of the UK port sector for the wide range of challenges associated with climate change,
- A discussion of the findings of the research is set out in Chapter 6,
- Chapter 7 draws together the conclusions from the entire research, and includes a summary of future work recommendations.

1.5 Thesis methodology

This thesis aims to assess the vulnerability to, effects of, and responses to extreme weather events affecting UK ports, and to determine how well the port sector is adapting to the pressures and challenges of climate and climate change. To achieve this the understanding of past and present vulnerability of ports to extreme weather events, and adaptation to climate change needs to be improved.

Four objectives were developed to improve understanding of UK ports, their vulnerability to extreme weather events and preparedness for the many challenges of climate change:

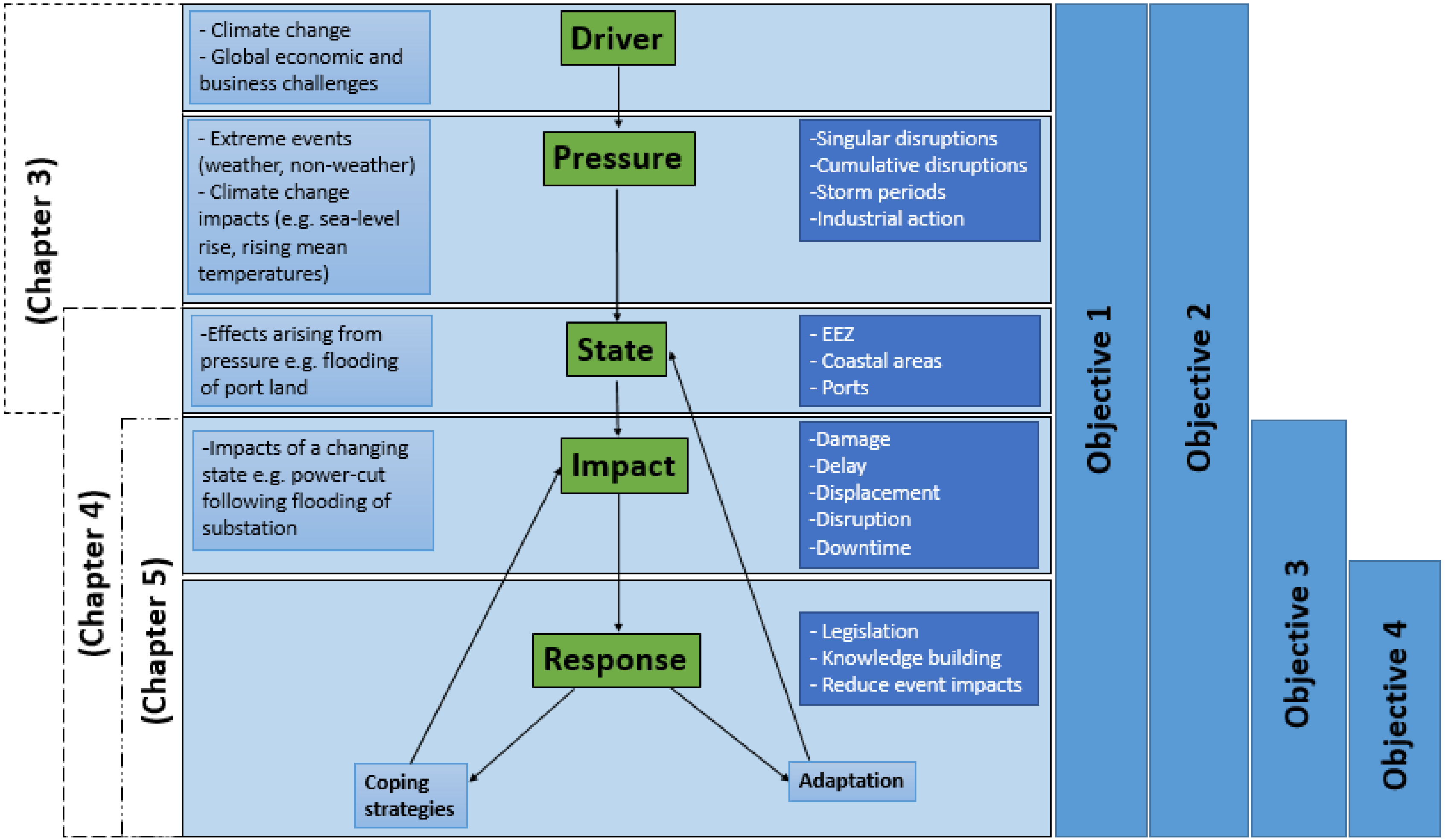


Figure 1.4: Framework of the key stages of research within the thesis mapped onto the results chapters and objectives.

Objective 1: *To determine the historic nature, and extent, of impacts of extreme weather and non-weather events on UK ports and the use of coping mechanisms as responses to disruptions.*

A historical scoping study of extreme weather and non-weather events that affected UK maritime zones – coastal areas, EEZ (Exclusive Economic Zone) and ports – between 1950 and 2014 was developed by building a database of recorded events (see Section 3.2).

Objective 2: *To examine disruptions to dock-side port operations due to extreme weather and non-weather events under present conditions.*

A database of vessel activity for three case-study ports was developed for the period September 2013 to September 2015 to assess the types, duration, impacts and responses of ports to extreme events (see Section 4.2).

Objective 3: *To assess how well UK port infrastructure and operations are prepared for the current and future challenges of extreme weather and climate change.*

Objective 4: *To propose measures for enhancing the adaptation preparedness of the UK port sector for climate change.*

The final stage of research assessed how well the UK commercial port sector is currently prepared for the future challenges of climate change through an assessment of Adaptation Reports and questionnaire disseminated to all currently operating UK commercial ports (see Sections 5.2 and 5.3).

Chapter 2: Literature Review

2.1 Port disruptions

2.1.1 Types of port disruptions

Ports must contend with a wide range of pressures and challenges that have the potential to disrupt their operations and functionality. Coastal areas, including ports, experience a wider range of potential types of disruption (Kron, 2012) than their terrestrial counterparts. When ports, particularly larger ports, experience periods of disruption the effects of this can be felt within the local and national economy (Rose and Wei, 2012). The range of types of potential disruption differ in the severity and nature of their likely impacts, the duration of the events, and the frequency of their likely occurrence. Some types of disruption are generic and have the potential to affect all ports (e.g. human error), whereas others only affect ports in certain locations (e.g. tsunami) or with particular operations.

Port disruptions are split into extreme weather events (Section 2.2) and non-weather events (see Section 3.3.1). Non-weather events can be further divided into natural and human-induced disruptions (see Appendix A). The range of extreme event types that can affect ports are diverse and represent the broad range of potential challenges for successful port operations. Types of disruptions that are human-induced (such as instances of human error) can be harder for a port to prepare for and defend against, as they are often unpredictable both in terms of their timing and impacts. Human error and not responding effectively to a potentially dangerous or disruptive condition (Baker and Seah, 2004) are major causes of accidents that occur in ports and maritime areas. Additional complex challenges arise from business issues, such as competition between ports, supply chain issues and industrial action (Loh and Van Thai, 2014) which have the potential to affect port operations on short to long time-scales.

Natural types of disruption, including earthquakes, tsunamis and subsidence (Sekovski et al., 2012) pose significant challenges for successful, and safe, port operations. Ports are particularly vulnerable to such risks due to often being constructed on consolidated materials (Wood and Good, 2004) and reclaimed land.

2.1.2 Recovery and responses to port disruptions

Ports are not always able to return to their "normal" functionality after experiencing a severe disruption to their business and operations (Sanchez et al., 2003). For example, the 1995 Great Hanshin Earthquake had devastating impacts for Kobe port in Japan. Following the earthquake the port's status declined from the 6th largest container port in the world (in terms of annual throughput) to the 45th, and some trade sources were never recovered (Chang, 2000; Shafieezadeh and Ivey Burden, 2014). This decline arose due to the long duration of implications of the earthquake, in the form of permanent loss of business to other ports and the long recovery time (around two years) which left the port unable to compete with technological and equipment advances at neighbouring ports.

Severe disruptions can have impacts for supply-chain resilience (Loh and Van Thai, 2014). When recovering from extreme events ports often put in place coping strategies to either reduce the extent or duration of impacts (Rose and Wei, 2012). These strategies are often general in nature, and can be applied to impacts experienced by a range of extreme event types. Examples of coping strategies include:

- Using stored resources – Either accessing back-up supplies of fuel to ensure that port operations such as the movement of high-level cranes can continue, or by using stockpiles of cargoes to reduce the occurrence of shortages to suppliers.
- Temporary re-routing of vessels – Diverting to other local ports or ports managed by the same parent company. Re-routing can reduce delays experienced by vessel and cargo clients but repeated incidents can increase the likelihood of vessel contracts being permanently moved to an alternative home port.
- Utilising employee resources – Often used as a short-term response to reduce the impacts and longevity of negative impacts from extreme events. Examples include redeploying staff to alternative roles, or the use of overtime to reduce delays to cargo or passenger movements.

2.1.3 Future port disruptions

The diverse range of extreme event types, particularly extreme weather types, and potential impacts (Table 2.1) facing ports and their successful operations are expected to alter in future decades due to the multifaceted implications of climate change. Current implications of extreme events, such as periods of time where cargo or vessels cannot be safely moved, may become

Table 2.1: The implications of extreme weather and non-weather event impact types on port operations

Affected aspect of operation	**Implications of extreme event impacts**
Cargo	Unable to load or unload cargo Damage to, or loss of, cargo
Equipment	Port equipment unable to be safely operated (e.g. high level cranes) Damage to equipment
Passengers and staff	Unable to safely embark or disembark passengers Injuries or deaths
Vessels	Vessel unable to either dock at or leave port Delay to scheduled services Damage to vessels
Infrastructure and/or general operations	Port temporarily inaccessible due to flooding or snow and ice Power disruptions halting port operations Temporary or long-term loss of trade Infrastructure damage Port closure

more frequent with climate change. In addition, new risks facing port operations may emerge as the impacts of climate change become more developed. Sea-level rise, rising mean temperatures, potential shifts in storm patterns and changes in supply and demand are all predicted to have impacts on the nature and severity of port disruptions.

The range of extreme event types that have been historically identified as affecting UK ports are limited compared to those experienced internationally (see Appendix A). This thesis is focused on the UK port sector, rather than ports globally. International examples of impacts of extreme events on ports, and their extent of climate change preparedness are detailed in Sections 2.2.2 and 2.4.2.6 to set extreme events and port adaptation into a wider context.

2.2 The importance of extreme weather events

2.2.1 Extreme weather events and UK ports

Extreme weather events are external shocks (Amundsen et al., 2010) that can result in impacts on scales ranging from the local to the national or even international (Department for Transport, 2014a). Extreme weather is broadly considered as conditions that occur at the top or bottom ends of the spectrum of historical conditions for a known weather event type (The Royal Society, 2014). The severity of an extreme weather event is related to the nature and duration of its impacts (Wisner et al., 2004). Any damage or disruption to normal port operations due to extreme weather events can have severe and often diverse consequences to a range of factors including the economy, society, supplies, and on a port-specific scale – business reputation (Rose and Wei, 2012).

The consequences of extreme weather events can have severe impacts on a range of time-scales from hours to months or even years. Damage or disruption arising from extreme weather can be caused by a broad range of types. The impacts of each type can be diverse, and the most severe impacts of such events can act as catalysts for change to enhance a port's resilience to future events. "Just-in-time" deliveries, where cargo arrives in port in response to demand rather than having reserves kept in storage, tend to be most severely affected by extreme weather events. Subsequently any disruption to "just-in-time" deliveries can have knock-on effects on production processes which are often dependent on the efficient and timely delivery of intermediate materials required for manufacturing (Kopp, 2012a).

Extreme weather event types (such as wind storms or storm surges) rarely occur in isolation (The Royal Society, 2014). More commonly, combinations of multiple event types experienced at the same time can result in a range of interlinking pressures which are more complicated and severe to contend with (Welsh Government, 2011; Wisner et al., 2004). The impacts of extreme weather events are multi-dimensional in nature (Government Office for Science, 2004). It is important to carefully differentiate between the natures of more frequent nuisance and rare catastrophic events, as their impacts tend to be very different (Sayers et al., 2002). However, it must also be noted that repeated nuisance events can have cumulative impacts and costs for the society and economy, despite not occurring in such a dramatic and often media-worthy form (Varley, 1994).

Some aspects of port operation have a higher level of vulnerability to extreme weather events. For example, if high level cranes are damaged during an extreme event the repercussions can be significant on a port-wide basis. If cranes are out of operation, delays to cargo operations both to and from the port can have long-term negative impacts in the form of large financial costs incurred both to a loss in trade and for the repair or replacement of damaged cranes.

2.2.2 Examples of severe extreme weather events that have affected ports through history

Extreme weather events have affected the UK's ports throughout history with records of severe events extending back hundreds of years. 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 approximately 5.2 million (Lee and Schofield, 1981). A number of studies have investigated particular extreme events that have affected the UK's ports, maritime industry and trade. A notable example is the 1953 storm surge (Baxter, 2005; Flather, 1984; Gerritsen, 2005; Risk Management Solutions Inc., 2003; Schneider et al., 2013) which had devastating impacts for countries including UK, Belgium and the Netherlands, creating legacies which include the Dutch Delta Plan and UK's Thames Barrier (Environment Agency, 2012; Jonkman and Kelman, 2005; Wadey et al., 2015a). Whilst the extreme damage of the 1953 storm surge remains in the public memory it has been shown to act as a catalyst for improved UK coastal protection.

In recent years major ports in countries and regions such as the United States and Australia have experienced severe extreme weather events including:

- Hurricane Katrina (August 2005) – Cargo was diverted from large ports in Louisiana and Mississippi to smaller ports including Wilmington, Pensacola, Panama City and Morehead City (Dalesio, 2005). Five years after the hurricane Gulfport in Mississippi was only operating at 80% of its previous level (Becker et al., 2014).
- Hurricane Sandy (November 2012) – Closure of the New York and New Jersey ports for seven days. Response included the diversion of 57 vessels (including one cruise ship). Much of the redistributed cargo was processed at Virginia international terminals and brought back to New York and New Jersey by rail, barge and truck (CMA CGM Australia, 2012; NACS, 2013; The Port Authority of New York and New Jersey, 2012).
- Cyclonic wind event (April 2015) – A number of Australian ports in the Sydney area were closed for 2-3 days (Kembla, Botany and Jackson, Newcastle had restricted access) due to damaging winds (up to 74 kph) and high seas (World Maritime News, 2015b).

2.3 Climate change and ports

2.3.1 Extreme weather events and climate change

The timing, frequency and impacts of extreme weather events are predicted to potentially change due to climate change (Zanuttigh, 2011) (Section 2.4). The severity of such future events may also exceed recorded historical conditions (The Royal Society, 2014). Ports often have operating thresholds in place for extreme weather conditions (Scott et al., 2013b). These thresholds vary between the regulatory (such as high-level cranes powering down when wind gusts exceed a particular velocity) and the non-regulatory (such as for rainfall or fog where there are no regulations in place for ceasing work, and decisions are based on the opinion of operators).

The number of reported extreme weather events are increasing (Schuster, 2013). The exposed coastal locations of ports increases the risks associated with these potentially damaging or disruptive events (Mendelsohn et al., 2012). Risks faced by port operations can be described by a simple combination of a hazard, exposure and vulnerability (Figure 2.1):

Risk = Hazard x Exposure x Vulnerability

The risks predicted to affect ports due to climate change are expected to be unique for the port sector, reflecting the juxtaposition of ports on the boundary between the marine and terrestrial environments, and the importance of connections to transport infrastructure networks (Kong et al., 2013; Wilbanks et al., 2012). The impacts of climate change are expected to be broad, as both

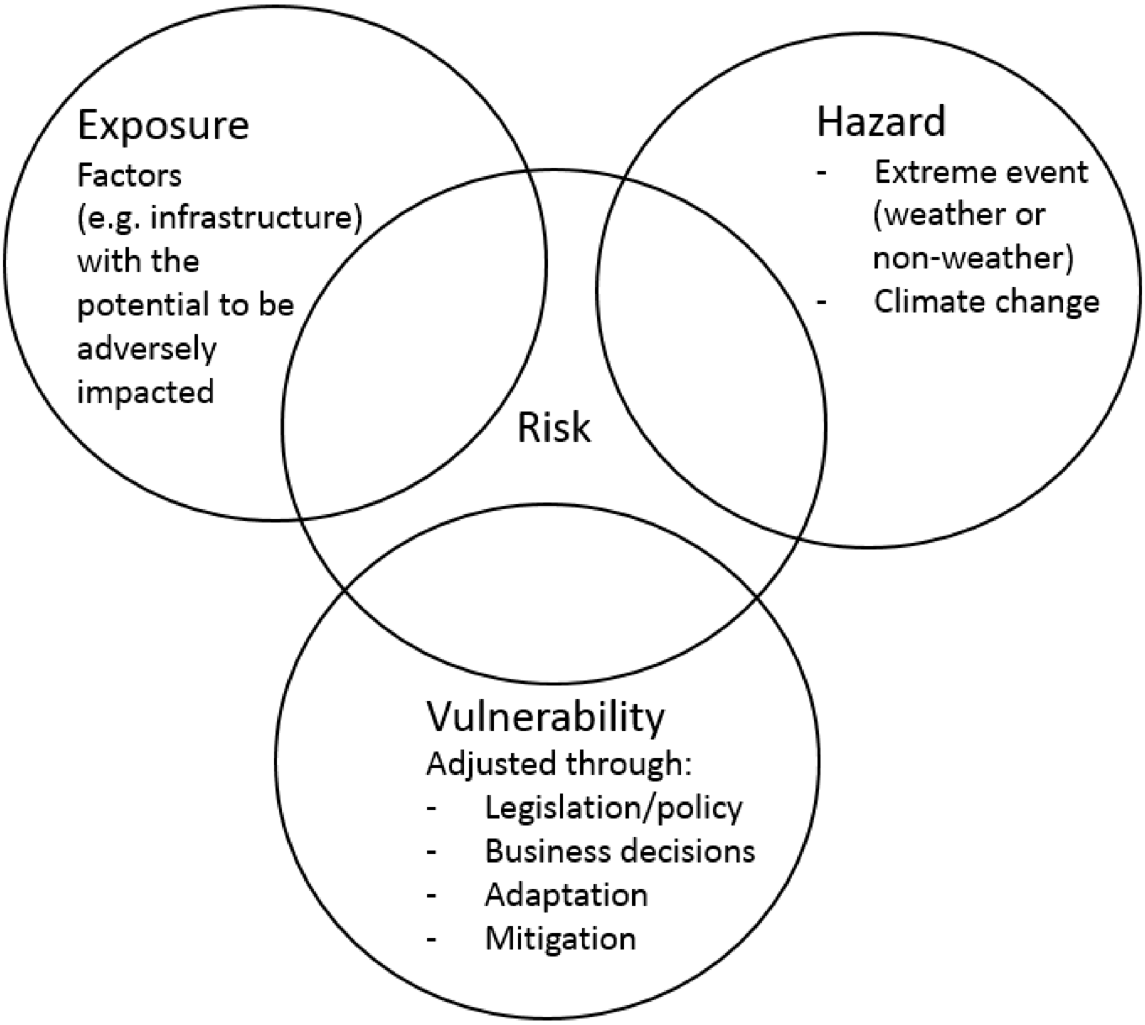


Figure 2.1: Risk equation for extreme events and climate change which arises due to its interaction with exposure and vulnerability (adjusted from IPCC (2014a)).

risks, and interdependencies between risks are expected to shift (Kousky and Cooke, 2009). If ports are not well prepared for the risks and challenges associated with climate change the effectiveness of their future operations may be threatened (Mullett and McEvoy, 2011). The sequence of events that arise from climate change risks can be described by the Driver Pressure State Impact Response (DPSIR) model (Figure 2.2):

- Driver – A global-scale factor (e.g. climate change) that puts pressure on a resource or asset (e.g. a port).
- Pressure – Stresses (e.g. extreme weather or non-weather events) that can affect the conditions or operability of an asset or resource.
- State – Observable changes in an asset or resource (e.g. reduced infrastructure robustness).
- Impact – The effects and consequences of a pressure (e.g. flooding of a port's substation).
- Response – Decisions or actions implemented to reduce or avoid impacts (e.g. development of storm surge warning systems).

It makes good business sense for ports to have a detailed understanding of the weather risks they face both now and in the future due to climate change. If these risks, and the potential need for adaptive action, is not considered ports in future decades is likely to experience an increased frequency and severity of extreme event impacts. Extreme weather events can act to change the perception that climate change is not an issue for ports and their successful future operations (Capstick and Demski, 2016). However, few ports to date have kept publically available records of events that have negatively affected their operations (Royal Haskoning, 2011b). The UK port sector considers itself well prepared for extreme weather events (see Table 6.2), and do not consider records of historical extreme events of particular importance.

However, UK ports are still affected by extreme weather events (see Appendix D and Section 4.4). By tackling the issue of the so-called “adaptation deficit” (Dilling et al., 2015; Nicholls et al., 2010), whereby ports begin to take action by adapting to current extreme weather challenges, the impacts of climate change on port operations and infrastructure would be likely to be substantially decreased.

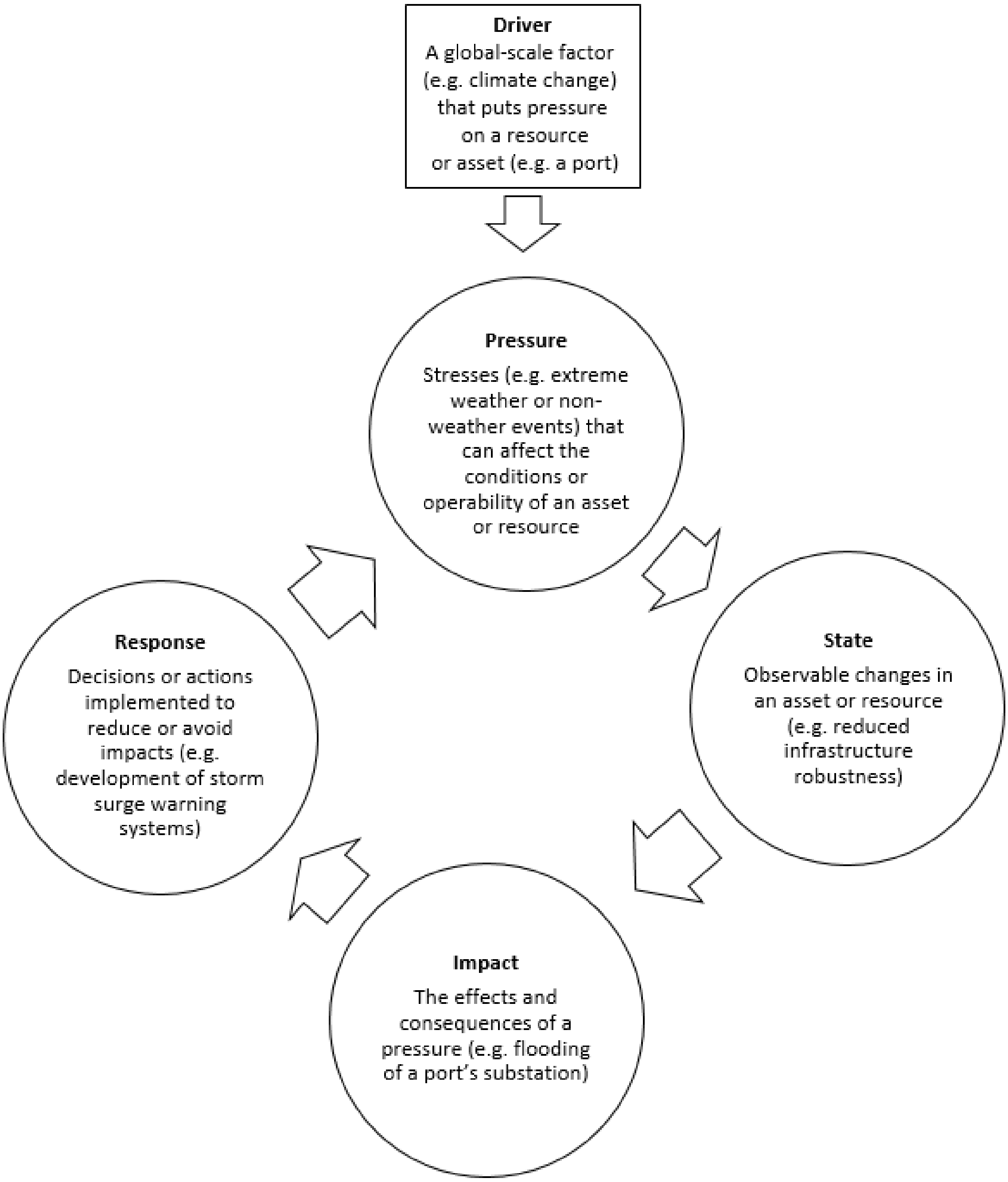


Figure 2.2: Driver-Pressure-State-Impact-Response model of climate change risks for the UK port sector.

2.3.2 Potential impacts of climate change

Climate change provides a new challenge for ports both due to potential changes in the nature and severity of extreme events, and shifts in baseline conditions (e.g. sea-level rise and rising mean temperatures). Historically infrastructure developments in ports have been simply motivated, using knowledge from historical, and predictably consistent, coastal conditions (Becker and Englander, 2014; Moser et al., 1990). With increased awareness of predicted future climate change risks it is expected that the port sector will begin to put in place a diverse range of adaptation measures.

The UK's 2009 climate projections (UKCP09) were developed to provide predictions of how the occurrence and severity of impacts from causes of extreme weather are expected to change with climate change. UKCP09 projections utilised data from a combination of UK (MetOffice) and internationally developed climate models, and were assessed to determine the most likely impacts of change (DEFRA, 2009b). Confidence in predictions of changes associated with climate change varies. The robustness of models of changes to averages are greater than that of extremes (DEFRA, 2009b). Currently models are unable to resolve what changes are likely to occur on a local level (Kopp, 2012a). The UK's busiest commercial ports have been advised to use UKCP09 climate projections to advise identification of their adaptation needs (see Section 5.2).

Rising sea-level, storm surge heights, intensity of rainfall and rising mean and extreme temperatures (Chhetri et al., 2013; Townend and Burgess, 2001) are issues that ports will need to contend with more frequently and severely due to climate change. In 2012, a study of the UK transport sector suggested that milder winters will improve operating conditions for ports, although the unpreparedness of ports for more occasional severe extreme weather events may be a challenging issue without adaptation (HR Wallingford, 2012). The impacts of climate change are both diverse and complex. Effects experienced by ports from climate change can arise either directly (such as damage or flooding occurring from a wind storm or rising sea-levels) or indirectly (such as power cuts due to damage experienced by utility firms (Smith, 2015)) (Table 2.1). An additional concern being raised is that the potential increase in the frequency and severity of extreme weather events will impact the insurability of ports and their equipment (Kousky and Cooke, 2009).

2.3.2.1 **Climate change impacts and ports**

In the context of climate change the focus of this thesis will be on changes to the occurrence and severity of extreme weather events. The impacts of non-weather events will not be considered in as great detail as future changes to such events (for example occurrences of human error or industrial action) cannot be forecast.

2.3.2.1.1 Sea-level rise and coastal flooding

Without effective adaptation sea-level rise, and associated coastal flooding, is a confirmed risk for many coastal areas (Pugh, 2004) that are locations of dense commercial operations or residential occupancy. Combined risks from storm surges (storms and extreme tides) and sea-level rise will affect ports (Becker and Englander, 2014) by altering the total water level height. These changing risks will adjust the clearance between vessels, bridges and dockside, and increase the risk of damage to infrastructure, piers, buildings, high-level cranes, vessels and cargoes (Chhetri et al., 2015; Kopp, 2012a). Without raising the heights of quays and sea defences the frequency and severity of coastal flooding events is expected to increase (Townend and Burgess, 2001). As well as causing direct flooding damage, secondary impacts associated with corrosion and erosion by overtopping storm waters should be considered.

Additional risks associated with sea-level rise include the flooding of the local road network (Becker and Englander, 2014) or utilities (such as water and electricity) which can isolate a port and force its operations to temporarily halt (Chhetri et al., 2013). The complex interaction between intra- and extra-port infrastructure can result in a domino effect between a port and its utility and transport networks (Kron, 2012). This is due to the isolated position of ports on the boundary between the terrestrial and the marine environments and their reliance on the reliability of connections to wider infrastructure links.

2.3.2.1.2 Rainfall

Although the UK’s annual rainfall is expected to stay constant in quantity the intensity of rainfall events will increase (Savonis et al., 2012). This will have the potential to put pressure on port drainage, and risk flooding port buildings and cargoes (Table 2.1). Rising mean temperatures and high temperature events have the potential to impact multiple aspects of port functionality (see Appendix A) and infrastructure including degrading tarmac surfaces and deforming train tracks (Kopp, 2012a).

2.3.2.1.3 Wind storms

Shifts in the occurrence and severity of wind storm events due to climate change are debatable (Lennart Bengtsson et al., 2009; Schwierz et al., 2010; Sexton and Murphy, 2010). Changes to the positions of storm tracks are uncertain as there is no clear trend currently available in UKCP09 model outputs (DEFRA, 2009b; HR Wallingford, 2012). Whereas analyses published within the IPCC's AR5 and special report on extreme events and disasters identified potential poleward movements of storm track positions and a change in both the frequency and severity of storm events (IPCC, 2012, 2014b). Winds cause rough seas and these can have negative implications for vessels and damage cargoes (Popovic et al., 2014) (see Appendix A).

2.3.2.1.4 High temperatures

Both means and extremes in temperature are expected to increase with climate change. UKCP09 projections state that mean summer temperatures may increase from 1-9.5°C, and 0.7-4.4°C in the winter months (DEFRA, 2009).

2.3.2.1.5 Other climate change impacts

To date there has been little or no exploration of how changes in the occurrence of snow and ice and poor visibility events may affect the UK port sector in future decades. Current UKCP09 projections have large uncertainties for future changes in these event types (DEFRA, 2009).

2.3.2.2 Variations in climate change impacts between ports

The impacts of climate change is expected to vary with port location. A number of factors, such as port type and location, play a role in determining how severely a port will be affected by extreme weather events and climate change (Chhetri et al., 2013). For example UKCP09 model predictions anticipate that east coast ports will experience more issues from storm surges in future decades (DEFRA, 2009b). The outcomes of climate change impacts will range from general business threats, such as broad effects on financial profitability (Chhetri et al., 2013), through to damage to specific equipment or cargoes.

Ports are not just vulnerable to the impacts of climate change that directly affect their operations. The interconnectivity of transport networks and of trade can result in disruptions occurring beyond port boundaries having tangible, and sometimes devastating impacts on port operations (Scott et al., 2013b).

2.3.3 Variations in climate change impacts and port responses

The impacts of climate change on ports will depend, in part, on their baseline vulnerability. In terms of extreme weather and climate change, vulnerability refers to the susceptibility to particular climatic pressures which can arise from how the environment and people interact (Wisner et al., 2004). McCarthy et al. (2001) considers the level of vulnerability experienced at any time to be a combination of the characteristics and rate of change of the extreme weather condition to which an environment, in this case a port, is exposed, and the adaptive capacity and sensitivity of this environment (Burton et al., 2002) for loss to occur (Uitto, 1998). Hinkel (2011) suggests that the vagueness and diversity of vulnerability definitions and its theoretical rather than tangible nature means that vulnerability cannot be measured.

Less severe disruption events, such as those that disrupt port operations, tend to be, to a great extent, absorbed into day-to-day operations, highlighting port resilience (Osthorst and Manz, 2012). These so-called routine events occur on a more frequent basis and infrastructure has been developed to contend with the broad range of pressures that the events cause. For the port sector resilience describes the ability of a region to resist extreme events without suffering devastating losses to infrastructure, commodities, lives (Mileti, 1999) or the economy (Rose and Wei, 2012). Resilience can also be interpreted as the level by which a system is able to self-organise, and build its adaptive capacity (Adger et al., 2005). Such conditions arise naturally if the region has an inherently higher level of baseline resilience (such as ports located in sheltered estuaries), or if adaptation strategies are put in place to enhance its robustness. Consequently exposure does not always translate into risk or damages (Nicholls et al., 2008) (Figure 2.1). High frequencies of less severe disruptions can have cumulative negative effects by eroding resilience, which can result in severe negative impacts on port operations. In some cases increasing resilience can be perceived as a process that has a range of benefits for a number of groups, including internal and external stakeholders (Becker et al., 2014). By improving a port's resilience to climate change risks, such as sea-level rise, likely side-effects include building resilience to other current causes of damage or disruption (e.g. wind storms or storm surges) (DEFRA, 2009a).

Resilience is a critical factor which must be considered alongside port climate change adaptation, and details the extent by which a system, community or business is able to adapt and adjust to circumstances that cause stress or shocks (The Royal Society, 2014). Increasing resilience through changes to behaviour or societal attitudes can also have positive influences on the effectiveness of other resilience increasing techniques such as through enhancements to health and safety policies. The greater the resilience of a port to disruptions, the more quickly and effectively a system or circumstance will theoretically be able to cope with abnormal circumstances.

Research by Tsatsou (2014) of 40 port cities spread across 10 countries found distinct differences in adaptation responses between ports. Ports situated in natural bays tended to respond more proactively to climate change risks. The extreme weather and climate change risks experienced by ports also differed on whether the ports were located in natural harbours or were fully artificially constructed (such as ports located on reclaimed land). Artificially constructed ports were shown to be more prone to flooding, reflecting their synthetic structure and drainage networks, whereas natural ports were more able to cope with the same quantities of water aided by the presence of naturally developed drainage channels.

2.3.4 Port sector climate change awareness

Since the 1990s the level of awareness of risks associated with extreme weather and climate change has increased, with a focus on the social and economic aspects of risk (Burton et al., 2002). This increase in scientific and engineering knowledge has the potential to accelerate the rate of adaptations put in place to defend ports (Townend and Burgess, 2001) in response either to actual or expected extreme events or risks (Fussel, 2007). It would be helpful if the port sector feels that there are important incentives (Becker et al., 2014) for putting in place adaptation measures to encourage ports to take steps to prepare for the predicted challenges of climate change. This is an important issue to consider as ports have a short business planning time-scale which is in conflict with the longer climate change prediction time-scales. It is proposed that ports who act as adaptation "pioneers" by setting an example to the rest of the sector, will benefit in terms of gaining a competitive advantage (CDP, 2015), at least on the short to medium time-scale. However, this would not currently be of benefit for countries such as the UK, where ports are managed by private companies, who do not share knowledge on adaptation successes or what has been learnt (see Section 6.5.2). Increased climate change awareness and training is a beneficial tool for the port sector (Chhetri et al., 2015) both for dock-side staff and management (Chhetri et al., 2013).

Climate change risks, in the form of sudden shocks due to extreme weather events, needs to become an important consideration for decision-makers in ports in terms of both risks facing passing vessels, as well as those that berth within UK ports. The reputation of a port that has implemented techniques to strengthen its resilience, as well as its connectivity, is enhanced (Felixstowe Dock and Railway Company, 2011; OECD, 2014) as it is perceived as a more secure option for trade. Secondary benefits arising from climate change include reduction in dredging frequencies or fewer occurrences of extreme cold conditions for certain ports (e.g. parts of Europe), reflecting how the effects of climate change are expected to be diverse and vary greatly by location.

Global port communities, such as the International Association of Ports and Harbours have demonstrated that they are actively considering climate change in their actions (Inoue, 2012) such as implementing measures to reduce greenhouse gas emissions (e.g. using cleaner fuel sources and investments in using electric rather than diesel power for port equipment). However, to date such measures focus purely on climate change mitigation, such as a tool box produced to assist port mitigative actions (International Association of Ports and Harbors, 2008).

2.4 Responses to climate change

Adaptation and mitigation actions comprise the two types of positive response that can be taken against climate change and can take place on all levels from grass roots to international scales:

- Climate change mitigation - Actions to reduce or prevent the emissions of greenhouse gases, such as carbon dioxide and methane into the atmosphere.
- Climate change adaptation - Actions or decisions taken to reduce potential risk, such as those associated with climate change (e.g. sea-level rise) or extreme weather events through both hard (e.g. building defences) and soft (e.g. policies or ecosystem manipulation) measures.

This thesis is focused on climate change adaptation rather than mitigation. Climate change mitigation is, currently, a more well developed range of methods than climate change adaptation. Mitigation actions have effects on a global scale, where as the need for effective adaptation is localised and, in the context of this research, port-specific. Port climate change adaptation is a still developing topic for which limited publically available research is available. Further research, and improved adaptation techniques, are required to inform ports on how, and when, best to adapt to the many potential challenges of climate change.

2.4.1 Climate change mitigation

Documentation produced by, or for, ports on the topic of climate change have primarily focused on climate change mitigation actions (Fussel, 2007; Ng et al., 2016). To date mitigation actions have focused on the reduction of emissions through the development of renewable energy generation (Hooven et al., 2011; Tsatsou, 2014) and tend to use a polluter pays initiative. In the 1990s and 2000s much focus on the topic of climate policy has been on mitigation rather than also considering the importance of adaptation (Adger et al., 2009). Even broader international measures, such as the Kyoto Protocol, which have impacts on an international scale, were focused on mitigation rather than adaptation, with mitigation being framed as the only way to effectively act against climate change (Khan and Roberts, 2013). Discussions have mainly been on the contribution of the port sector to greenhouse gas emissions and the importance of putting in place mitigation measures (Kopp, 2012a). This has been the focus both on national and international scales (Urwin and Jordan, 2008) and has lead to policy responses for mitigation being more well developed than adaptation (Burton et al., 2002), such as within the UK's 2008 Climate Change Act which has detailed legislation on how greenhouse gas emission reductions will be achieved.

Mitigative action in ports primarily comprises increasing operational efficiency and consequently reducing emissions (Belfast Harbour Authority, 2013a). These definitions are strongly aligned with the perspectives of many UK ports (e.g. Southampton, Belfast).

A focus still remains on mitigative actions, as the port sector has found that highlighting its dock-side operations as 'green' or having an emissions reduction initiative improves public and client perspectives, and consequently encourages business with shipping companies and other services. For example, in 2011 Peel Ports who operate the port of Liverpool developed a 20 year strategy for business growth which highlighted the intention to make the port a "green gateway" to the UK. Measures being developed include the introduction of hybrid-energy high-level cranes and collaboration with energy developer RES to build a biomass power plant on the port's land (Peel Ports, 2011).

2.4.2 Climate change adaptation

2.4.2.1 Climate change adaptation and ports

There is no single agreed definition of adaptation and definitions differ between nations and area of focus. For example the United States Global Change Research Program (2014) considers adaptation as an issue arising from more factors than just climate change, and describes any response made to changing environmental conditions that reduces negative impacts, or results in the development of new benefits (e.g. a reduced need for dredging). Broader definitions are also explored, such as by Tol et al. (2008) who consider adaptation to also to include responses to an environmental change regardless of whether the outcomes of such action are successful or unsuccessful. It is only in recent years that the global port sector has begun to consider climate change adaptation as an important action, although this research is still very much in its infancy (Becker et al., 2018).

Adaptation is being developed as a policy response to complement mitigation (Corfee-Morlot and Agrawala, 2004). In terms of ports, adaptation refers to actions taken by decision-makers to increase the port's resilience to sudden shocks and creeping change arising from climate change. When responding to pressures from extreme weather conditions adaptations are designed to reduce the occurrence of negative impacts, such as delays, damage and financial effects (Popovic et al., 2014) (Figure 2.3 and Table 2.1) or to take advantage of potential positive opportunities (IPCC, 2000). It has been suggested that under incremental change, such as sea-level rise, beneficial potential options to increase resilience may be overlooked (Adger et al., 2005; Kates et al., 2012). When preparing for climate change a number of adaptation types are available to the port sector (Table 2.2) (McEvoy and Mullett, 2013; Sayers et al., 2002). These adaptation types can be broadly categorised according to two motivations (this issue is further discussed in Section 6.3.3.3):

- Climate change specific decisions – Collaboration with other ports or businesses, develop backup operations, flood prevention, new insurance options, preparedness for temperature extremes, securing power supply.
- Multiple motivations – Amended operations, improved technology, improved visibility, increased on-site storage, infrastructure robustness, knowledge building, planning improvements, updated regulations.

Without effective adaptation some ports may become unfavourable locations relative to competing ports, as predicted potential changes in sea level and storm patterns develop (Hanson and Nicholls, 2012), as many are located in vulnerable areas by design (Becker et al., 2014). Ports are areas of densely populated infrastructure and operations. The level of development, and the prime position of ports makes adaptation in situ a preferred economic option than relocation of port operations (Messner et al., 2013; Smith, 2015). The greatest costs of port adaptation lies in high density of infrastructure (Osthorst and Manz, 2012), which encompasses both the structure of the port itself and the equipment employed (Kopp, 2012b).

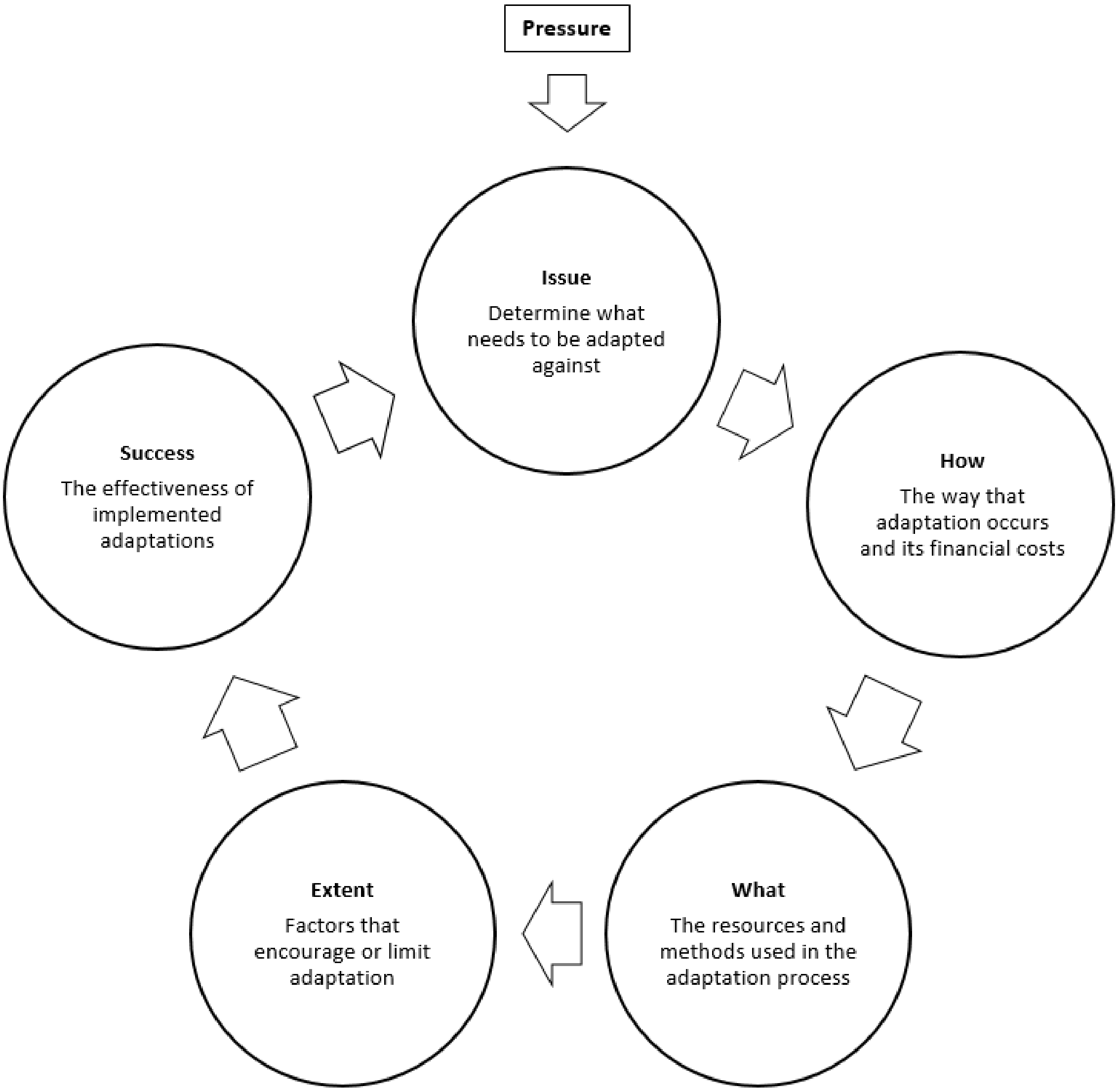


Figure 2.3: Adaptation assessment cycle to assess changing baseline conditions and risks.

Table 2.2: Adaptation types available to ports and examples of adaptation being implemented by UK ports

Adaptation types (adapted from (McEvoy and Mullett, 2013))	Examples of adaptation actions underway by UK ports
Planning improvements	• Develop flood risk management plans • Improve/refine planning guidance • Recovery procedures for cranes • New container stacking strategies • Marine works license applications must be climate proof
Preparedness for temperature extremes	• Improved refrigeration/cooling • Under-ramp heating • New grit stores • Purchased snow blowers • Supply new workplace clothing to accommodate temperature extremes
Improving visibility	• High visibility lighting • Radar enhancement
Infrastructure robustness	• Improved defences • Increase infrastructure resilience • Wave aligned developments • Replace quay/raise quay level
Securing power supply	• Generator upgrade • Backup generators • Monitor lightning
Increased on-site storage	• Increased capacity for truck and container storage during periods of delay
Flood prevention	• Containers on plinths • Replacing tarmac • Increased drainage capacity • Mobile pumping units
Improved technology	• Trains operate in higher winds

New insurance options	• Assess new insurance options
Updated regulations	• New logistics park development will meet 1:1000 flood risk
Develop backup operations	• Remote IT access
Knowledge building	• Water level monitoring, assessing the rate of SLR etc.
Amended operations	• Amend maintenance schedules around storminess • Change dredging schedules
Collaboration	• Mutual-aid forum
Adapting to climate change benefits	• More moorings for leisure activities

Adaptation to climate change can be described as a "wicked problem" (Bours et al., 2013), whereby its complex and difficult nature does not lead to a clear solution or course of action (Brown et al., 2014b), particularly where ports have to adapt to both extreme weather events and creeping or continual change (Savonis et al., 2012). Adaptation actions taken by port decision-makers have the potential to have significant effects and financial costs (Vellinga and De Jong, 2012), for decades to come (Hanson and Nicholls, 2012). Therefore, it is important to consider the timescale that adaptation measures will have an influence over, particularly as there is no one-size fits all solution (UNCTAD, 2013), reflecting the need for individual adaptation plans for each port (Mimura, 2013; Parker and Kirkpatrick, 2012). Such challenges mean that actions taken can result in problems or instances of maladaption (Moser and Boykoff, 2013), and can occur over a range of different timescales. Even if adaptations do not result in maladaptation it is very difficult to determine whether an adaptation has been "successful" as quantifying whether damage or disruption has been reduced is challenging to pinpoint (Barnett et al., 2013). A lack of response to climate change may have a number of secondary effects on successful port operations such as reducing the reliability of shipments by increasing the cost of shipping and enhancing waiting/lay-over times (Kopp, 2012b). Such impacts may act to make just-in-time deliveries no longer favourable (Felixstowe Dock and Railway Company, 2011).

Adaptation measures are highly context-specific and there is not a "one-size fits all" solution available (Chhetri et al., 2013; McEvoy and Mullett, 2013). In many cases the response following an extreme event could be classed as a knee-jerk reaction, or a quick response which acts to prevent a similar future occurrence from having as severe impacts, usually in the form of hard engineering measures. Additionally, a "window of opportunity" (Amundsen et al., 2010) can arise in the wake of an extreme event known as a "useful catastrophe" (Morss et al., 2011), acting as a starting point for a greater response, such as implementation of new policies or improved infrastructural developments. Examples of such responses include the enhancement of sea defences, construction of the Thames Barrier and tidal gauge network following the 1953 storm surge. Sea-level rise of up to 1 meter was incorporated into the design (Gilbert and Horner, 1984). More recently, the abnormally stormy winter of 2013/14 has alerted a number of port operators to risks such as increased challenges to flooding due to sea-level rise, and potential changes in storminess which were not previously considered within adaptation strategies (ABP, 2014; Dover Harbour Board, 2015).

It is important to recognise the importance of so called "wise adaptation" measures, which not only respond to short-term challenges, but also builds adaptive capacity for the future through enhancements to society in terms of sustainability and quality of life (Palutikof et al., 2013a). The concept of adaptive capacity is designed to enhance an organisation's ability to react to the pressures of climate change (e.g. developing monitoring programmes) and is strongly related to available financial resources (Sekovski et al., 2012). However, adaptive capacity and actual implemented adaptations are two very different factors (Adger and Barnett, 2009). Just because adaptation capacity is present does not mean that adaptation will follow. The UK port sector has the ability to adapt against climate change, although to date few ports are actively implementing adaptation measures.

Changing conditions and risks need to be continually assessed when putting in place adaptation measures (Wheaton and Maciver, 1999). Assessment cycles are triggered by a pressure, such as a changing baseline condition (such as sea-level rise or shifts in storminess). For the port sector this cycle tends to be in the form of (Figure 2.3):

- An issue arising due to a changing pressure,
- The techniques and resources used in the adaptation process,
- The extent of adaptations being implemented, and whether they are influenced by factors that either encourage or limit the adaptation process,
- The effectiveness of implemented adaptations for reducing risks or pressures,
- Appropriate feedback into identifying climate change issues that need to be adapted against.

Ports tend to respond to short-term hazards rather than longer-term changes, such as sea-level rise (Morss et al., 2011). Port decision-makers currently focus on known tangible climate and business risks. There is a distinct mismatch in timescales between port planning and climate change (see Figure 6.3), and this issue is discussed in Section 6.6. Ports should actively consider, and take steps for adaptation rather than just broadly following and complying with policy requirements (Inoue, 2012).

2.4.2.2 Costs and benefits of adaptation

When identifying suitable adaptation options it is important that the balance of costs and benefits of adaptation measures are identified. The IPCC classes adaptation costs as “the costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs” (IPCC, 2007). In the port sector climate change adaptation can result in disruptions to normal operations during the period of transition. Maladaptation (see Section 2.4.2.4.2) is an additional adaptation cost, as resources (in the form of money and time) can be invested in adaptation measures that have no benefits, particularly in the longer-term.

Benefits of adaptation are described by the IPCC as "the avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures" (IPCC, 2007). Effective adaptation within the port sector has the potential to attract new clients by highlighting their resilience and ability to remain operational in extreme weather conditions.

2.4.2.3 Adaptation types

Adaptation can occur in ports through a number of key options and cannot be met by a single action or decision alone (Table 2.2). It is critical for ports to streamline climate change adaptation within their broader risk management strategies and policies (Chhetri et al., 2013). Adaptation measures can be either direct or indirect in their nature. Direct adaptations are designed to reduce exposure to or impacts from an identified receptor (Eisenack and Stecker, 2012), whereas indirect adaptations act as an enabler for a receptor (such as policy enhancements). Adaptations can also be either reflexive (adapting for their own benefit) or facilitating (adapting to benefit others) in nature (Hinkel, 2007).

A IPCC report, published in 2012, identified six general approaches across society for adaptation or risk management: increased resilience to risks that are changing, lessening vulnerability, lowering of exposure, preparedness, response and recovery, shifting risks and sharing of the impacts and transformation (IPCC, 2012). Although these approaches are broad-reaching, ports do not tend to adapt according to these options. Instead, ports tend to adapt in three distinct ways: autonomous (or spontaneous) adaptation, planned (or proactive) adaptation and reactive (or responsive) adaptation).

2.4.2.3.1 Autonomous adaptations

Autonomous adaptations are often in the form of actions which are enhancements to existing measures or behaviours that are already in place (IPCC, 2014b). In many circumstances autonomous adaptations tend to occur due to factors or issues other than climate change and do not occur as a conscious or decisive response to climate change pressures or challenges (IPCC, 2007). In UK ports autonomous adaptations tends to arise from developments to port infrastructure or replacement of equipment that has shorter lifespans than climate change timescales. Examples of expected future autonomous adaptation include the relocating of power cables underground and the replacement of cranes with fully automated models (Felixstowe Dock and Railway Company, 2015).

2.4.2.3.2 Planned adaptation

Planned adaptation has a number of benefits including less severe disruption during its implementation and is often a more cost-effective strategy (Church et al., 2010). Planned adaptation can be perceived as a “public good” as its greatest benefits are often not felt for years (or decades) after its implementation (Moser and Boykoff, 2013). This is a complex issue for the port sector as it is not known whether current port operators, and business owners, will still own the same ports and experience the benefits that they have invested in. Three methods to encourage planned adaptation are: new legislation on adaptation, templates to guide the adaptation planning process within ports (Messner et al., 2013) or changed insurance that consider adaptation as a benefit within pricing plans (Schuster, 2013). In some circumstances extreme events can act as triggers to influence changes in planned adaptation, particularly if impacts experienced are especially severe or long in duration. If too much adaptation is planned (such as raising a quay higher than would be needed under known sea-level rise forecasts) costs can be substantially higher without providing any additional benefits.

The interaction of many climate risks (such as sea-level rise, increasing mean temperatures and changes in storminess) highlight how effective planned adaptation could be designed to counteract multiple challenges at once (Moser and Boykoff, 2013). However, adaptation needs no longer to be viewed as an additional cost or an “add-on” to port designs and behaviours, and instead to be viewed as an integral part of normal activities and development (Ekstrom and Moser, 2013).

Case studies of successful planned adaptation measures include the Thames Barrier in London, UK (which was completed in 1982 and began operating in 1984) (The Royal Society, 2014) and the Eastern Scheldt storm surge barrier in the Netherlands (which became functional in 1986) (Palutikof et al., 2013b). The careful planning, rather than reactive action, of these developments has allowed the incorporation of long-term design lives – 50 and 200 years respectively. Protective infrastructure developments tend to have a lead-in time of at least 30 years, highlighting the need for proactive adaptation to begin in the near future (Hanson et al., 2010). More recent successful adaptations include the port of Dover’s Western Docks Revival project which includes the development of a new cargo terminal which has been designed to include sea-level rise forecasts (Port of Dover, 2011).

2.4.2.3.3 Reactive adaptation

To date adaptation has tended to occur reactively, for example when damage occurs (Tompkins et al., 2008). For example, following the partial flooding of Immingham port during winter 2013/14 a new dock gate has been designed and installed. Few ports, whether in the UK or internationally, have taken steps towards putting in place adaptation measures (Becker et al., 2018). These actions are often undertaken urgently to enable quick recovery and repair without incorporating improvements to prevent a similar circumstance from occurring in the future (The Royal Society, 2014). Outcomes of reactive adaptations tend to have higher costs in terms of finance and impacts on society (Kalra et al., 2014). Transformative circumstances (Park et al., 2012), such as where a port’s current defence systems becomes vulnerable to damage can act to encourage adaptation. This action, with the character of “closing the stable door after the horse has bolted”, has various levels of success due to the often urgent need for action, and can lead to maladaptive steps being taken (Palutikof et al., 2013b).

2.4.2.4 Implementing adaptation measures

Adaptation can occur in two ways: top-down and bottom-up. Top-down adaptations are motivated by government-level involvement to encourage decisive adaptations, and can potentially be limited by an unrealistic expectation of the guidance that scientific predictions can provide (Dilling et al., 2015). Bottom-up adaptation, in contrast, occurs on a local scale (such as for an individual port) and is associated with an assessment of adaptation needs on an individual, specific, basis (Butler et al., 2015). The success of such adaptation techniques varies greatly, reflecting issues such as differences in knowledge, perspectives and finances. To date adaptation by the UK port sector has been bottom-up in nature, as little guidance on the role and nature of climate change adaptation has been provided by the UK government.

2.4.2.4.1 The challenge of effective adaptation

Adapting to climate change is a “Goldilocks problem” as it is challenging to determine the right balance between over-protection (where too much money is invested into adaptations such as sea defences) and under-protection (where investment will be wasted as damages will still occur) (Pugh, 2004). This is especially difficult as a tolerable, or accepted, level of risk from climate change shifts through time (Hall et al., 2012). Also, it is difficult to attribute a lack of damage from extreme events to an adaptation measure – i.e. it is often challenging to identify the specific benefits gained from an investment (Xiao et al., 2015). One technique to prevent over or under investment from occurring is to implement adaptive management techniques (The Royal Society, 2014). Adaptive management is a cycle of: identifying intended adaptations, implementation and monitoring, and regular evaluation to determine if any adjustment will be needed to increase the effectiveness of implemented adaptation measures. Adaptive management allows adjustments to future adaptive decisions by continually assessing current and future needs by incorporating new and improved information as it becomes available. To date adaptive management has not been implemented within the UK port sector.

Well designed and considered adaptations act to either alleviate or prevent disruption or damage caused by extreme events (Xiao et al., 2015). This is an important issue as much of the international trade received by the UK passes through a restricted number of bottlenecks (Bailey and Wellesley, 2017; Centeno et al., 2015). Adaptations viewed as particularly beneficial tend to be classed as: (Scott et al., 2013b; UKCIP, 2007):

- No/low regrets – Where costs (e.g. financial) are low and outweighed by the benefits regardless of how severe the impacts of climate change may become. For example where restrictions on coastal engineering projects in storm vulnerable locations result in reduced damage to infrastructure and financial costs (UKCIP, 2007).
- Win-win – Adaptations that provide additional benefits other than just reducing risks from climate change (Scott et al., 2013b). For example, the development of coastal engineering projects that not only reduce damage costs from storms but also encourage the development of a new habitat for protected species.

2.4.2.4.2 Unsuccessful adaptation

Maladaptation is the opposite of successful adaptation (Dilling et al., 2015), and refers to circumstances where poor decision-making or a lack of knowledge leads to adaptive measures actually increasing rather than reducing risks from climate change (The Royal Society, 2014). On a more complex level, adaptations are associated with feedbacks that can develop new previously unknown risks, vulnerabilities and challenges (Belliveau et al., 2006). Poor adaptation decisions have the potential to enforce negative change that can impact future generations (Adger et al., 2009). For ports that are beginning to consider implementing adaptations it is important to assess and map key risks for their operations (Tsatsou, 2014), otherwise these may be maladaptive in nature. Maladaptation is more likely to occur if the focus is on implementing the most adaptations for the lowest price, rather than implementing the most suitable or effective adaptation measures (Tompkins et al., 2010).

2.4.2.5 Adaptation challenges and complexities

Adaptation decisions tend to be motivated by key pressures (Tompkins et al., 2010) (Figure 2.2), and these pressures are also relevant to the port sector (Figure 2.1):

- Damage or disruption experienced to a port and/or its operations,
- Legislation or policy requiring ports to take action,
- Financial incentives to reduce costs incurred from extreme events,
- Societal pressures (such as from clients).

Uncertainties in specific impacts from climate change make adaptation decisions more difficult (Nursey-Bray et al., 2013; Wade et al., 2013). Inadequacies in available policies, financial resources and knowledge can limit the extent of adaptation that can occur (Fussel, 2007), and may restrict the ability of the port sector to adequately protect all of their stakeholders (Becker et al., 2014).

The economic and trade interconnectivity of ports between regions and countries potentially enhances vulnerability (UNCTAD, 2013), as disruptions in one region can have cascade effects on an international scale through supply chains (Kron, 2012). In 2015 powerful explosions at Tianjin Port in China had long-term impacts (on the scale of months) for international trade, particularly in terms of electronics (Lloyd's List, 2015a). Tianjin port is an important exporter of chemicals that are important to the functioning of the international electronics industry (Zhao, 2016).

Adapting to climate change is an often expensive and time-intensive process, but the potential costs of damage or disruption from not adapting can be greater (Kopp, 2012a). However, the need to put in place adaptation measures is only one of multiple pressures currently experienced by ports. It is important that the port sector begins to prioritise climate change adaptation alongside other organisational risks (Chhetri et al., 2013). Other key challenges faced by the port sector includes competition between ports (both nationally and internationally), increased time pressures on turning around cargo (Yeo et al., 2014), increased throughput and investments into more efficient technologies.

When taking adaptation decisions the implications of what would happen if an adaptation fails needs to be considered. For example, raising the height of coastal defences may encourage development (e.g. businesses and housing) behind the sea defences. The potential impacts of any breach increases with the density of population or operations located behind the defences (Hinkel et al., 2014; Welsh Government, 2011). For example, in December 2013 the unexpected flooding of Immingham port affected the operation of multiple businesses located on port land on a scale of weeks to months (Watson, 2017). One of the worst affected businesses was a company who supplies bandages and other surgical tools to hospitals located across the UK.

It would be beneficial for ports to understand the full range of current risks (including a worst-case scenario) facing their operations before new measures are developed or implemented (Burton et al., 2002). A key challenge for timely and effective adaptation is to improve the knowledge and awareness of climate change and adaptation issues of those who work in port environments (Scott et al., 2013b). The perspectives of those working in such environments is greatly different from those in scientific or legislative professions, and therefore it is appropriate to frame the issues of climate change adaptation appropriately to the needs and operations of the port sector. Competition between ports will encourage adaptation (Xiao et al., 2015) to prevent business losses following an extreme event, or to glean trade from more severely impacted ports. In some cases experiencing a certain extreme event cause may encourage adaptation for more causes than just that which caused the damage or disruption (Capstick and Demski, 2016). To date this has not yet occurred within the UK port sector.

Ports must be able to invest in protecting against extreme events and associated climate change challenges without incurring substantial additional costs to their clients. The impacts of extreme events on internal and external stakeholders differ. More indirect or intangible impacts tend to affect external rather than internal stakeholders (Becker et al., 2014), such as delays in rebuilding or replacing damaged items of infrastructure (Hallegatte et al., 2011), and can be described as secondary or consequential impacts (Handmer et al., 2012).

Additional adaptive challenges are posed to decision-makers by uncertainties in climate change impacts, as many assume that future conditions can be accurately predicted on scales beneficial for regional or local policy and adaptations (Haasnoot et al., 2013). Such perspectives highlight the need for flexibility in legislation, an additional challenge for policy-makers (McDonald, 2011; Nicholls et al., 2013), to allow adjustments as further information becomes available (Aerts et al., 2014). This is of particular importance for the port sector due to the long life-span of its infrastructure and equipment.

The UK was one of the first countries to implement policies incorporating adaptation (Juhola et al., 2011) for its key sectors, an important action considering that its vulnerability to extreme events is increasing (DEFRA, 2013). Examples of measures implemented to reduce vulnerability to sea-level rise include tidal and sea defences, and adjustable infrastructure such as the Thames Barrier which is able to defend against a 1 in 1000 year event (de la Vega-Leinert and Nicholls, 2008; McFadden et al., 2009). Disruptions to the economy by extreme weather events has been accepted as a threat by the national government (DEFRA, 2013), whilst climate change is considered by some ports as a general business risk (Felixstowe Dock and Railway Company, 2011).

2.4.2.6 Barriers to climate change adaptation

Barriers to adaptation refers to factors that hinder the planning, identification and implementation of adaptation measures (Eisenack et al., 2014). A number of barriers to timely and effective adaptation are currently apparent in the port sector (Becker et al., 2011a; O'Keeffe et al., 2016) and hinder a port's ability to achieve progress in adaptation (Biesbrock et al., 2013; Hinkel, 2011; Huang et al., 2011). Current barriers to port adaptation are broad and are underpinned by how UK ports are organised and operate. Eight main barriers to adaptation have been identified and can be grouped into three main types (Table 2.3):

- Interaction between port business operations and climate change risks – Financial budgets, priorities, responsibilities, time-scales.
- Knowledge on climate change and how to effectively adapt – Awareness, limitations of scientific data/port-specific climate change predictions, technology and equipment.
- Legislation relating to climate change and the port sector.

Time-scale differences between the long-term scientific view of climate change and the shorter 25-30 year port infrastructure lifespan (Becker et al., 2011a; Becker et al., 2014) can act to limit implementation of adaptive options whilst predictions of future conditions remain uncertain. The extent of awareness of the importance of climate change risks for port operations has been shown to be as important as financial availability and technological advances in terms of aiding or hindering adaptive responses (Adger et al., 2009).

A number of studies have identified that the careful framing of policy changes have the potential to reduce barriers to climate change adaptation (Wise et al., 2014). Effective framing enables successful connections with an intended audience. For the UK port sector it is important to highlight that climate change will have important impacts on the success of future port operations. Research in the US has highlighted that many port operators feel that sea level rise will not be considered as an issue this century (Becker et al., 2011a). In many ports worldwide policy and available resources has focused on mitigation rather than adaptation (Ng et al., 2015). Mitigation acts to reduce the extent of climate change, but has no effect on exposure to potential disruptions. In the past two decades the extent of research considering and analysing adaptation implementation and its options has become more widespread in policy (Corfee-Morlot and Agrawala, 2004).

Table 2.3: Current identified barriers to adaptation in the UK port sector and how they affect the success of proposed adaptation measures.

Barriers to adaptation in the port sector	
Awareness	Port operations are business focused, and many of those working in port environments may not be aware of whether climate change will be an issue for their operations (Chhetri et al., 2013)
Financial budgets	Investments in port sector are strongly motivated by justifying costs and benefits which is a challenging issue in the context of climate change. For example, if sea defence heights are raised to prevent flooding it is difficult to attribute the number of extreme events that are protected against. Globally, larger ports tend to have more available financial resources which can be used for adaptation (Tsatsou, 2014) and have a greater level of concern regarding climate change (Ng et al., 2013)
Legislation	Compared to much of the industrial sector ports are not well regulated in terms of climate change as the Government perceives commercial ports as best place to advise their own adaptive decisions and actions (Department for Transport, 2007), a perspective that has remained in place following the development of UK adaptation policy (UK Government, 2017). Corporate responsibility can play an important role in motivating adaptation decisions,
Limitations of scientific data/port-specific climate change predictions	Climate scenarios for changes in certain risk causes are currently highly uncertain about the extent of change that will occur (Kalra et al., 2014; Parris et al., 2012). Many climate models are currently unable to effectively resolve changes on a local scale. A number of UK ports are not prepared to start adapting to climate change until available predictions become more certain and local in scale
Priorities	It is challenging for port decision-makers to put in place climate change adaptations whilst also effectively investing in and reacting to present-day pressures (Roh et al., 2016)
Responsibilities	Uncertainties over who is responsible in identifying climate change risks and adaptation needs can hamper adaptive progress (Mojafi, 2014)

Technology and equipment	The extent of potential adaptations can be limited by available technology, technological expertise and equipment. New technologies and behaviours may need to be developed to address climate change adaptation (Ng et al., 2015).
Time-scales	UK port planning timescales ranges up to 25 years for large infrastructure projects (Becker et al., 2014), whereas the time-scale of climate change is much longer. Port infrastructure tends to have design lifetimes in excess of 50 years highlighting that climate change adaptation needs to be actively considered in new port infrastructure developments. It has been suggested that ports should focus their adaptation efforts on infrastructure that has the longest operational lifetimes (Meyer, 2008) as infrastructure with shorter lifetimes is likely to be automatically enhanced when they are replaced or upgraded due to improvements in climate change predictions and port policy. The whole lifetime of infrastructure needs to be considered, else ports may need to carry out repairs or replacements during its lifecycle (Hallegatte et al., 2011)

2.4.2.7 Climate change adaptation in the UK

The UK's adaptation strategy to climate change has been, in the past decade, underpinned by the Climate Change Act (2008) which is a policy framework that is designed to promote active adaptation. Housed within this framework are three key programmes used to help prepare the nation for climate change:

- National Adaptation Programme – An assessment of the needs and risks facing the UK due to extreme weather and climate change, and how the UK Government is taking steps to defend the nation's continued successful functionality (DEFRA, 2013). The National Adaptation Programme is a national summary of what the Government, key businesses and society are doing to prepare for climate change.
- Adaptation Reporting Power – The Secretary of State has the authority to instruct certain eligible (termed "reporting") organisations, including the UK's busiest ports, that operate in the public sector to produce written assessments of how well they are adapting to climate change (DEFRA, 2010b) and to send these assessments to DEFRA for analysis.
- Climate Change Risk Assessment (CCRA) – A five year assessment cycle of how climate change will affect key areas of UK business, society and environment (DEFRA, 2012). CCRA reports are produced by the Committee on Climate Change's Adaptation Sub-Committee.

To date the UK Government has not provided detailed specific climate change adaptation guidance. Available legislation, included within the 2008 Climate Change Act purely states that UK ports need to adapt to climate change and gives no detailed guidance (such as on expected timescales for the entire port sector to assess its adaptation needs). The justification for this position by the UK's Government is detailed in the Port Policy Review Interim Report (Department for Transport, 2007) where it was stated that "commercial port operators are best placed to make decisions about where and when to invest". This approach, which is "hands-off" in nature, has resulted in limited adaptive steps currently being taken by UK commercial ports. In response to the Adaptation Reporting Power the busiest commercial ports in England and Wales are in general beginning to consider their adaptation needs (DEFRA, 2014a). Port sector climate change adaptation is currently limited, with much further acceptance and action required. This issue is considered in much further detail in Chapter 6.

2.4.2.8 Climate change adaptation in other countries

Both the vulnerability to extreme events and the causes of damage or disruption experienced differs both between and within countries (Pelling et al., 2004). Table 2.4 summarises the extent

Table 2.4: The current extent of port sector climate change adaptation across multiple countries

Country	**Extent of port sector climate change adaptation**
Australia	• Ports are not currently required to assess their adaptation needs • A number of Australian ports have voiced a wish to be provided with information on likely risks they will face due to climate change
Italy	• Integration between improving the resilience of both port cities and ports themselves to the risks of climate change • The development of large-scale projects such as *Vento e Porti* which is designed to increase knowledge of risks from wind storm extreme events by increasing safety and improving forecasts of disruptions to operations
Republic of Ireland	• Not all ports in mainland Ireland are managed by operators who believe that climate change exists • Of the ports that accept climate change is a potential issue awareness of the likely future impacts for their successful operations is limited
The Netherlands	• Contradiction between parts of Rotterdam that are adapting (City of Rotterdam and the Dutch National Government) and those that are not (Port of Rotterdam Authority) • The level of defences are being developed to protect against at least 1:1000 flood events
United States of America	• The largest American ports are beginning to adapt to climate change • The extent of adaptation varies both between ports and States • Naval managed ports will not begin to adapt until given additional guidance from the Government • Not all upgrades or repairs currently consider climate change

of port sector climate change adaptation that has been analysed within the published literature across multiple countries.

O'Keeffe et al. (2016), who assessed the climate change adaptation awareness of port stakeholders in Ireland, highlighted a lack of climate change awareness, or even belief in climate change impacts.

The Italian port sector is currently focusing on actions to reduce the local impacts of climate change. Plans for the future are on a broader scale to increase the resilience of both cities and ports (Cusano et al., 2015) such as through the *Vento e Porti* project which has been developed to provide forecasts of winds to increase port operator awareness of potentially disruptive conditions.

Rotterdam port in The Netherlands has undergone extensive adaptation for climate change despite not having a plan for adaptation or actively referring to climate change scenarios (Smith, 2015; van Barneveld, 2013). Adaptations already in place include raising of quay heights (by 3.5 to 5.5 meters) and the development of the Maesland storm surge barrier which protects part of the port (Zhong et al., 2012). These developments were designed to protect the port to at least 1:1000 flood events. The City of Rotterdam and Dutch National Government are putting in place steps to adapt to climate change whereas, despite recognising the risks of climate change, the Port of Rotterdam Authority has yet to put together an adaptation plan (Smith, 2015).

In the USA the nation's largest ports are beginning to take action to prepare for the future challenges of climate change (Messner et al., 2013). However, these steps are in many cases only dealing with part of the issue. San Diego Unified port, for example, developed a Climate Action Plan which was designed to "protect and enhance its future success" (Port of San Diego, 2013) – although the report only considered mitigation measures. The port is developing a climate change adaptation plan although it is predicted that it will take a number of years to be completed (Hooven et al., 2011). The port is currently focusing on exploring soft adaptation options, which are adaptations in the form of knowledge, new policies or management strategies. In San Diego implemented adaptation measures include knowledge building, monitoring and updating internal policy documentation (Smith, 2015).

Some responses to extreme events that have been taken by American ports have been described as poorly designed, and not adequately considering climate change. For example following 2012's Hurricane Sandy coastal engineering projects were encouraged (The Royal Society, 2014) despite being located in at risk locations. The motivation behind this behaviour was instigated by new rules to encourage swift recovery from the impacts of Hurricane Sandy, rather than considering the risks of rebuilding in areas at risk from future extreme events. (State of New Jersey, 2013). A study by Smith (2015) of climate change preparedness found gaps in guidance given to American Naval ports, including that no guidance on climate change adaptation has been provided by the United States Department of Defense to planners in Naval ports.

In 2013 the Australian National Climate Change Adaptation Research Facility produced a sequence of reports on adapting ports to climate change (Scott et al., 2013b). Adaptation policy in Australia is a new and developing concept (Mullett and McEvoy, 2011), and ports are not legally required to assess their climate change adaptation needs (McEvoy and Mullett, 2013). This research, for which the scope was Australian ports, had three stages: identifying both current and future risks facing ports, an assessment of those risks and an analytical review of available adaptation options. A key point highlighted by the research is the unique nature of, and extreme event risks experienced by, each individual port – reinforcing the concept that there is not a “one size fits all” solution for adapting ports for climate change, even within a country. Climate change is only one of many issues that affect successful port operations and should be considered in conjunction with other factors. Supply chain issues are currently an important, and complicated, challenge for Australian ports, and may become more so with climate change. The study was designed to provide Australian ports with improved knowledge on likely present and future risks from extreme weather events and climate change, and a weighting system to highlight the relative importance of these issues (McEvoy et al., 2013). An important conclusion of this research is that current uncertainties in climate models and predictions must not deter the implementation of adaptation measures (particularly those that have no or low-regrets).

McEvoy and Mullett (2013) and Kong et al. (2013) were involved within the Australian 2011-2012 “Climate Resilient Seaports” project, which was designed to better understand climate change risks facing ports and their infrastructure, to assess the current level of resilience in place, and to identify points of vulnerability within port infrastructure. The potential risks of rare catastrophic events have not yet been well considered by Australian ports, as a focus has been on less severe, but more common, events. A key issue identified for Australian ports is that few extreme weather event causes have defined thresholds recorded for when operations should cease or safety policies put into play. Three ports situated on the east coast were used as case studies: Port Kembla, Gladstone and Sydney, and the range of operations they carry out act as analogues for many other Australian ports. The analysis focused on the likely impacts of risks that have long-term deteriorative effects on specific infrastructure components and their materials (concrete, steel and timber). Outputs of this research were the development of a software tool that can classify the projected impacts of climate change on a particular material type or design, and a Container Terminal Operation Simulator (CTOS). The tool is intended to act as a starting point for ports to be able to assess the likely level of risk that their current infrastructure faces. CTOS was designed to mimic the movement of containers through a terminal and allowed assessments of how operational performance is impacted by extreme weather events. Another output of the project was the development of an Online Decision-Support Toolkit (McEvoy et al., 2013). An analysis of this toolkit found it not to be user-friendly in its design and there has been little uptake or interest in its use by ports to guide their knowledge on climate information.

Becker et al. (2011a) carried out a survey of 342 of the busiest and most important commercial ports in the world. A total of 89 ports responded to the survey, representing a 26% return rate. The survey was designed to assess: the time-scale that ports consider when implementing new infrastructure, whether climate change is considered within ports and perceptions on climate change risks for their operations (Becker et al., 2011b). Misunderstandings in the difference between adaptation and mitigation had previously been identified, so an explanation of the two terms were included within the survey brief. Most ports who responded are neither planning for, or discussing, climate change and the need for adaptation. Globally ports are concerned that climate change adaptation is an important issue for their future operations. However, port decision-makers want to know more about adaptation as they do not feel well informed either of the risks they will face or both how and when they should begin to put in place adaptation measures.

2.4.3 Port sector responses to climate change

To date ports globally have more commonly considered, and implemented, mitigation measures compared to adaptations (Becker et al., 2011b). Mitigation is not as effective at reducing vulnerability to climate change as adaptation measures (Pielke, 2007). This is due to the differences in scale between the two types of response. Mitigation measures have impacts on a global scale, whereas adaptation measures are targeted and have benefits on a local scale. Regardless of the extent of implemented, or proposed, mitigation measures it must be noted that an amount of climate change is “locked-in” to occur due to the amount of greenhouse gases that have been historically emitted into the atmosphere.

For the port sector to effectively prepare its future operations for the risks and pressures of climate change it is important that adaptation and mitigation measures begin to be implemented in conjunction with each other, as they are complimentary in nature (Swart and Raes, 2007). Effective integration of adaptation and mitigation will reduce the vulnerability of the port sector to the impacts of climate change, whilst also limiting the extent of climate change (such as sea-level rise) that will occur. Little publically available literature is currently available on the topic of combining adaptation and mitigation for the port sector, whether for the UK or globally.

2.5 UK port legislation

Port operating and management legislation is specific to the country in question due to the unique range of operations, needs and priorities in place. The scope of this thesis is restricted to the UK port sector and its adaptation preparedness for climate change. An assessment of international port legislation would not be of relevance to this research. Therefore, only policies and legislation relating to UK ports are discussed in the following sections.

2.5.1 Multiple scales of UK port governance and environmental legislation

Governance of ports occurs on a number of scales, ranging from the international (e.g. IMO regulations to reduce greenhouse gas emissions from shipping (International Maritime Organisation, 2017)) through to local management by port operators (e.g. port specific environmental policies (Dover Harbour Board, 2017)). Such governance ranges from a national requirement to consider climate change impacts when planning new port infrastructure (e.g. Climate Change Act 2008 (Department for Transport, 2012)), through to ports determining their own points of weakness in terms of climate change and extreme events (e.g. Dover Harbour Board (2015) identified that their western docks have a higher risk to coastal flooding). This multi-level complex structure can act to slow or limit changes (such as infrastructure developments or upgrades) that occur in the port, (Adger et al., 2009) both through different layers of management and the implementation of policies (Amundsen et al., 2010), or ensure homogeneity between regions (McDonald, 2011; Palutikof et al., 2013a). Communication and collaboration between these levels has been shown by a range of studies to be key in aiding development of port resilience through technological, infrastructure and legislative means (OECD, 2014). Governance on multiple levels is particularly important in the context of response to disruptions, allowing the most efficient and effective responses in terms of physical and financial resources required for recovery (Adger et al., 2005; Amundsen et al., 2010).

Only a few national policy documents such as the National Policy Statement for Ports (Department for Transport, 2012) deal purely with ports. To develop a fuller understanding of policy affecting port decision-makers a wider scope is needed, encompassing national and regional documentation such as *A Sea Change: A marine bill white paper* (DEFRA, 2007). The publication of *A Sea Change* represented an important first step in identifying the need for enhanced environmental legislation and policy for the marine sector. This was followed by the development of the Climate Change Act which entered into force in 2008 (Section 2.5.3).

2.5.2 UK port policies and operational legislation

Legislation and policy, particularly in terms of enhancing the effectiveness of current legislative frameworks (Eisenack et al., 2014; Mcdonald, 2013), can be used as an important tool to encourage behavioural changes in businesses and society to important issues such as adaptation (McDonald, 2011). Changes to national legislation for issues that have generic impacts tend to be more effective than locally developed policies as it enables the consistent application of legislation across multiple regions.

Policies have the potential to either encourage or restrict adaptation. In some circumstances national-scale adaptation policies can limit the ability of local governments or organisations to respond (Amundsen et al., 2010) to the unique combination of challenges and pressures they experience. Alternatively, policies can act as a catalyst for adaptive change, leading to adaptations being put in place by organisations which had not independently considered the risks they face. In terms of the UK port sector the Climate Change Act is one factor that is helping to restrict progress in adapting to climate change. The vagueness of the included statement, that advises the port sector on climate change, without giving more detailed context, does not provide ports with enough guidance to consider either how or when to begin taking adaptive steps.

Since the mid-1990s the awareness of, and interest in, policy has increased for the port sector (Pallis et al., 2010), highlighting that this is a field of interest that is still developing. This change reflects the expansion of ports, and shifts in both trade demand and port technology. However, most policies relating to climate change adaptation in the port sector are very broad and vague in their wording, representing “statements of intent” rather than decisive adaptive action (Urwin and Jordan, 2008). This is addressed in further detail in Section 5.2.

2.5.3 UK port climate change legislation

The Climate Change Act was passed by parliament and entered into force in November 2008. This legislation was designed to provide a target reduction level for greenhouse gas emissions through mitigation measures, whilst also providing incentives for authorities to take action against the predicted impacts of climate change through adaptation measures. In response to this legislation the Secretary of State is required to provide regular reports detailing an assessment of current and potential risks (up to the end of the 21st Century) faced by climate change for the UK (Wade et al., 2013). Section 62 of the Climate Change Act details the required steps to be taken by reporting bodies (or devolved authorities) such as harbour or major authorities:

“Reporting authorities: non-devolved functions

Directions by Secretary of State to prepare reports

(1) The Secretary of State may direct a reporting authority to prepare a report containing any of the following:

a) An assessment of the current and predicted impact of climate change in relation to the authority’s function
b) A statement of the authority’s proposals and policies for adapting to climate change in the exercise of its functions and time-scales for introducing those proposals and policies
c) An assessment of the progress made by the authority towards implementing the proposals and policies set out in its previous reports”

“(4) This section does not apply to devolved functions.”

In the scope of this Act:

- Reporting authority – Organisations identified by the Government as of national importance (such as the busiest ports in England or Wales),
- Devolved authority – Organisations in Northern Ireland or Scotland which are governed on a regional level rather than from the UK Government,
- Devolved function – Operations carried out by businesses which are devolved (located in Northern Ireland or Scotland).

Under the Adaptation Reporting Power, which was issued to the Secretary of State for the then Department of Energy and Climate Change (now the Department for Business, Energy and Industrial Strategy) in the 2008 Climate Change Act, eligible “reporting authorities” were directed to submit a report. These reports were required to provide the Department for Environment, Food and Rural Affairs (DEFRA) information on weather and climate risks likely to affect “reporting authorities” and the adaptation measures that are being planned or put in place.

In the context of the Adaptation Reporting Power eligible “reporting authorities” were multi-sectoral, including 47 UK organisations across utility firms, road and rail networks, airports and harbour authorities. Government analysis of port sector adaptation preparedness for climate change focuses on the reports produced by nine eligible ports or port clusters (8 from England and 1 from Wales) (see Figure 5.2 for further detail):

- Dover,
- Felixstowe,
- Harwich Haven,
- Liverpool,
- Milford Haven,
- Port of London Authority,
- Sheerness,
- Southampton, Immingham, Hull and Grimsby,
- Teesport and Hartlepool.

Eligible harbour authorities were those who move in excess of 10 million tonnes of cargo per annum and are located within either England or Wales (ports located in the devolved countries of Northern Ireland and Scotland are under the authority of their respective countries). Ports classed as eligible by the Department for Transport include "traditional" ports who carry out cargo operations and those responsible for pilotage services and conservancy operations. Whether ports were eligible was also determined by their ownership.

The assessments produced in response to the 2008 Act required an analysis that incorporated perspectives on both current and future (up to the end of the 21st Century) risks from extreme weather and climate change. The results and perspectives presented in these reports were then used to inform reports produced by multiple government departments (including DEFRA and the Department for Transport).

Currently devolved nations in the UK are Northern Ireland and Scotland, and Wales will increase its extent of devolution in 2018. Therefore, for reporting authorities other than those located in England and Wales:

"64 Consent of, or consultation with, devolved authorities

(1) The Secretary of State must obtain the consent of a devolved authority before issuing guidance under section 61 or giving a direction under section 62." (Climate Change Act, 2008).

Section 61 refers to: Guidance by Secretary of State to reporting authorities, and section 62: Directions by Secretary of State to prepare reports.

Guidance provided for reporting authorities by DEFRA suggested three main useful data sources to assist in developing adaptation reports: UK Climate Projections (UKCP09, via the UKCIP website), Environment Agency guidance, and reports produced by the government on the transport sector (DEFRA, 2010b). All ports used the same primary data source for assumptions of climate conditions – UKCP09 and referred to medium emission scenarios. This emission scenario views a future with a global population that peaks in the mid-21st Century and new technologies are developed to use a range of fossil and non-fossil energy sources (IPCC, 2014b). The quantity and types of data sources varied between ports from the specific (such as in-house knowledge and experience) to the national (e.g. IPCC AR4, the then latest report). Adaptation reports produced by consultancy firms used different data sources to give a more complete, top-down style, perspective on assumed climate and extreme weather event risks compared to bottom-up style reports that were produced in-house. The differences in perspectives, and completeness, between the submitted Adaptation Reports has not be assessed within Government reports.

In response to this Act affected organisations were requested to submit an initial report in 2011, with updated reports to be provided by 2016. For some of the ports contacted these reports represented their first detailed assessment of how climate change is likely to affect their operations and functionality (Wright, 2013). These reports inform the content of national scale assessments including Climate Change Impacts, Adaptation and Vulnerability assessments, Climate Change Risk Assessments (Wade et al., 2013) and the National Adaptation Programme which will be published in 2018.

As of 2017 two rounds of adaptation reports have been received by “reporting authorities”, and a third round of reporting is intended to be submitted between 2019 and 2021 (DEFRA, 2018). In the first round of reporting contacted ports were compulsorily required to submit a report by October 2011. A second round of reporting took place in 2013/14 with reports submitted in 2015, however, participation in this updating stage was voluntary. Ports who did not participate in this second stage were motivated by no significant changes in risks identified, or little or no adaptations put in place, since 2011 (DEFRA, 2013, 2014b). The Committee on Climate Change (2015) finds this a concerning development stating that progress is lacking for the commercial port sector compared to a number of other UK sectors (such as utility networks including energy and water). A full analysis of the published Adaptation Reports, and their usefulness for assessing the adaptation preparedness of the UK port sector, is located in Section 5.2.

A number of studies have broadly considered the published Adaptation Reports. The UK’s National Policy Statement for Ports (Department for Transport, 2012) focuses on mitigation to reduce port emissions. There is limited consideration of the need for climate change adaptation, with the focus being on the purpose of the Adaptation Reporting Power (Section 2.4.2.5).

2.6 Summary

The challenges and pressures experienced by ports are complex, with disruptions arising from a diverse range of extreme events which can potentially have significant impacts on successful port operations. It is predicted, however, that with climate change both the severity and frequency of impacts from extreme events with become more complicated. Ports are vulnerable not just to the impacts of climate change that have direct impacts for their operations, but are also affected by knock-on effects from other ports due to the interconnectivity of international transport networks. Available responses to climate change by ports are a combination of mitigation and adaptation actions. Climate change mitigation techniques, and legislation, are currently more well developed than its counterpart, adaptation. It is important that the port sector begins to put in place carefully planned adaptations, as without preparing for future risks some ports may become vulnerable locations and may lose trade to competing ports. A number of barriers are currently present to timely and effective adaptation within the port sector. Port sector adaptation has, to date, been largely limited to the busiest ports in England and Wales and is occurring in response to the Climate Change Act 2008 and associated Adaptation Reporting Power. Further research is required to more fully integrate climate change adaptation into the UK commercial port sector (see Chapter 5).

Chapter 3: Historical analysis of UK maritime regions and extreme events: 1950-2014

3.1 Introduction

UK maritime zones are vulnerable to extreme weather and non-weather events. However, the frequency, impacts and outcomes of these events are currently poorly resolved for maritime zones. To date no database of extreme events affecting UK coastal areas, EEZ and ports has been publically available. Records of extreme events affecting maritime zones are restricted to academic papers and reports released by the media or Government that detail a particular event.

It is vital to assess the vulnerability of UK maritime zones to disruptive or damaging extreme events. The UK's maritime activities are vital to maintaining the nation's quality of life. The maritime sector comprises 2.1% of UK GDP (House of Commons, 2014) and 95% of trade by volume, and 75% by value enters the UK by ship (HR Wallingford, 2012).

Extreme events can have severe impacts for the UK including damage to infrastructure, cargo and vessels, pollution, temporary port closure, interruptions to trade and even the loss of life. Changes and complications to these impacts are predicted to occur in future decades due to climate change. An improved, and more complete, understanding of historic extreme events would be beneficial in aiding predictions of how climate change will affect UK maritime zones.

This first stage of research developed a database of all recorded extreme events that affected UK maritime zones between 1950 and 2014. This stage of research was designed as a scoping study to assess the vulnerability of UK commercial ports to extreme events compared to other maritime zones. An analysis of the database will be instrumental in determining whether further research to assess the impacts of changing extreme event risks due to climate change is of importance for the UK port sector.

The research aims to determine the nature, and extent, of impacts of extreme weather and non-weather events on UK ports and the use of coping mechanisms and adaptations as responses to disruptions. Four key objectives of this research were identified (Figure 3.1):

a) To develop a database of disruptive extreme events that affected UK maritime zones since 1950,
b) To determine the natures of disruptive extreme events that negatively affect UK maritime zones (cause, severity, impacts and responses),

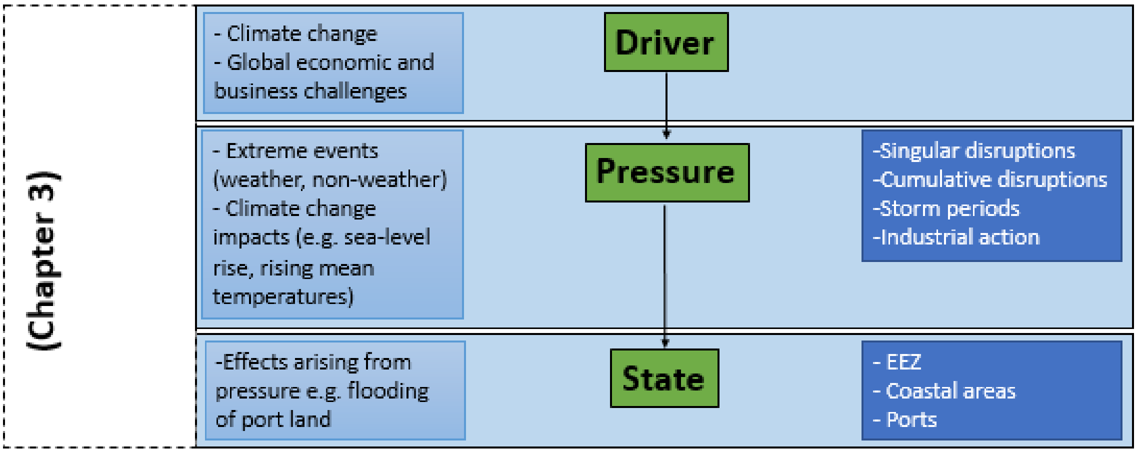


Figure 3.1: Framework of the research reported in Chapter 3.

c) To critically assess temporal and spatial trends the occurrence and impacts of disruptive extreme events,

d) To analyse how frequently and severely ports were reported as being impacted by disruptive extreme events compared to other maritime zones.

3.2 Data and methods of study

3.2.1 Data

A review of publically available data sources identified that no database of extreme event impacts on UK coastal areas, EEZ or ports was available. Instead, extreme events tended to be individually reported in newspapers, and some of the most severe or significant events were analysed within academic papers.

Three zones of interest were identified for this stage of the study, encompassing the UK's maritime heritage (Figure 3.2):

- Coastal areas – The terrestrial region directly affected by the coast and ocean (landwards of the Mean High Water Spring level, which is on average 1 meter away from the land interface), such as areas protected by sea defences.
- EEZ – An area which extends a maximum of 200 nautical miles (370km) from a baseline, or in most cases, the low-water line, seawards (United Nations Convention on the Law of the Sea 1982, Article 57). This defines the area of water which is almost exclusively under the influence of the marine, rather than the terrestrial, environment.
- Ports – A harbour where vessels can dock and load/unload cargo or passengers.

The study excludes estuaries, except when a port and its boundary is located within an estuary.

A critical analysis of literature and media sources was carried out to assess the frequency, severity and causes of extreme events that impacted UK maritime zones between January 1st 1950 and December 31st 2014. This scoping study was developed as the first publically available record of extreme events that have affected UK maritime zones. Reports of extreme events prior to 1950 were found to be less complete, as events were not regularly reported within the media. This was particularly apparent during the two World Wars when extreme, non-war related, events were not regularly reported within the media. Extreme events do not automatically translate into

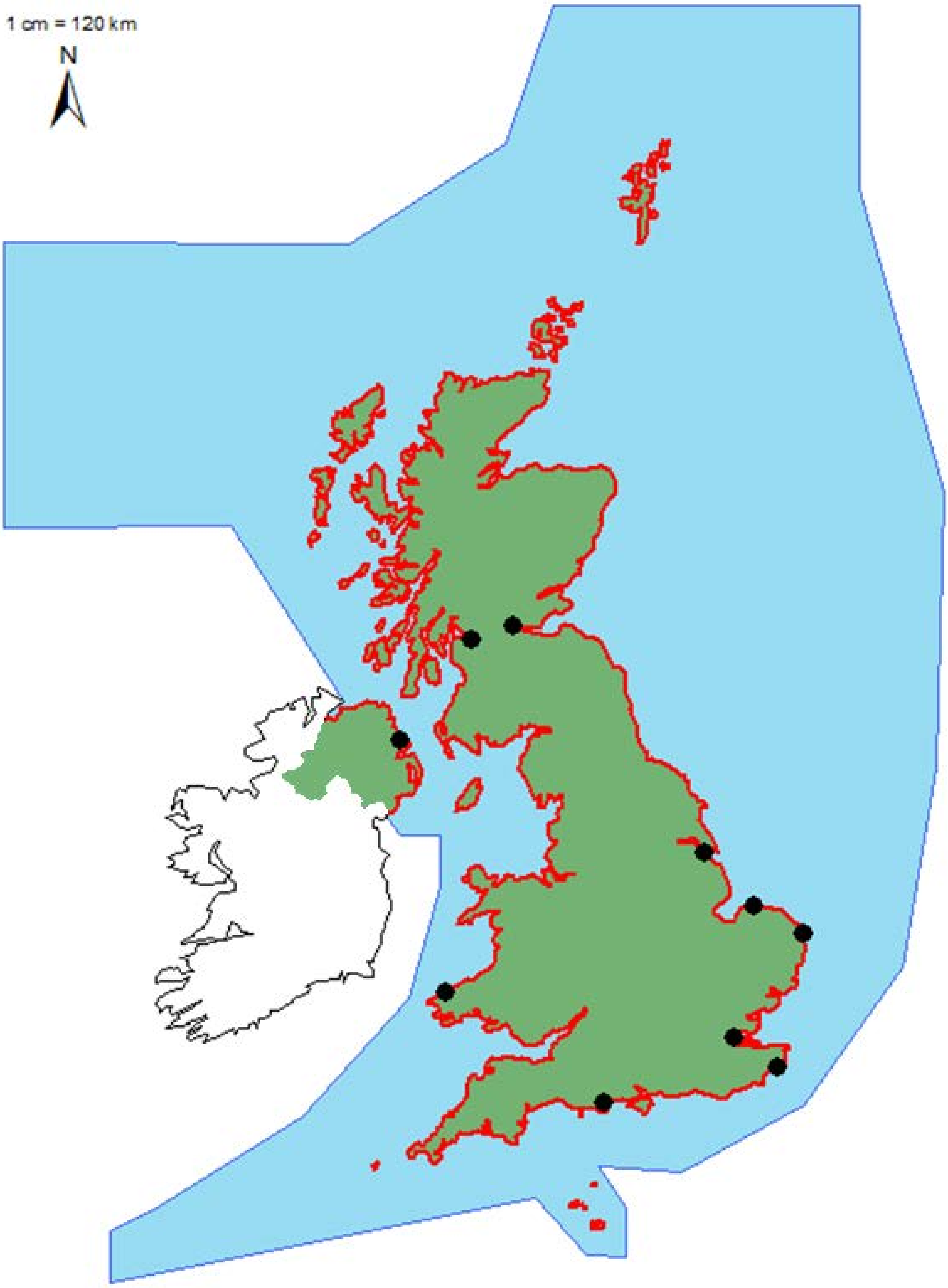


Figure 3.2: Map of UK maritime zones. Coastal areas are in red, EEZ in blue and examples of UK ports in black.

disruptions. Within the context of the database only extreme events that resulted in negative implications were recorded.

The primary data sources used for the database were newspapers and online news reports, with additional records from academic journal papers, white papers, Commons Sittings transcripts (accessed via http://hansard.millbanksystems.com/) and reports from the AAIB (Air Accidents Investigation Branch) and MAIB (Marine Accidents Investigation Branch) (see Table 3.1 for the full list of data sources).

A data-bias was present within the database, and becomes particularly apparent from the mid-1990s onwards (see Section 3.2.2 for an explanation of how this issue was overcome). This arose from the increase in Internet-based media and general improvements in communication on issues that affect businesses and the public (such as blogs, and Twitter). Prior to the wider availability of Internet news, and media, reports tended to only report on the most severe disruptive extreme events, or those likely of particular interest to the newspaper's readership. Before the development of Internet-based media, data relating to port closures or delays due to extreme events were not publically available.

The increased reporting of less severe, or more localised, disruptive extreme events since the 1990s can give the impression that the frequency of disruptive events affecting ports, coastal areas and the EEZ has increased over the last 20 years. Less severe events are almost exclusively reported in the digital, rather than printed media. There is low confidence that all less severe disruptive events that occurred between the 1950s and mid-1990s, and events that affected areas of lesser public interest, have been recorded within the database. For example, records of confirmed disruptions for the UK's smaller commercial ports are inconsistent, and are often only reported by a single source. In contrast, the accuracy of more severe events can be validated by combining multiple ports. It is certain that not all disruptive extreme events have been resolved within the database, so the data analysis is focused on the more severe events (Level 4 and above of a seven point severity scale – see Section 3.2.1 for classification details) for which news reports and other data sources were more readily available.

3.2.2 Methodology

To allow meaningful comparisons and analysis between disruptive extreme events over time, a severity scale was developed building on the methodology used by Ruocco et al. (2011). In their study Ruocco et al. (2011) produced a severity scale to classify flood events and associated

Table 3.1: Data sources used to develop the database of historical disruptive extreme events.

Data type	**Data sources**
Newspapers and online news reports	BBC; Belfast Telegraph; Bournemouth Echo; East Anglian Daily Times; Fleetwood Weekly News; Ipswich Star; Irish Independent; ITV News; Lowestoft Journal; Sky News; South Wales Argus; Southern Daily Echo; STV News; The Argus; The Daily Mail; The Daily Mirror; The Grimsby Telegraph; The Guardian; The Herald; The Independent; The Met Office; The Shetland Times; The Telegraph; West Coast News; Western Morning News; Yahoo! News
Online business and media reports	Aon Benfield; Association of Drainage Authorities; BEAMER; Blue and Green Tomorrow; Boston.gov.uk; Bureau of Maritime Affairs Monrovia; Burnham on Sea; Chambers and Cooke Freight Ltd.; Commercial Motor Magazine; COSCO; Cruise and Maritime Voyages; Devon County Council; Direct Ferries; EMSA; Environment Agency; eSurge; Felixstowetv; Flood and Storm Emergency Relief; Flood Disasters; Geschichteclubstahl; Heart; HHV Ferry; ICIS; Lloyds Loading List; Margate Local History; Marine Insight; Maritime Journal; North Sea Installations; Port Strategy; RMS; Royston Crow; Scarborough Maritime Heritage; Sea Defences; Seefunknetz; SPICe; Tenby Council; The Whales and Dolphins of Clacton Pier; Trade Wind News; UK Haulier; URS Corporation; Vertikal; Weather Forecast;
Journal papers	Baxter (2005); Brown et al. (2010); Burke (2013); Dawson et al. (2009); Fink et al. (2009); Flather and Davies (1976); Flohn and Fantachi (1984); Grumm (2012); Haigh et al. (2011); Jonkman and Kelman (2005); Keane (1976); Kemp (2013); Lamb (1991); Lamb (2012); Law et al. (2003); Levinson (2008); Lumbroso and Vinet (2011); McCallum and Grahame (1993); Odell et al. (2013); Palmer (2011); Paté-Cornell (1993); Rogers (2011); Ruocco et al. (2011); Smith (2007); Steers et al. (1979); Vinnem (2013); Wadey (2013); Wadey et al. (2015); Wolf (2007); Zong and Tooley (2003)
White papers and	Anchors and Chain Cables Act, 1967; Drilling Rig “Ocean Prince” (loss); Floods (east coast); MV Braer; Oil Pollution (Devon coast);

Commons Sittings transcripts	Scotland (flood damage); Scotland (storm damage); Scottish Highlands (storm damage); Sea Defences and Flood Damage and Flooding, North Wales; Sikorsky Helicopter Crash; "Torrey Canyon" (agreement on claims)
Investigation reports	AAIB; Association of British Insurers; Department for Transport; EDF Energy; HM Government; HR Wallingford; International Maritime Organisation; MAIB; Maritime and Coastguard Agency; MunichRe; United States Court of Appeals; Willis Re

disruption and damage. The impacts of disruptive extreme events referred to within the severity scale are a combination of financial and societal components (Table 3.2), with the societal variable of fatality, or fatalities, having the greatest severity. The severity scale ranked disruptive extreme events from Level 1 (least severe) to Level 7 (most severe) (Table 3.3). For ease of comparison between disruptive extreme events across the decades the financial impacts of events were converted to pounds sterling equivalent to January 1st 2018.

The bias present within the database was overcome by focusing the analysis on the more severe events (classed as Level 4 to Level 7). The impacts of events classed as Level 4 were consistently reported within media reports as they were severe enough to be considered “news-worthy” (such as instances of houses evacuated or fatalities).

Keywords and phrases were used to identify incidents of disruption within literature and media reports (Table 3.4). Each disruptive event was classified according to its primary cause – i.e. the main cause of negative impacts. Sequential disruptions, such as wind storms arising from separate storm fronts were recorded as distinct events, even if they only occurred a day or two apart from each other. Recorded storm surge extreme events and instances of flooding were validated against the SurgeWatch database (Haigh et al., 2015), which to date provides a record of UK coastal flooding events since 1916.

For each identified disruptive extreme event seven variables were recorded: location, scale, frequency, cause, duration, recovery, disruptive effects and consequences. The collected data, when analysed in conjunction with the developed severity scale, aided an analysis of how vulnerability varied between regions.

3.3 The nature of recorded disruptive extreme events

3.3.1 Types of extreme events

The 88 identified extreme events were categorised into seven weather, or non-weather causes of disruption:

- Human error – Poorly chosen or timed decisions or actions that result in disruptive impacts (e.g. misjudging vessel movements resulting in a collision between a vessel and the dockside).
- Mechanical or structural fault – Weakness or fault in infrastructure, vessels, equipment, facilities or buildings.

Table 3.2: Financial and societal impact components that determined the severity of recorded extreme events.

	Impact component	
Extreme event impacts	**Financial**	**Societal**
Damage to craft, goods, equipment or infrastructure	✓	
Delays to vessels or operations	✓	✓
Destruction or loss of craft, goods, equipment or infrastructure	✓	✓
Environmental pollution	✓	✓
Fatalities	✓	✓
Flooding of businesses	✓	✓
Flooding of homes	✓	✓
Injuries	✓	✓
Temporary port closure	✓	✓

Table 3.3: Criteria of the severity scale ranking for disruptive extreme events affecting coastal areas, ports and the EEZ.

Severity Scale Levels	Criteria	Region(s) affected		
		Coastal areas	Ports	EEZ
Level 1	Overtopping in the immediate coastal area	✓	✓	
	Rough coastal conditions causing slight delays (<3 hours) in progress of vessels		✓	✓
Level 2	Overtopping extends beyond immediate coastal area; minor damage to sea defences	✓	✓	
	Delay to service (e.g. progress of passenger ferry or inability to dock not exceeding 15 hours)		✓	✓
	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	✓	✓	✓
Level 3	Localised breaching of sea defences and minor flooding	✓	✓	
	Service delays between 15 and 24 hours or cancellations to passenger services (e.g. ferries)		✓	✓
	Moderate damage to vessel, offshore platform or aircraft; minor environmental damage (e.g. small oil spill <7 tonnes - Ornitz & Champ, 2002)	✓	✓	✓
Level 4	Severe breaching of sea-defences resulting in flooding/evacuation of homes and or businesses (>50 buildings)	✓	✓	
	Damage to port or harbour (including infrastructure); port partially functioning or closed for <3		✓	

	hours			
	Service delays exceeding 24 hours; major damage to vessel, offshore platform or aircraft		✓	✓
	Cargo damage or small-scale loss; major injury requiring hospitalisation	✓	✓	✓
Level 5	Port closed for prolonged periods (>3 hours); cargo severely damaged or lost		✓	✓
Level 6	Vessel sinks or is irreparably damaged		✓	✓
	Singular fatality; major environmental damage (e.g. extensive oil spill >7 tonnes)	✓	✓	✓
Level 7	Port severely damaged	✓		
	Destruction of sea defences/loss of natural defences (e.g. beaches); extensive flooding resulting in destruction of buildings or infrastructure; vessel, offshore platform or aircraft sinks or is irreparably damaged	✓	✓	
	Multiple fatalities	✓	✓	✓

Table 3.4: Keywords used to identify potential extreme events within literature and media reports (including news reports and Twitter Tweets).

Primary cause	**Identifying terms**
Human error	Accident, mistake, incident, grounding, collision, error, shortcut, sunk
Industrial action	Action, blockage, industrial, interruption, strike, delay
Mechanical or structural fault	Failure, flaw, grounding, collision, sunk, mechanical
Poor visibility	Fog, mist, visibility
Rough seas	Storm(y), choppy, rough, waves, tidal, coastal
Snow and ice	Frost, slip, hazard, snow, ice
Storm surge	Flood(ing), coastal, sea defence, sea wall, breach, damage, waves, tidal
Wind storm	Gusts, speed(s), blown, wind

- Poor visibility – Where visibility during periods of fog or mist is reduced to such an extent that operations cannot continue as usual.
- Rough seas – Where wave heights are high enough to cause damage to vessels, dependent on vessel size, or port structures.
- Snow and ice – Where snow and/or icy conditions prevent safe working practice (e.g. causing slip hazards or preventing the safe operation of equipment).
- Storm surge – The combination of pressure and wind effects resulting in a temporary rise in sea-level.
- Wind storm – A storm characterised by strong wind gust speeds. Wind storms are classified as where wind speeds exceed 55 kilometers per hour.

The frequency, severity and impacts of extreme events were found to differ between causes. The most commonly recorded causes of disruptive extreme events were found to be wind storms, human error and mechanical faults, which comprised over 70% of the total recorded events (Figure 3.3). The timing, and density of occurrence, of extreme events differed between weather and non-weather causes. Weather events were identified as having a strong seasonal character. All events arising from weather events were recorded between October and March, with 65% of these events occurring between November and January, the Northern Hemisphere autumn and winter.

Non-weather events were most commonly classed as Level 7, the most severe events, where severe long-term damage or multiple fatalities had occurred. Storm surges were the weather event most commonly recorded as associated with incidents of death or damage. Wind storms, in contrast, despite being the most frequent cause of recorded events were most commonly classed as Level 4 or Level 5 events, largely reflecting delays to port operations. Weather events generally occurred on regional or national scales, whereas non-weather events tended to have impacts confined to a local scale.

The most severe extreme events to have affected the UK since 1950 were associated with substantial damage, financial costs and the loss of multiple lives. Case studies of two of these events: the 1953 storm surge and the Piper Alpha oil rig fire are detailed in Appendix F.

Recorded mechanisms of damage or disruption varied strongly dependent on the event type in question. Storm surges, for example, tend to primarily affect coastal areas or ports by flooding, or by the overtopping or breaching of sea defences. The impacts of extreme events arising from human error tended to be more event specific, such as damage to vessels, platforms or aircraft, with secondary impacts such as the loss of cargo or the release of pollution into the environment.

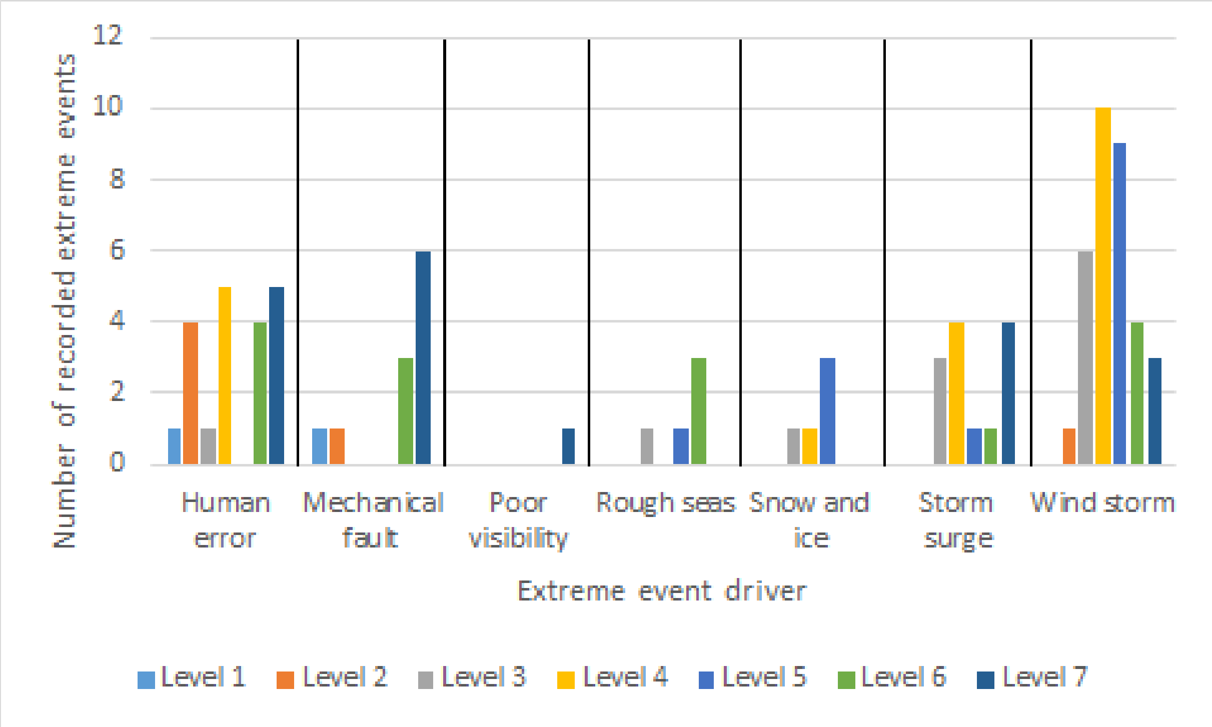


Figure 3.3: Number of recorded extreme events caused by the seven extreme event types between 1950 and 2014.

Half of the recorded disruptive extreme events arose due to multiple causes (see Appendix D). During such events a primary cause, the main cause of damage or disruption, was identified, and one or more other causes were shown to cause additional pressures, or compound the impacts arising from the primary cause. The frequent occurrence of secondary disruption causes during extreme events highlighted how multiple event causes are interrelated (Table 3.5). Of the recorded events 25% were associated with two causes, and 22% from three or more causes. Wind storms, storm surges and rough seas were often recorded together. Wind storms were identified as the cause associated with the largest range of other event types, as 71% of wind storm events had additional damage or disruption occurring from additional sources, such as storm surges or human error. Rough seas were more commonly recorded as a secondary, rather than primary type with 83% of events occurring as a minor component of the disruptive impacts. Two-thirds of storm surge events were associated with secondary impacts from rough seas, causing vessel delays, or closures to ports situated beyond the impact region of the storm surge itself.

3.3.2 Impacts of, and responses to, recorded extreme events

Extreme events can have extensive financial costs for the UK, particularly in terms of repair and necessary upgrades. Since 1950 four out of the five most expensive extreme events to affect UK maritime zones were wind storms, with the remaining event caused by a storm surge (Table 3.6). The most expensive event was the January 25th 1990 wind storm which caused insured losses of £4.2 billion. The January 31st East coast storm surge caused absolute financial losses of £1.26 billion. As many of the homes that were damaged or washed away during that event did not have insurance the financial cost of that event are thought to be much greater than recorded values.

Some extreme events were found to act as catalysts for the implementation of coping strategies and adaptations (Table 3.7). Such responses tended to occur if:

- An event resulted in multiple deaths and gained a significant amount of media attention,
- The impacts of the event was reviewed by an organisation (e.g. Department for Transport, Maritime and Coastguard Agency),
- The event caused substantial damage or disruption to “normal” operations or functionality of a maritime zone.

Table 3.5: The interrelation of weather and non-weather extreme event types

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

Table 3.6: Insured losses from the five most expensive UK maritime extreme events since 1950

Date	Event classification	Insured losses (2018 values) (The National Archives, 2018)
January 25th 1990	Wind storm	£4.2 billion
October 15th – 16th 1987	Wind storm	£3.63 billion
January 31st – February 1st 1953	Storm surge	£1.26 billion (absolute)
January 2nd – 4th 1976	Wind storm	£856.8 million
January 17th – 19th 2007	Wind storm	£508.2 million

Table 3.7: Long-term adaptations and responses taken in response to damage or disruption in maritime zones due to extreme events

Date	Event classification	Responses/outcomes
January 31st – February 1st 1953	Storm surge	• Thames Barrier • £20 million spent on flood defences • Storm warning tidal gauge system • New flood risk policy • Demolition of many pre-fabrication houses
18th March 1967	Human error	• £3 million compensation after French and British governments sued jointly, and £25,000 for affected individuals • International Maritime Organisation (IMO) improved its documentation on pollution prevention
13th December 1981	Mechanical fault	• Environment Agency spent £7.5 million on sea defences at Burnham-on-Sea
1st September 1999	Mechanical fault	• Association of Classification Societies added a new paragraph advising surveyors
26th October 2002	Wind storm	• Queen's Harbour Master (QHM) Portsmouth imposed regulations for high winds, and the use of tugs
14th December 2002	Human error	• Automatic tracking system installed for all vessels passing through the Dover Strait
3rd November 2005	Storm surge	• Hayling Island sea defences upgraded
17th January 2007	Wind storm	• Recommendations made to classification societies to improve ship design
19th December 2007	Poor visibility	• Department of Transport reviewed its guide to good practice

31st January 2008	Wind storm	• Department for Transport recommended to carry out an urgent study of RoRo vessel stability
2nd November 2008	Mechanical fault	• Recommendations to Maritime and Coastguard Agency (MCA) for extra vessels to be fitted with bilge alarms
3rd April 2012	Wind storm	• Met Office to improve the clarity of terminology used for severe weather warnings
5th December 2013	Storm surge	• Immingham port upgraded its lock gates to a 1:1000 level of protection

3.4 Variations in vulnerability to extreme events between maritime zones

Of the 88 recorded disruptive events 62% negatively affected ports, 36% the EEZ and 33% coastal areas. Coastal areas and ports were impacted most frequently by extreme events caused by weather types, 90% and 76% of events respectively. In contrast 56% of extreme events that affected the EEZ were caused by non-weather types.

The most common type of disruptive events depended on the maritime zone (Figure 3.4). Coastal areas were most frequently impacted by wind storms and storm surges, with a small number of recorded events occurring due to human error or snow and ice. The main types of damage or disruption for the EEZ were mechanical faults, wind storms and human error, and no extreme events were identified as being caused by poor visibility. 66% of mechanical fault events that had negative impacts for the EEZ were categorised as Level 7.

Ports were found to be most commonly affected by wind storms, with two-thirds of recorded wind events classed as either Level 4 or Level 5. Ports were the only maritime zone which was affected by all seven identified types of extreme events. Wind storms were shown to be one of the most frequent type of damage or disruption for all three coastal zones. Areas affected by the greatest number of extreme events were not necessarily the areas affected by the most severe events. The majority of extreme events recorded in the EEZ were related to offshore platforms – 50% of events in the 1960s, 100% in the 1970s and 83% in the 1980s. Extreme events affecting the UK's EEZ were most commonly recorded in the shipping zone which includes the Dover Strait, the narrowest part of the English Channel which has a high density of vessel movements, including frequent passenger vessels connecting the UK and France. As Rotterdam (The Netherlands), Hamburg (Germany) and many other Northern Europe ports are accessible through the English Channel the volume of maritime traffic passing through the UK's EEZ is several times larger than what UK trade implies.

Almost one quarter of extreme events was shown to have affected more than one type of maritime zone, such as both EEZ and coastal areas. Eleven events affected all three zones simultaneously, although the impacts of these events differed between maritime zones.

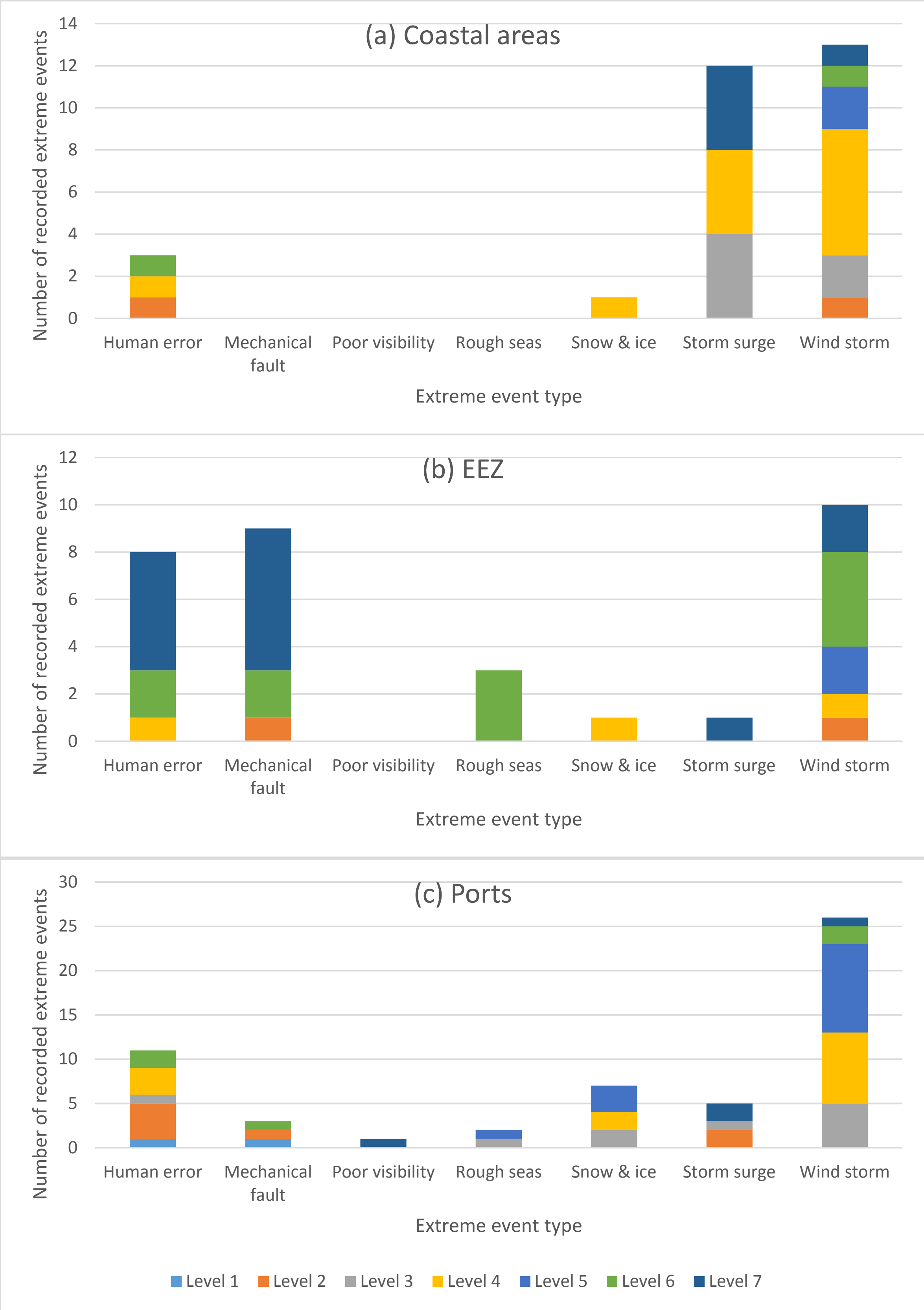


Figure 3.4: Frequency of event types affecting the three coastal zones, and the severity of recorded events (a) coastal areas, (b) EEZ, (c) ports. Events that were recorded as affecting more than one coastal zone are recorded multiple times.

3.5 Spatial variations in frequency of disruptive extreme events

The frequency of disruptive extreme events was found to vary spatially across the UK's coastal areas, EEZ and ports. The UK's coastal area is split into 18 regions, 16 of these were affected by at least one event, and event severities ranged from Level 1 to Level 7 (Figure 3.5). The greatest number of events, nine in total, affected coastlines adjacent to the Irish Sea. Risks identified due to flooding in coastal areas adjacent to the Irish Sea are primarily driven by storm conditions within the sea, such as high winds or storm surges. Southern England was impacted by eight and seven events respectively. The south and south-east coasts of England have a history of being affected by coastal flooding. Level 7 events were most commonly recorded as affecting the South and East coasts of England.

The UK's EEZ is separated into 24 shipping regions (BBC, 2018). Extreme events recorded as affecting the UK's EEZ were most commonly classed as Level 6 and 7 events (Figure 3.6). Two shipping regions: Forties located in the North Sea – which is the location for many offshore oil platforms – and Plymouth off the South-west coast of England recorded both the most severe, and frequent occurrence, of extreme events. Within the EEZ extreme events were most commonly driven by human error or mechanical faults in the form of:

- Collisions that occurred in busy shipping lanes between vessels,
- Accidents and faults associated with offshore platforms.
- The concentration of events in busy shipping lanes or concentrated locations of offshore platforms reflect that densely packed operations were associated with a higher likelihood of extreme events occurring.

Extreme events were recorded as negatively affecting 31 of the UK's 162 commercial ports, with 24 of the ports affected being classed as major by the Department for Transport (2016a) (Figure 3.7). Reports of disruptions from minor ports are considered as less reliable in this analysis as less data is available in media reports for these ports. Ports recorded as being affected most frequently by extreme events were concentrated along the south and south-east England coast, Humber Estuary and Northern Ireland. Felixstowe and Dover ports were negatively impacted by the most events, 18 and 16 respectively, with the next most disrupted port, Belfast, recorded as being affected by six events.

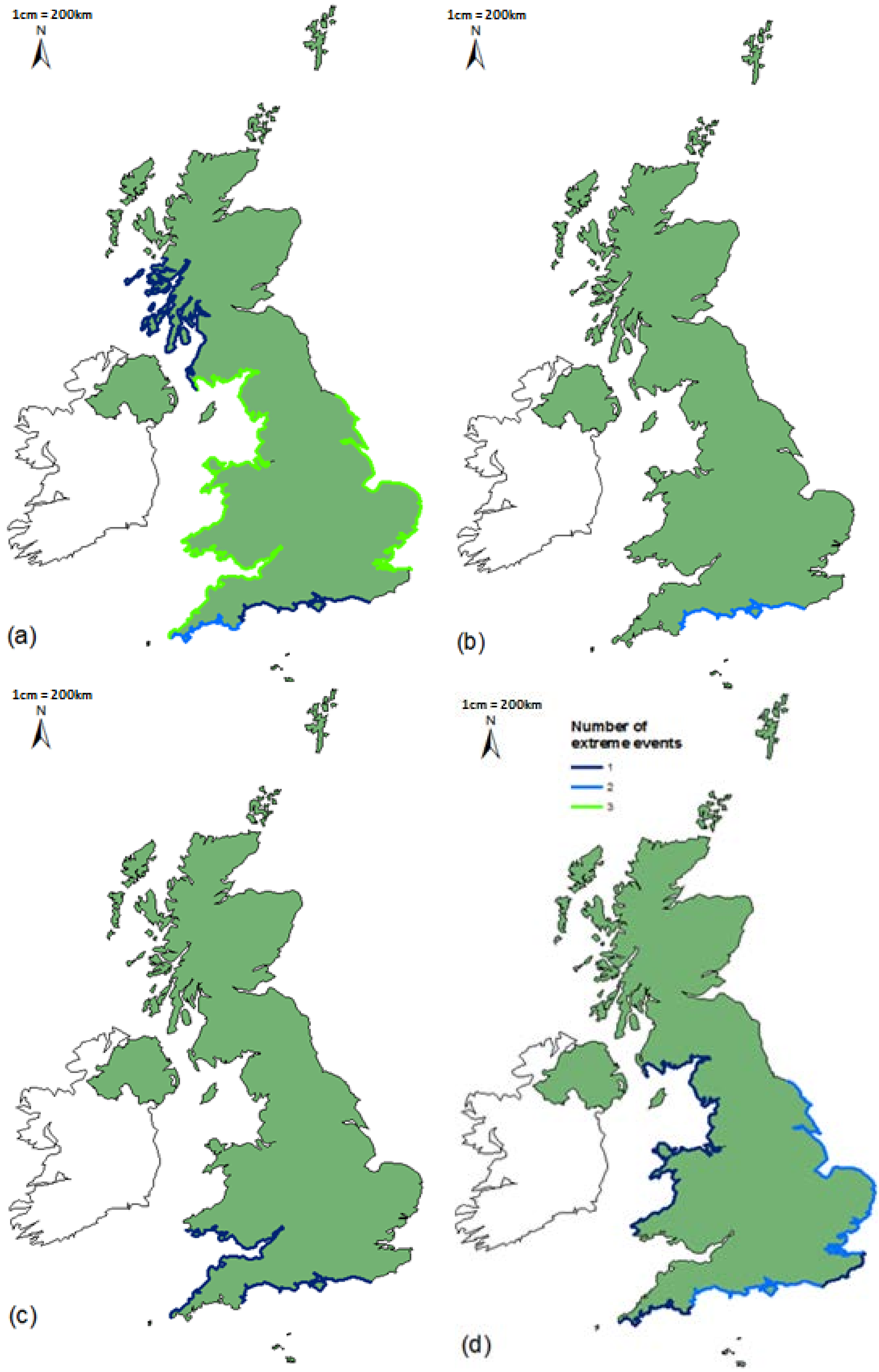


Figure 3.5: Number of recorded disruptive extreme events affecting coastal areas (a) Level 4, (b) Level 5, (c) Level 6, (d) Level 7.

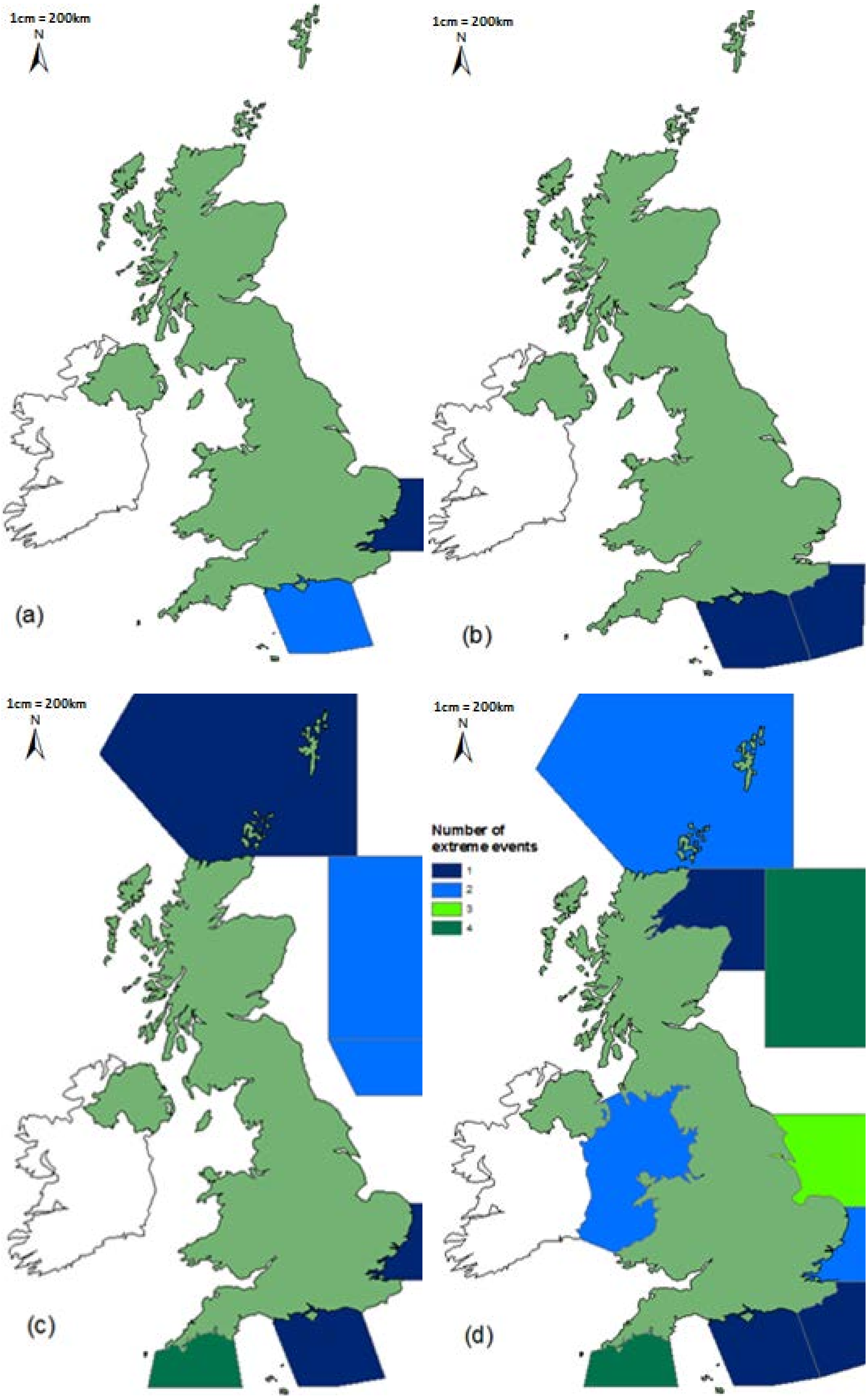


Figure 3.6: Number of recorded disruptive extreme events affecting EEZ (a) Level 4, (b) Level 5, (c) Level 6, (d) Level 7.

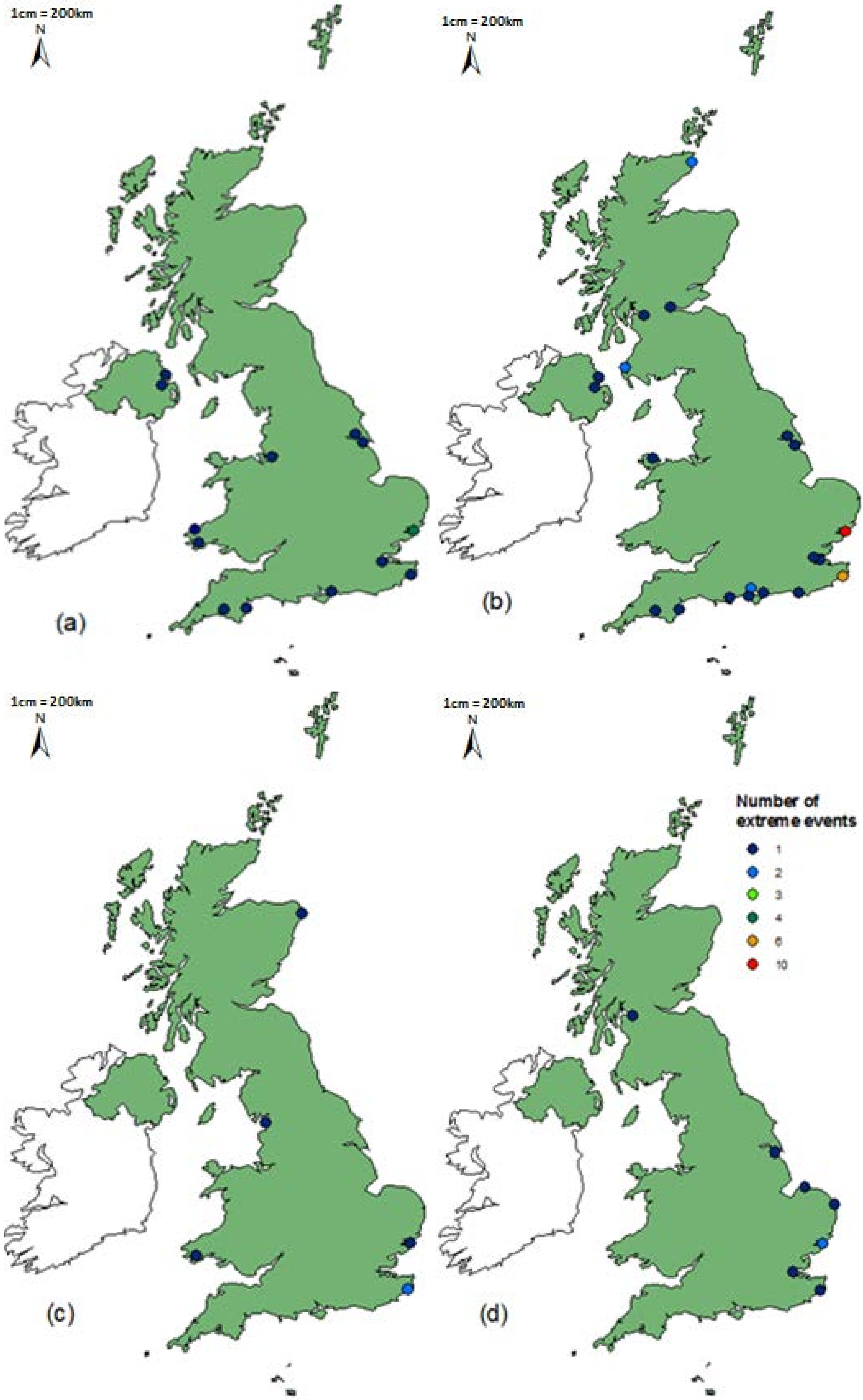


Figure 3.7: Number of recorded disruptive extreme events affecting ports (a) Level 4, (b) Level 5, (c) Level 6, (d) Level 7.

3.6 Temporal variations in the frequency and types of disruptive extreme events

The severity, frequency, impacts and types of extreme events recorded within the database altered through time. From the 1990s onwards less severe events (Level 1 to Level 3) were recorded more frequently (Figure 3.8). Potential reasons for this change are detailed in Section 3.7. The percentage of recorded disruptive extreme events that were classed as Levels 6 or 7 have declined overall from 100% of events in the 1950s down to 7% of events in the first half of the 2010s. A slight peak in recorded Level 6 and 7 events was observed between the 1960s and 1980s after offshore oil platforms began to be installed in the North Sea oil field.

The most frequent, and severe, type of disruption has changed through the decades. The severity of recorded storm surge events have declined from Level 7 in the 1950s through to Level 3 in the 1980s. Since the 1990s extreme events caused by wind storms have increased in frequency, but have declined in severity. Prior to the 1990s wind storms were recorded more rarely, but tended to be classed as Level 6 or Level 7 events. Since 2000 wind storms have been most commonly recorded as Level 4 or Level 5, representing events that are more disruptive rather than damaging or deadly.

A decline in the severity of storm surge events was observed through the study. These improvements reflected increased coastal resilience following a number of improvements to sea defences, the development of a tidal gauge network, the Thames Barrier and higher standard Met Office predictions. This decline in severity highlights how legacies from extreme events can be far-reaching with major implications.

The numbers of deaths associated with disruptive extreme events declined during the study (Figure 3.9). The lowest values of deaths were recorded during the first half of the 2010s, despite the abnormally stormy winter of 2013/14 where the UK endured repeated stormy conditions, including 12 distinct wind storm events (Kendon, 2014). The largest death tolls were associated with storm surge and human error types, and arose due to events that resulted in the severe damage, or loss, of vessels, aircraft or offshore platforms.

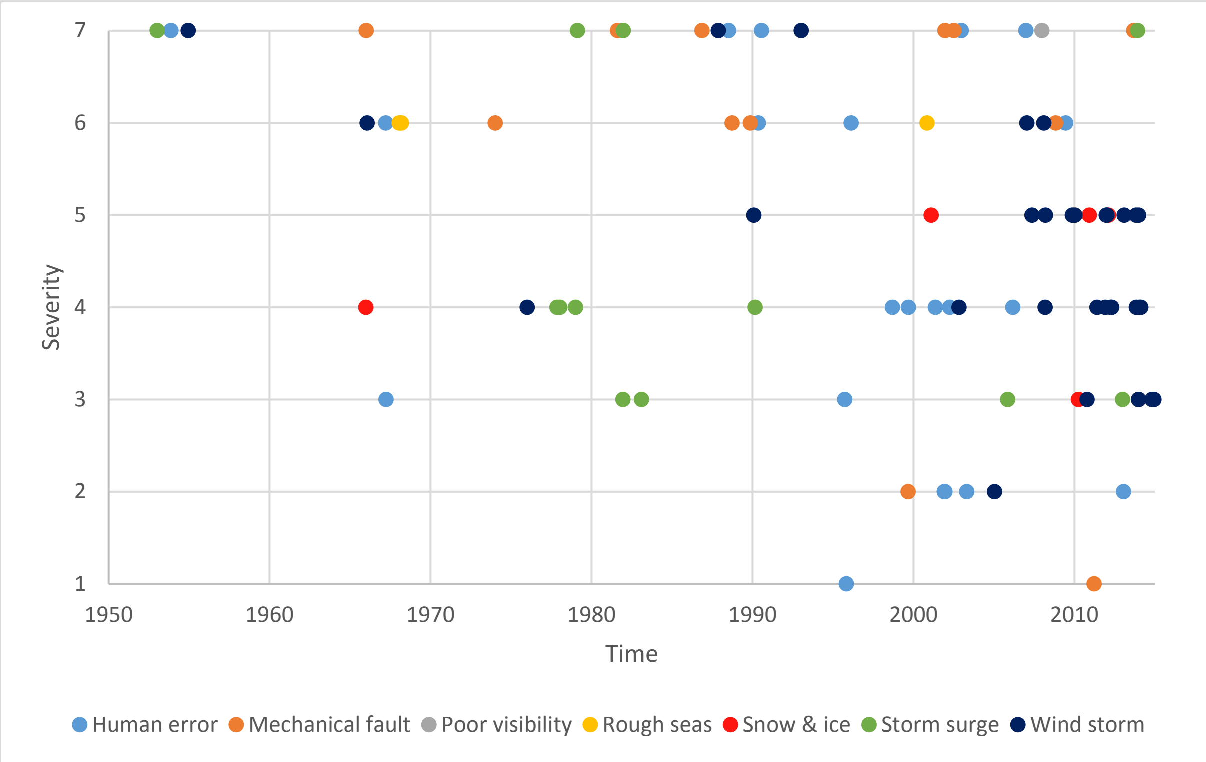


Figure 3.8: Severities of recorded extreme events since 1950, and their primary types.

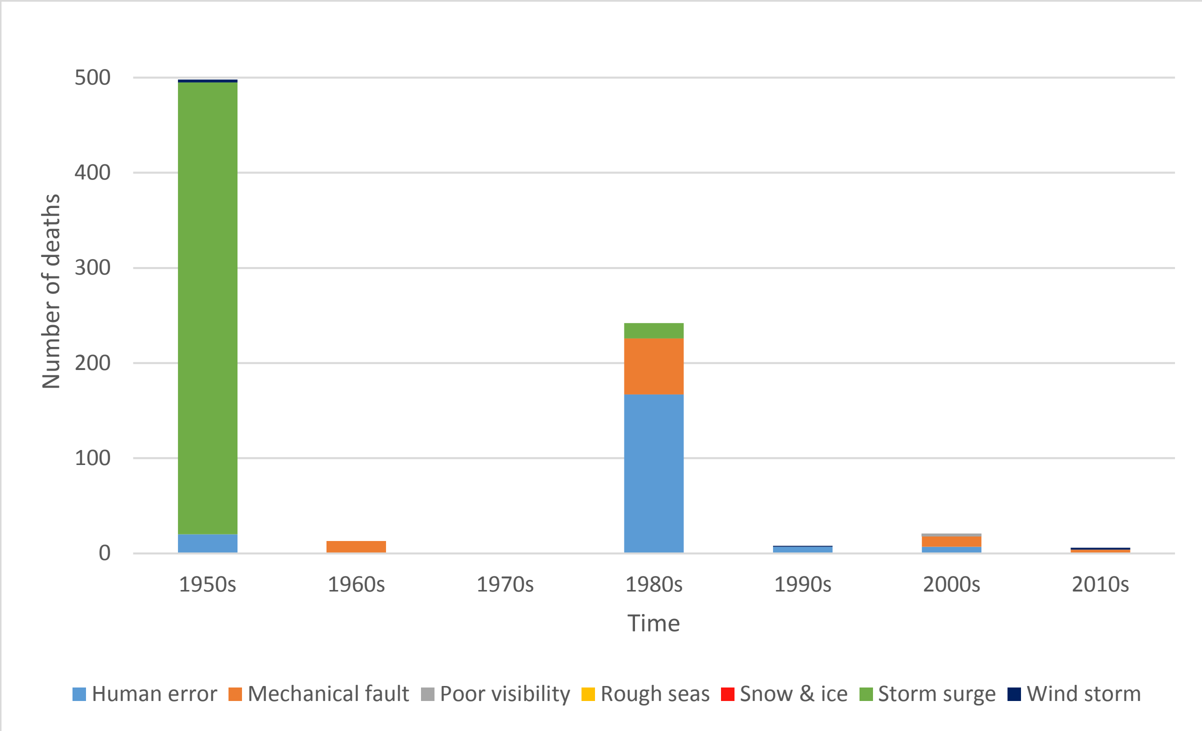


Figure 3.9: Number of deaths attributed to disruptive extreme events affecting UK maritime zones between 1950 and 2014.

3.7 Discussion

3.7.1 Extreme event types and their impacts

A diverse range of extreme event types, which can have a broad range of impacts on their functionality and operations, affect UK maritime zones. Both weather and non-weather events have the potential to cause damage and disruption. Prior to this study no publically available dataset of extreme events that affected UK maritime zones was available. The 88 disruptive extreme events recorded, and analysed, within this study provide a unique detailed perspective on the many challenges the UK's maritime zone faces due to extreme events. Increased available knowledge on the likelihoods and impacts of each extreme event type can guide effective adaptation by decision-makers when steps are undertaken to reduce their vulnerability to potential causes of damage or disruption (Boulter et al., 2013).

As would be expected, weather types of extreme events are strongly dictated by seasonal conditions. UK maritime weather is more severe during autumn and winter months, and is typically characterised by an increased frequency of depressions and storms. In the database 65% of weather driven extreme events were recorded between November 1st and January 31st, and all weather occurred between October and March. During the winter months the instances of extreme events arising from human error or mechanical faults also increased as adverse conditions enhance strain on equipment, and provide poorer operating conditions (e.g. restricted visibility or rougher seas). It is critical that decision-makers are aware of periods of increased risk of extreme events occurring and have coping strategies ready for implementation if the need to contend with potentially disruptive conditions arise.

During periods of poor visibility the likelihood of extreme events caused by human error increased in the EEZ and ports, despite the use of safety equipment such as sonar or AIS ship position tracking. Analyses of the causes of such extreme events by official bodies such as the *Marine Accident Investigation Bureau (MAIB)*, found many of these events arose due to poor judgement, rather than resulting as a direct consequence of potentially hazardous weather conditions. In addition, other instances of human error were found to arise from poor communication, staff not paying full attention to their actions, or attempts by vessel captains to take time-saving shortcuts away from recommended shipping lanes and routes.

Nine of the recorded extreme events had impacts that extended beyond the United Kingdom. The types of these events were primarily storm surges or wind storms. For example the January 1953 storm surge also severely impacted The Netherlands and Belgium, and the October 2013 storm surge negatively affected multiple countries including Belgium, Denmark, Germany and The Netherlands, and the port of Rotterdam was closed for a day. Large-scale, powerful, extreme events such as these were more likely to be classed as Level 7, highlighting the importance of decision-makers in preparing, and putting in place coping strategies, before a predicted severe event reaches the UK or its waters.

Disruptive extreme events have the potential to impact multiple aspects of society, including physical and natural structures and environment, business operations, finance and quality of life for workers, tourists and residents. All disruptive extreme events have the potential to cause negative financial impacts for the affected maritime zone. Specific financial implications range from damage to a vessel, or cargo through to weakening of infrastructure or the need for large-scale environmental clean-up operations. More generic financial impacts include losses of business, or tourism, due to delays or an area being closed to operations for a period of time.

Of the five most expensive disruptive extreme events recorded in the database four events had wind storms as the primary type, and the fifth event was primarily caused by a storm surge, with additional negative impacts from wind (see Table 3.6). Financial data available for the January 1953 storm surge refer to total rather than insured values, such as irreparable damage to buildings or other properties, as at that time many homes and businesses did not have insurance. Interestingly, only one of the most expensive events was classed within the top five most severe events, highlighting the role of insurance claims in the financial impacts of extreme events.

3.7.2 Maritime zones and extreme event vulnerability

The most common type of extreme events differed between maritime zones. Extreme events affecting coastal areas and ports most commonly arose from wind storms, with additional events occurring due to mechanical faults, human error and storm surges. From the 1990s the number of extreme events recorded per year increased. This likely arose from increased reporting of lesser events following the developing of digital news reporting. Online news offers readers access to events that are locally relevant, as well as providing a greater breadth of news articles (Maier, 2010).

Spatial peaks in the distribution, and concentration, of recorded extreme events arose from a myriad of circumstances, for example, shipping routes around the UK are unevenly distributed, with increased risks of incidents involving vessels in areas with higher vessel traffic density. One of the UK’s areas of most dense vessel traffic is the English Channel. Vessels passing through this zone include those connecting the UK to France, routes moving between Ireland and mainland Britain, and connections to Northern Europe.

The differences in the impacts of disruptive extreme events between maritime zones was highlighted by the Dover region, to the south-east of England. The shipping zone Dover, which includes the Dover Strait, is most commonly impacted by extreme events arising from human error, reflecting the pressures of the busy shipping lane. In contrast, the port of Dover, which caters primarily for passenger traffic, is most commonly affected by wind storm events. Its passenger vessels do not sail if conditions are too rough, or if secure docking is not possible. Also, disruptions affecting French ports such as Calais, to which Dover is strongly connected, can delay operations due to knock-on effects.

The frequency and severity of recorded extreme events also varied within maritime zones. Extreme events affecting the UK's eastern EEZ region were dominated by mechanical faults, a consequence of the North Sea oil field and associated offshore platforms. The discovery of North Sea oil and the subsequent installation of drilling from the mid-1960s (Brown et al., 2014a) onwards presented an additional potential source of maritime disruptions, including risks faced by sea or aircraft transporting crew to and from offshore platforms. The earliest extreme event associated with offshore platforms was recorded in December 1965 following the collapse and subsequent loss of the first offshore platform, *Sea Gem*, which had only been operating for six months (Burke, 2013).

Of the three maritime zones, ports were affected most frequently by disruptive extreme events. After 2000 a higher frequency of more severe events (Level 4 and above) affecting ports was observed. This shift arose from a number of factors: increased reporting of delays and closures (such as digital news reports and blogs), stricter port health and safety operational guidelines, and the increased use of larger high-level cranes, which are vulnerable to high winds. In recent years multiple steps have been taken to increase health and safety in potentially disruptive conditions (BSI, 2013). Felixstowe port situated on the east coast, for example, is vulnerable to wind storms passing across the North Sea, recording more frequent events than those ports situated in more sheltered locations (such as Southampton and many London ports). A recent study by TT Club found that 29% of asset claims were weather related, with 10% arising from wind storms affecting quay cranes (TT Club et al., 2011).

The frequency, and severity, of physical damage to ports and their infrastructure declined in severity and occurrence through the database. In recent years, delays to port operations have become a common source of disruption from extreme events, and arise following either port closure, or a temporary inability of vessels to dock or move cargo. Closures of ports resulting from the presence of snow and ice events mainly reflected stringent health and safety regulations that were implemented to reduce risks for people and equipment operating in port environments.

3.7.3 Spatial and temporal trends in recorded extreme events

The frequency of recorded extreme events differed through the database, reflecting a combination of seasonality, new technologies and changing behaviour altering the risks faced by maritime zones and increased reporting of extreme events in the media.

The role of seasonality in the likelihood of extreme weather events highlights the potential need for decision-makers in marine areas to contend with a concentration of multiple pressures and causes over a short time-period. Awareness of such trends in the occurrence of extreme weather events is of vital importance for stakeholders operating in maritime zones.

The increased reporting of extreme events resulting from mechanical faults or human error present in the database do not represent a decline in equipment or health and safety standards. This instead can be attributed to increased activity in maritime zones including the use of offshore drilling platforms (over 280 operating in the UK's EEZ at present) and increased vessel traffic travelling to and from ports and through UK waters (Department of Energy and Climate Change, 2014).

Shifts in the most common, or severe, types of damage or disruption reflects in part the changing use of UK maritime zones. From the 1970s to 1990s human error and mechanical faults became a greater issue reflecting, in part, the burgeoning North Sea oil business which provided an additional source of potential vulnerability to disruptive extreme events following the installation of the first offshore oil platform in the mid-1960s. An increase in the frequency of wind storms affecting port operations, apparent from the 1990s onwards reflects a combination of the increased mechanisation of ports and the development of more stringent health and safety measures and regulations.

3.7.3.1 Responses to extreme events and their level of success

Recorded extreme events can be broadly categorised into two groups: events that are accepted as a business risk, and those viewed as a disaster. Less severe events, such as those that disrupt port operations, tend to be absorbed into day-to-day operational schedules and profit margins, and are accepted as a "fact of life" (Osthorst and Manz, 2012). Behaviour such as this highlights the important role that coping strategies, and increasing resilience through adaptation measures, can reduce the extent of impacts from disruptive extreme events.

The diversity of extreme event types, severities and impacts identified highlights the broad range of challenges present for decision-makers in maritime zones to protect their operations. Serious extreme events were found to generate a "window of opportunity" for improvements or adaptations (Hall et al., 2012; Tompkins et al., 2010).

Adaptation decisions have, in the main, been made in the wake of events and tend to be response-led, rather than acting proactively in line with predictions of likely risk or vulnerability (for examples of proactive adaptation see Appendix I). Some adaptations following extreme events arise in terms of developmental improvements, such as the installation of enhanced sea defences, and legislative upgrades. Such responses were found to primarily occur following either moderate or high severity events which either affected a broad region, or very high severity events focused on a particular location.

Instances of where adaptations or changes to behaviour are difficult to identify, as reports of damage or disruption are often more news-worthy than examples of success. The Thames Barrier was developed in response to the flooding experienced during the 1953 storm surge. As of January 2018 the Barrier had been closed 181 times since entering operation in 1982 (UK Government, 2018) to prevent flooding in Central London.

Two similar extreme events that can be compared are the storm surges of January 31st 1953 and December 6th 2013. In 1953 a total of 475 people lost their lives, 24,000 homes were damaged and substantial flooding and damage was experienced to England's East coast and multiple ports. In contrast, in 2013 the surge heights exceeded those recorded in 1953 in multiple locations (including Lowestoft and Great Yarmouth) (Met Office, 2014; Spencer et al., 2015; Wadey et al., 2015b), 7 homes were washed into the sea, 75% of Immingham port was inundated by seawater, but no lives were lost. Although both of these events were very severe, and classed as Level 7, the extent and duration of damage and disruption experienced in 2013 was much less than its 1953 counterpart. The differences in impacts between these two events arose from two factors, lower wave heights (3.8m in 2013 compared to 7-8m in 1953 (Spencer et al., 2015)) and improvements to knowledge and technology. Technological improvements can largely be attributed to enhanced sea defences, better quality housing (compared to the vulnerable pre-fabricated homes that were damaged or destroyed in 1953) and the use of warning systems to allow evacuation and coping strategies to be put in place.

This marked difference in the scale of impacts highlights the benefits that adaptations, such as the Thames Barrier and tidal warning system provide (Lumbroso and Vinet, 2011; Met Office, 2014). Such developments do not provide an unlimited level of protection for coastal residents and users. Higher quality defences, and other protective measures can reduce risks from storm surge and coastal flooding events, but will not eradicate them, as severe events with long return periods continue to be a risk.

Improvements to sea defences, for example, reduces the likelihood, but cannot eradicate the occurrence of damage or disruption from extreme events. Key examples of such circumstances include:

- Immingham port, Lincolnshire (5th December 2013): A storm surge flooded 75% of the port by overtopping the dock gates. The port was closed for a couple of days due to a power failure, as the port's substation was flooded. Businesses operating on port land reported disruptions to their operations for a few weeks after the event occurred (ABP, 2014, 2017; Wadey et al., 2015b). The port's operators, ABP, has announced that it is installing new, higher, dock gates that would be able to contend with a similar storm (ABP, 2017).
- Dawlish, Devon (5th February 2014): During storm conditions a sea wall at Dawlish collapsed, and the coastline railway line, which is the primary rail connection to south-west England, was partially washed away. It took 2 months, and £35 million, for the repairs to be completed. Additional, larger, unquantified financial losses for the region were associated with lost revenue from passenger transport and reduced tourism for the area (BBC, 2015).
- Hayling Island, Hampshire (3rd November 2005): Flooding occurred by long-period swell waves despite improved sea defences being recently installed (Ruocco et al., 2011). On several recorded occasions the UK's south England coastline has been negatively impacted by long-period swell from the Atlantic Ocean (Palmer, 2011).

Examples such as these highlight that risks from extreme events, which have the potential for severe negative impacts remain. Therefore it is vital that decision-makers continue to assess the risks that are faced, and act in anticipation, rather than in response, to extreme event types. This is particularly important, considering future challenges the UK's maritime zones will experience associated with climate change (Section 3.7.3.2 and Chapter 5), such as rising sea-levels and temperatures, as well as potential changes in overall storminess.

3.7.3.2 Climate change observed within the database

The nature of the UK's vulnerability to disruptive extreme events since 1950 has changed alongside shifts in industry, legislation and understanding of the impacts arising from extreme event types. Debate continues regarding whether climate change will enhance storminess for the UK (IPCC, 2012; Ulbrich et al., 2008). Any challenges would have implications for the frequency and severity of events. Since 1950 some baseline climatic conditions experienced by the UK have changed, although the extent of these changes vary:

- Sea-level: Since the 1950s the UK's average rate of sea-level rise has been estimated at 1.4 ± 0.2 mm yr^{-1} (Woodworth et al., 2009; Woodworth et al., 1999), with slightly lower rates along the English Channel (Wahl et al., 2013).
- Wind speed: No overall trend has been identified in wind speeds over the UK since the 1950s, and predictions for the next 60 years remain uncertain. By 2050 UK wind speeds may change by 0 to $-0.2ms^{-1}$ at the 50% confidence level (Sexton and Murphy, 2010).
- Significant wave heights: Changes to significant wave heights are uncertain, with some studies identifying a slight increase in wave heights since the 1950s in the waters to the south of England, and slight declines in wave heights to the north of the UK (Bertin et al., 2013; Dodet et al., 2010; Lowe et al., 2009). In contrast other research has concluded that wave heights have shown no change beyond natural variability (WASA Group, 1998).
- Increasing baseline sea levels poses additional challenges for improving protection levels against storm surges and associated flooding.

Since the 1950s flood event frequency has not increased despite rising sea levels (Ruocco et al., 2011), as coastal protection has been enhanced following an increased recognition of the risks posed by coastal flooding (Nicholls et al., 2013). An increased acceptance of the risk of coastal flooding and the advantages of sea defences have resulted in improvements to coastal protection.

3.7.3.3 Successes and weaknesses of the database

The database and associated severity scale had a number of successful outcomes:

- The severity scale effectively resolves differences between extreme events, and correctly distinguishes between the severity and longevity of impacts.
- The severity scale can be applied to maritime zone extreme events in other countries.
- Severe, or large-scale, extreme events are well resolved within the database.

- The length of the database allows an assessment of how changes in technology, legislation and the implementation of adaptation measures are changing maritime zones and the risks they face from extreme weather and non-weather event types.

Despite the above successful outputs of the database, a number of limitations were also identified:

- Not all extreme events that affected UK maritime zones were reported, therefore gaps are present within the database. An example of this is that records of extreme events affecting ports were dominated by major ports. Both large and small ports are affected by extreme events, so minor ports are not well resolved within the database.
- A data bias is present within the dataset. This has arisen from two issues: not all extreme events being reported, and increased reporting of less severe extreme events following the development of Internet-based media.

Comparisons between maritime zones identified that ports were affected by almost twice as many recorded extreme events as coastal areas or the EEZ. This is despite the UK port sector being reticent regarding providing any information about any weaknesses or disruption to their business operations. As not all extreme events that affect ports are reported, an important next step is to identify a method of all events that have negative effects for the UK port sector.

3.8 Key findings and summary

The main findings from this stage of the research are:

1. The interrelation and interaction between extreme event types creates a complicated challenge for UK maritime zones to contend with. The presence of one type can increase the likelihood of another type occurring, which can have more severe consequences (e.g. a human error event occurring during a period of poor visibility).
2. Improvements in knowledge and technology (e.g. sea defences, forecasting systems) have helped reduce the impacts of some extreme event types (e.g. storm surge, wind storm). The success of many of these improvements can be illustrated by comparing the devastating 1953 storm surge and its disruptive 2013 counterpart.
3. The development of new technologies and behaviours can alter the risks faced by maritime zones. The installation of offshore platforms, and early inexperience in this technology, were associated with an increased occurrence of recorded extreme events in the North Sea. In recent years ports have developed cautionary behaviours, such as pre-

emptively pausing port operations prior to an extreme event, which results in disruptions to port operations whilst reducing the likelihood of damage or injury.

Chapter 4: Present vulnerability of selected UK ports to extreme events

4.1 Introduction

In the previous chapter (Chapter 3) a database of recorded extreme events (weather and non-weather) that affected UK maritime zones, including ports, over the past six decades was detailed. Limited records for less severe events, and extreme events that impacted smaller UK ports, were available. Because it is not reasonable to assume that smaller commercial ports are affected by fewer and less severe extreme events than their larger counterparts, it was suggested that media reports were more likely to focus on the more dramatic events which would attract more interest from their readership.

A more complete, and reliable, record of disruptions to port operations is needed, independent of the media and its suspected bias (Figure 4.1). It is important to develop one or more proxies which can be used to identify disruptions to port operations regardless of the size of the port or the severity of the disruption.

This stage of research aims:

1. To develop a proxy method for identifying disruptions to port operations,
2. To use this proxy to determine how extreme event types and other factors affect UK port operations,
3. To investigate the specific impacts that extreme events have for UK port infrastructure and operations,
4. To identify the range of (short and long-term) responses made by ports to disruptions arising from extreme events.

4.2 Data and methods of study

4.2.1 Data

Automatic Identification System (AIS) data from commercial vessels and information from port and shipping company Twitter feeds were used to create a database of vessel activity for three study ports and the types, duration, impacts and responses of extreme events.

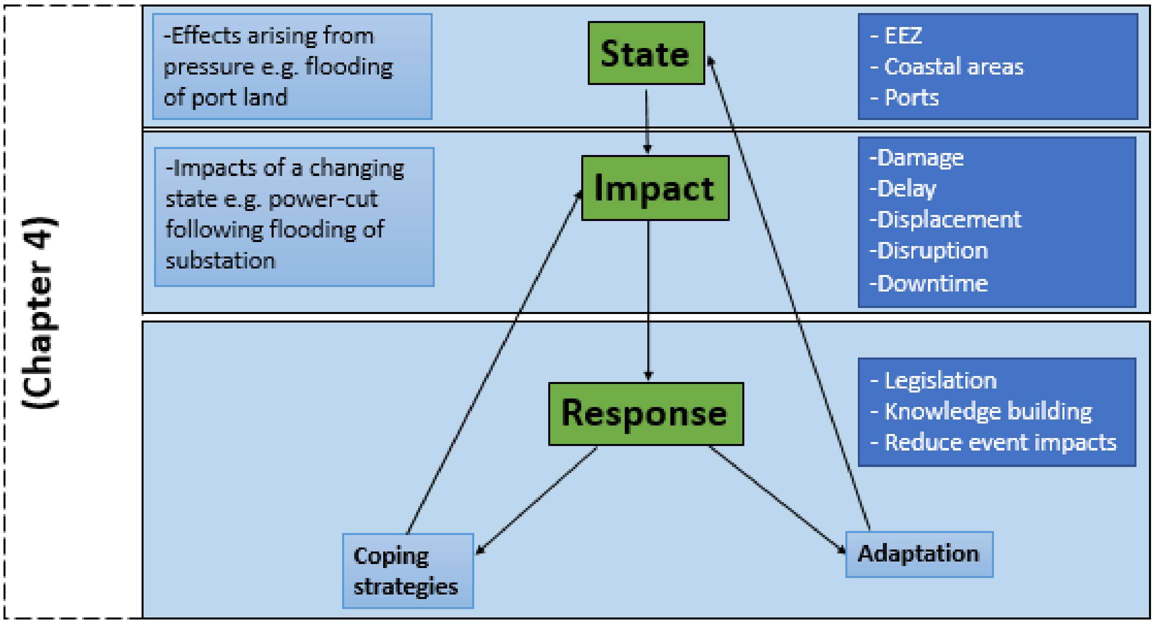


Figure 4.1: Framework of the research reported in Chapter 4.

AIS is a shipping tracking system that is legally required to be installed on all passenger vessels, and all cargo vessels of 300 giga-tonnes or over (International Maritime Organisation, 2005). AIS is used both by vessels and ports to monitor the speed, identity and course of vessels in their area, and is designed to help reduce the occurrence of collisions between vessels. Vessel positions are only available within 15-20 nautical miles of a terrestrial AIS receiver, which are located within ports.

Three case study ports were selected, representing some of the UK's busiest commercial ports and the main operation types: Dover, Felixstowe and Tilbury (Figure 4.2). AIS data were collected for all commercial vessels calling at the case study ports between 1st September 2013 and 30th September 2015. A longer, reliable, time-series of vessel activity was not available for analysis as prior to 2013 available AIS data was limited as not all UK ports had AIS receivers installed, and therefore would not be able to provide a coherent time-series for UK ports.

An incomplete dataset was excluded from this study: Southampton port. Despite known disruptions affecting the port during the study no extreme events were reported. Satellite data confirmed that storms passed over Southampton port during the period of study, so disruptions to vessel activity may have occurred. Ferries that operate from Southampton port into the Solent did not always have the AIS software switched on so it was not possible to identify disruptions that affected operations at the port.

Vessels used for fishing, research, private use, or as tugs were excluded from the analysis. Fishing, private use and small research vessels are not legally required to have AIS transceivers on board. Although tugs tend to have AIS systems installed their operations usually to occur within a port boundary, and their activity is largely dictated by the commercial vessels that require their assistance to enter a port. One date, 26th August 2014, was excluded from the database as AIS receiver errors were reported, meaning that the data was likely incomplete.

The data was sourced from the web platform "Fleetmon", which is a service provided by Jakota Cruise Systems GmbH (Fleetmon, 2015; Ware et al., 2014).

Twitter is a global internet social media service that enables companies, businesses and individuals to communicate information publically via individual accounts in 140 characters – in 2017 expanded to 280 characters – (known as Tweets), which can be accompanied with photos or videos (Twitter, 2017). Twitter can be used by individuals, or for organisations, to raise awareness of key events, such as security incidents or disruptions to transport services. In the port and shipping sector Twitter is utilised as an instantaneous communication method to contact truckers, shipping clients and passengers. Such communications can act to raise the awareness of whether

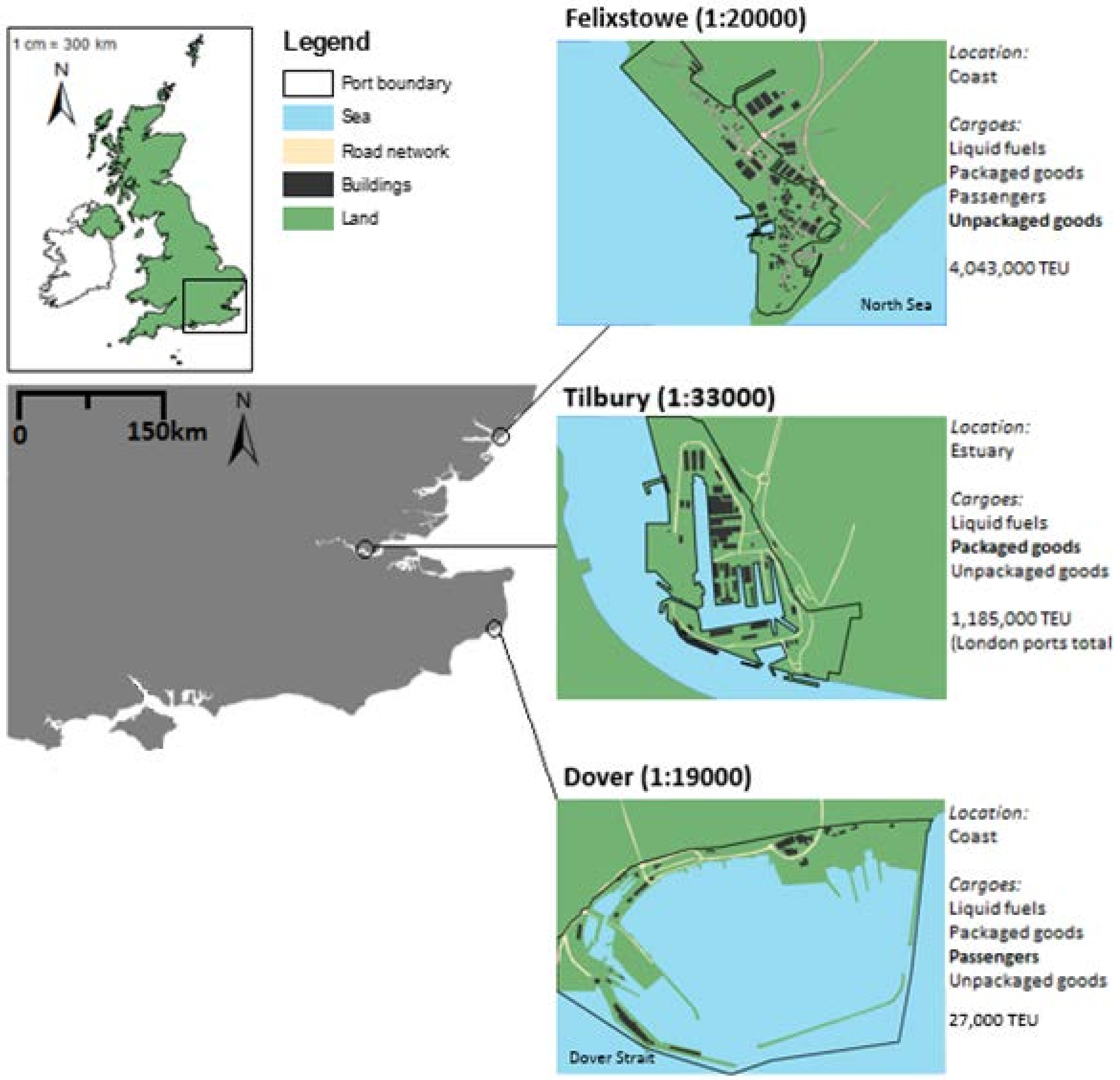


Figure 4.2: Locations of the study ports. Sub-images highlight the cargo operations (dominant cargo types are in **bold**) of each port. All port images are orientated north (Environment Agency, 2016; Google Maps, 2017).

Table 4.1: Similarities in cargoes handled between the study ports and the UK's other busiest ports.

		Other UK ports that move at least 10 million tonnes of cargo per annum												
		Belfast	Chatham	Clyde	Grimsby	Hartlepool	Hull	Immingham	Liverpool	Milford Haven	Port Talbot	Sheerness	Sullom Voe	Teesport
Study Ports	Dover			X			X							
	Felixstowe					X	X	X		X	X		X	X
	Tilbury	X	X		X	X			X	X		X		

any delays or stoppages are affecting a port, the cause(s) of any issues, and the predicted time to elapse before “normal” service is resumed.

Official Twitter feeds from fourteen relevant organisations (including port or harbour authorities and shipping companies) were analysed to identify information provided on disruptions or delays caused by extreme events (Tables 4.2). Twitter data provided diverse information on extreme events, including their timing, duration, cause (type), impacts and port/shipping company responses. A more detailed, and complete, record of extreme events was available for Dover port as regular travel updates are provided for its passenger services. Twitter Tweets from relevant organisations sent between the 1st September 2013 and 30th September 2015, matching the timing and duration of the AIS time-series, were searched using keywords. A full list of words used are recorded in Table 3.4.

The AIS data was coupled with data from relevant port and shipping Twitter feeds (Table 4.2). Data from Twitter and blogs added objectivity to the study by allowing comparisons of identified disruptions to port operations (in the form of Twitter and blog data) with variations in vessel activity data (from AIS). Tweets identified by keywords as reporting on disruptions were used to identify the extreme event type(s) and coping mechanisms and adaptations implemented by port decision-makers.

4.2.2 Methodology

AIS and Twitter data were analysed in conjunction to assess whether a time-series of vessel activity within port boundaries (in the form of AIS vessel position data) can be used as a new proxy method for identifying disruptions to port operations. AIS data was critical in identifying the timing and duration of disruptive extreme events, and gave insight into the responses made by port decision-makers in response to potentially disruptive conditions.

The time series for the number of ships within the port during each day were derived by the location provided in the AIS messages. AIS vessel positioning data was used to identify vessel movements within a determined port boundary. Raw AIS data for each individual vessel that entered a port of interest was collected, and data for each vessel was amalgamated into a database for each port. Data was analysed to determine how many vessels entered a port in a single day (from 00:00 to 23:59), and was used to form a time-series of vessel activity per day.

Table 4.2: Twitter feeds from port or harbour authorities and shipping companies for the three case study ports.

Port	**Twitter Feeds**
Dover	DFDS Channel Freight (@DFDSChnlFreight); DFDS Seaways UK (@DFDSSeaways), DFDS Seaways Updates (@DFDSUKUpdates); Eurotunnel LeShuttle (@LeShuttle); P&O Ferries Freight (@POFerriesFR8); P&O Ferries Updates (@POferriesupdate); Port of Dover Travel (@PoD_travelnews); Port of Dover (@Port_of_Dover)
Felixstowe	Port of Felixstowe (@FelixstowePort); Maersk Line (@MaerskLine); Maersk Line UK (@MaerskLineUK)
Tilbury	Forth Ports Limited (@forthports); Maersk Line (@MareskLine); Maersk Line UK (@MareskLineUK)

A number of lengths of running mean periods were tested to determine a period that was less noisy, but still represented effectively any dips or peaks in vessel activity beyond daily oscillations. A running mean of three days was identified as best representing the filtered time series shown in Figure 4.5 (a-c) for the three ports. The time series show different behaviour in each port. The variability shown includes local maxima and minima as well as longer-term changes.

Twitter data was used to detail the types of disruption, specific impacts of these events on the operation of the study ports, and the broad range of responses put in place by decision-makers in ports (for example, moving high-level cranes into temporary storage during a period of high winds). Where possible, multiple Twitter accounts were analysed in conjunction to check the validity of reports of disruption.

Twitter and blog data provided an objective way of identifying whether shifts in vessel activity occurred due to extreme events, or due to other longer-term factors (such as business challenges). By using separate sources of data (AIS and Twitter/blog data) disruptions to port operations were identified and assessed in an objective, and repeatable, manner.

4.2.3 Development of a proxy method and case-study selection

A proxy method refers to a variable that correlates with the variable of interest to the research – in this case disruptions to port operations. The use of a proxy method is of particular benefit when no reliable direct record of the variable of interest is available (Mann et al., 2007).

Disruptions to port operations, whether on the seaward or landward side, have the potential to disrupt normal vessel activity. Disruptions arising from extreme events can occur either directly by delaying a vessel's activity (such as its ability to safely enter or exit a port) or indirectly due to berths not being available or delays in unloading cargo or passengers.

The number of ships within the port at any given time changes between days, seasonally and interannually. Assuming, for a moment, that there is a regular pattern involving the number of ships in the port in "normal" conditions, the effect of a disruptive event could probably be identified by having fewer or more ships within the port as a result of the disruptive event.

Within this research an attempt is made for the first time, to use information from a time-series of vessel activity within port boundaries (in the form of the number of vessels entering a port in a 24-hour period) as a proxy for disruptive events to port operations.

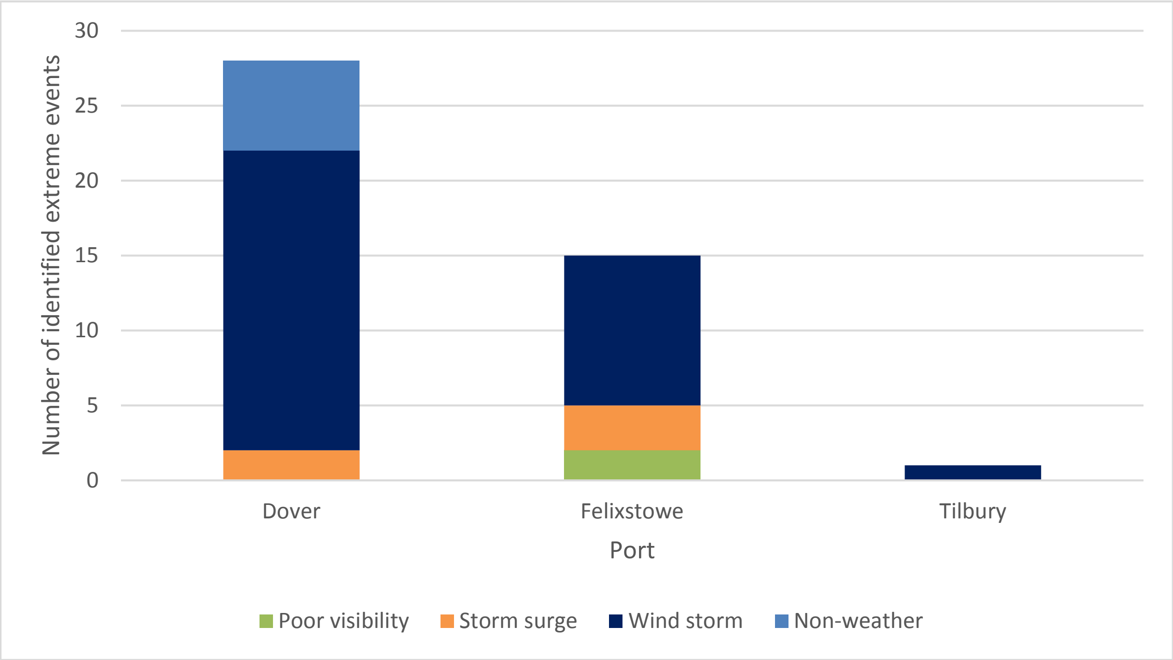


Figure 4.3: The types, and number, of extreme events identified as affecting the operations of the study ports.

4.3 The nature of port extreme events

Ports have the potential to be impacted by a wide range of extreme weather and non-weather events. Extreme events can cause disruptions to all varieties of freight traffic movement. During the study extreme weather events were found to negatively affect port operations on a scale of hours, or in the most extreme cases, days, whereas non-weather events had longer-term impacts (on the scale of days to weeks) (Section 4.7.1).

During the period of study, September 2013 to September 2015, four types of disruption were identified as negatively impacting the study ports: poor visibility, storm surge, wind storms and non-weather (in the form of industrial action) (Figure 4.3). Coastal flooding and rough seas were also observed, but only as a secondary impact, which occur as a result of primary impacts, of storm surge and wind storm events. The limited range of identified extreme event types compared to those identified in Section 3.3.1 and Appendix A is a characteristic of the short nature of the two-year time-series. For example, during the 64-year record of extreme events affecting UK maritime zones, seven identified types of disruption affected UK ports. It is expected that a longer time-series would resolve a more diverse range of extreme event types for the study ports.

The most frequent type of disruption was wind storms, which was identified as affecting Dover, Felixstowe and Tilbury ports during the study period. The only exception was for Dover port in 2015 where non-weather events, primarily in the form of industrial action, were identified most frequently, and had the longest duration of disruptive impacts.

Three types of extreme events particularly affected vessel activity and port operations during the two-year study period:

- Powerful singular events – An extreme event caused by a single type with the strength to potentially impact operations across an entire port, leading to the possibility of damage or disruption to both dock-side and landward operations.
- Clustered minor events – Where multiple extreme events caused by the same cause (such as wind storm or storm surge) occur in succession before port operations have fully recovered to "normal". The occurrence of repeated minor events can act to reduce the resilience of a port's functionality, increasing the extent of damage or disruption experienced.
- Singular minor events – An extreme event caused by a single cause with the potential to cause limited disruption to aspects of dock-side and landward operations. .

Table 4.3: Identified extreme events that negatively affected recorded vessel movements between September 2013 and September 2015. Wind storms classed as "major" by the MetOffice are marked by an asterisk (*) (using data from Kendon (2014)).

Extreme event date(s)	**Type**	**Port(s) that displayed affected vessel movements**		
		Dover	**Felixstowe**	**Tilbury**
16th September 2013	Wind storm	X	✓	X
10th October 2013	Wind storm	X	✓	X
27th-28th October 2013	Wind storm	✓	✓	X
3rd November 2013	Wind storm	✓	X	X
5th December 2013	Wind storm	X	✓	X
6th-7th December 2013	Storm surge	✓	X	X
11th December 2013	Poor visibility	X	✓	X
13th December 2013	Wind storm	X	✓	X
18-19th December 2013	Wind storm*	✓	X	X
21st December 2013	Wind storm	✓	X	X
23-24th December 2013	Wind storm*	✓	✓	✓

25th December 2013	Wind storm	✓	X	X
26-27th December 2013	Wind storm*	✓	X	X
30-31st December 2013	Wind storm*	✓	X	X
3rd January 2014	Wind storm*	✓	X	X
4-5th January 2014	Wind storm*	✓	X	X
21st January 2014	Storm surge	X	✓	X
25-26th January 2014	Wind storm*	✓	X	X
31st January – 1st February 2014	Wind storm*	✓	X	X
4-5th February 2014	Wind storm*	✓	X	X
8-9th February 2014	Wind storm*	✓	X	X
12th February 2014	Wind storm*	✓	✓	X
13th February 2014	Wind storm	X	✓	X
14-15th February 2014	Wind storm*	✓	X	X
3rd March 2014	Non-weather	✓	X	X
14th March 2014	Poor visibility	X	✓	X

9th October 2014	Wind storm	X	✓	X	
21st October 2014	Wind storm	X	✓	X	
14th November 2014	Wind storm	X	✓	X	X
9-12th December 2014	Wind storm	✓	✓	X	X
27th December 2014	Wind storm	✓	X	X	X
12-13 January 2015	Wind storm	✓	X	X	X
20th January 2015	Non-weather	✓	X	X	X
10th March 2015	Non-weather	✓	X	X	X
5th May 2015	Wind storm	X	✓	X	X
2nd June 2015	Wind storm	X	✓	X	X
29th-30th June 2015	Non-weather	✓	X	X	X

Seasonal trends were identified for the occurrence of disruptions arising from extreme events. Disruptions caused by extreme weather events tended to occur during the Northern Hemisphere autumn and winter (September to March). During the period of study non-weather events, in the form of industrial action (which were recorded only at Dover port), most commonly took place during the summer months (June to August) when the demand for ferry services were at their greatest (Section 4.5.1).

4.4 Winter 2013/14 storms

The first winter included within the study – 2013/14 – represented a period of abnormally stormy conditions, for which detailed meteorological data was available. The winter was particularly stormy in nature due to a combination of a strong jet stream and a sequence of low-pressure systems passing over the UK, causing the most wet and windy conditions recorded in the past 20 years (Kendon and McCarthy, 2015). Twelve wind storm events, classed as "major winter storms" were identified within Met Office data as passing over the UK (Table 4.3) between December 2013 and February 2014. These events were categorised into two groups of six extreme weather events: mid-December 2013 to early-January 2014, and late-January to mid-February 2014 (Kendon, 2014). Satellite images of these potentially disruptive events confirm that each storm passed over all three of the study ports.

Dover port experienced the most disruptions to vessel activity from these storms, with the port's operations shown to be negatively affected during all twelve wind storms (Figure 4.4). Felixstowe and Tilbury ports experienced disruption to their operations during 2 and 1 of the storm events respectively. Winter 2014/15 represented a more "normal" or "quiet" period, and was associated with fewer recorded winter storm events (Met Office, 2015). Two of the four identified potentially disruptive wind storm events that occurred during the winter negatively affected vessel activity at Dover and Felixstowe ports.

4.5 The impacts of extreme events, and other factors, on vessel activity

During the two-year study the impacts experienced by a port due to extreme events differed due to the event type in question (particularly whether weather or non-weather) and the severity of the event (Figure 4.3). If a port sustains damage during an extreme event (such as structural

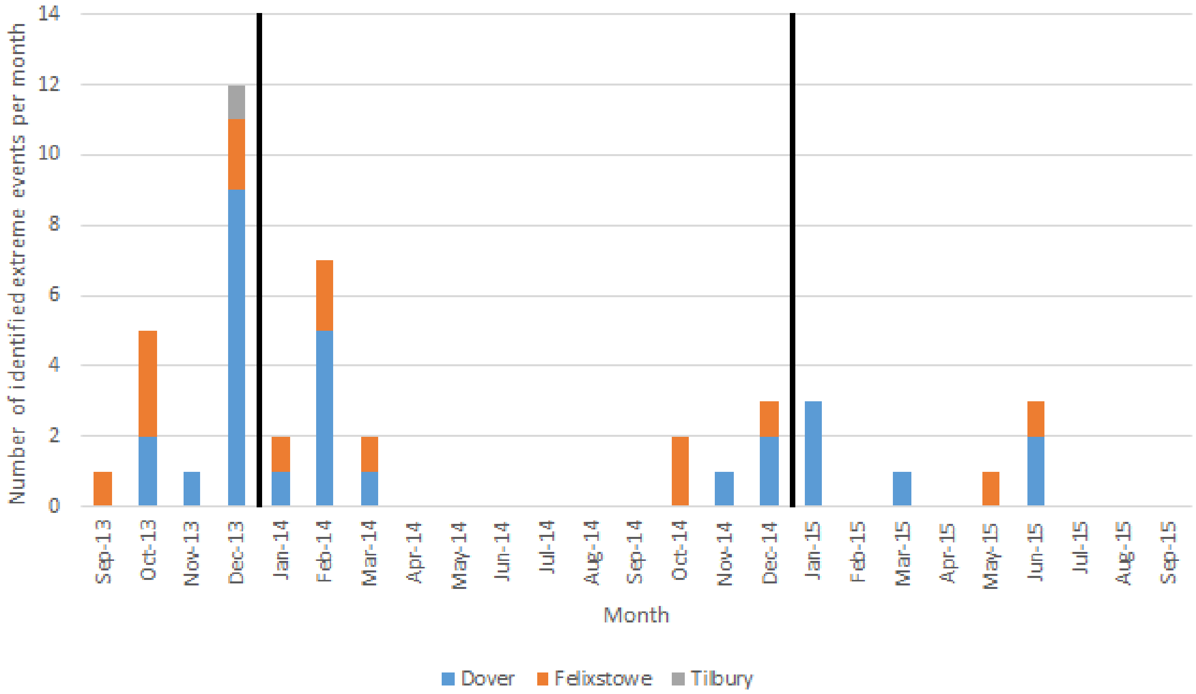


Figure 4.4: Timing of disruptions by extreme weather and non-weather events at Dover, Felixstowe and Tilbury ports. No extreme events were identified by the proxy method for Southampton port (the reasons for this are discussed in Section 4.7.4).

Table 4.4: Impacts of disruptive extreme events on port operations

	Impacts of disruptive events	**Cause of disruption**			
		Poor visibility	**Wind storm**	**Storm surge**	**Non-weather**
Aspect of port operations affected	Reduced vessel movements	✓	✓	✓	✓
	Tugs unable to operate	X	✓	✓	X
Port-wide disruption	Power disruption	X	X	✓	X
	High-level cranes unable to safely operate	X	✓	✓	X
	No access to dockside (from either seaward or landward side)	✓	✓	✓	X
	Port closed	X	✓	✓	X

damage or if high-level cranes cannot be repaired) the impacts can be more severe, lasting weeks or months depending on the severity of the damages received.

Less severe extreme events were associated with the following impacts: slowed down port operations (e.g. increased cargo load/unload times), and short-term delays (usually less than three hours) (Table 4.4). In contrast, severe events most commonly resulted in port closure, and for weather events this closure tended to be pre-emptive, occurring before impacts were felt for the port. The impacts, duration and consequences of extreme events differed between weather and non-weather types. These differences are most apparent when comparing the impacts of different types recorded during this study:

- Weather types – Associated with physical damage or the occurrence of conditions that pose a risk to port operations (e.g. wind storm gusts exceeding safe operational limits),
- Non-weather types – Tended to have disruptive impacts where human actions intentionally act to prevent normal operations from occurring. Any occurrence of damage was also identified as being intentional in nature.

Both powerful singular and clustered minor events had the potential to “leave a legacy”, where lasting impacts were identified for the port and its operations. The time-scales of recovery from such events varied strongly with the type. During the study period recovery from severe extreme weather events ranged from two to three days up to a week. A major challenge for ports following an extreme event was associated with the build-up of cargo both on the dock-side and on board docked vessels.

The impacts of extreme events for ports can be separated into two groups: those that affect an aspect of port operation, and more severe impacts that affect the entire port. Storm surge and wind storm events were identified as affecting a wider range of port operations than other types.

The most severe identified extreme weather events had durations of impact on scales of up to two days. Recovery times from these events tended to be most commonly between 1 to 24 hours after the event itself had either dissipated or passed beyond the location of the port and its operations. Extreme events arising from wind storms were the most common cause of damage or disruption to port operations during the period of study – 29 distinct events (Table 4.3). The duration of individual wind storm events ranged from three to four hours to one day.

Not all identified extreme events affected port operations. Extreme events that occurred overnight did not have a noticeable effect on vessel activity during the study. During the day port activities both on the landward and seaward sides are at their greatest, and extreme events were associated with a decline in vessel activity. Concentrated periods of vessel activity were identified as occurring in the wake of day-time extreme events, as port operators implemented measures to "catch-up" on shipping schedules.

4.5.1 Dover

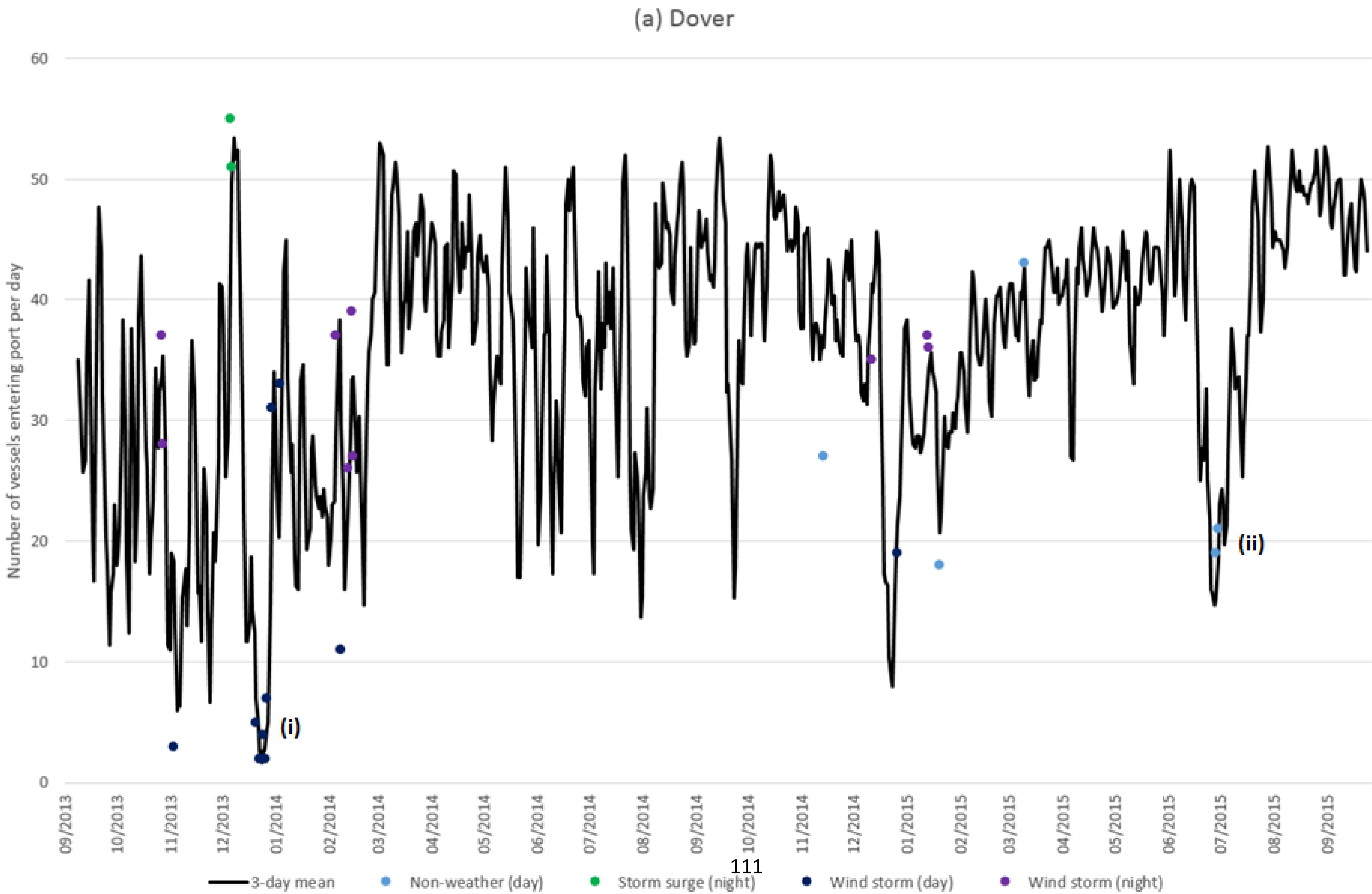
Both extreme weather and non-weather events had disruptive impacts for vessel activities and port operations at Dover port during the study. Although storm surge events were reported as affecting the port no impacts on vessel activity were identified as the events only occurred overnight.

During the night vessel activity within Dover port was lower, as passenger ferries operate fewer night-time services. Recovery from extreme events that occur overnight are easier for the port, and its operations (Section 4.7.1) as port decision-makers are able to implement coping mechanisms to reduce the severity, or duration, of extreme event impacts before the demand for port operations increases during the following day.

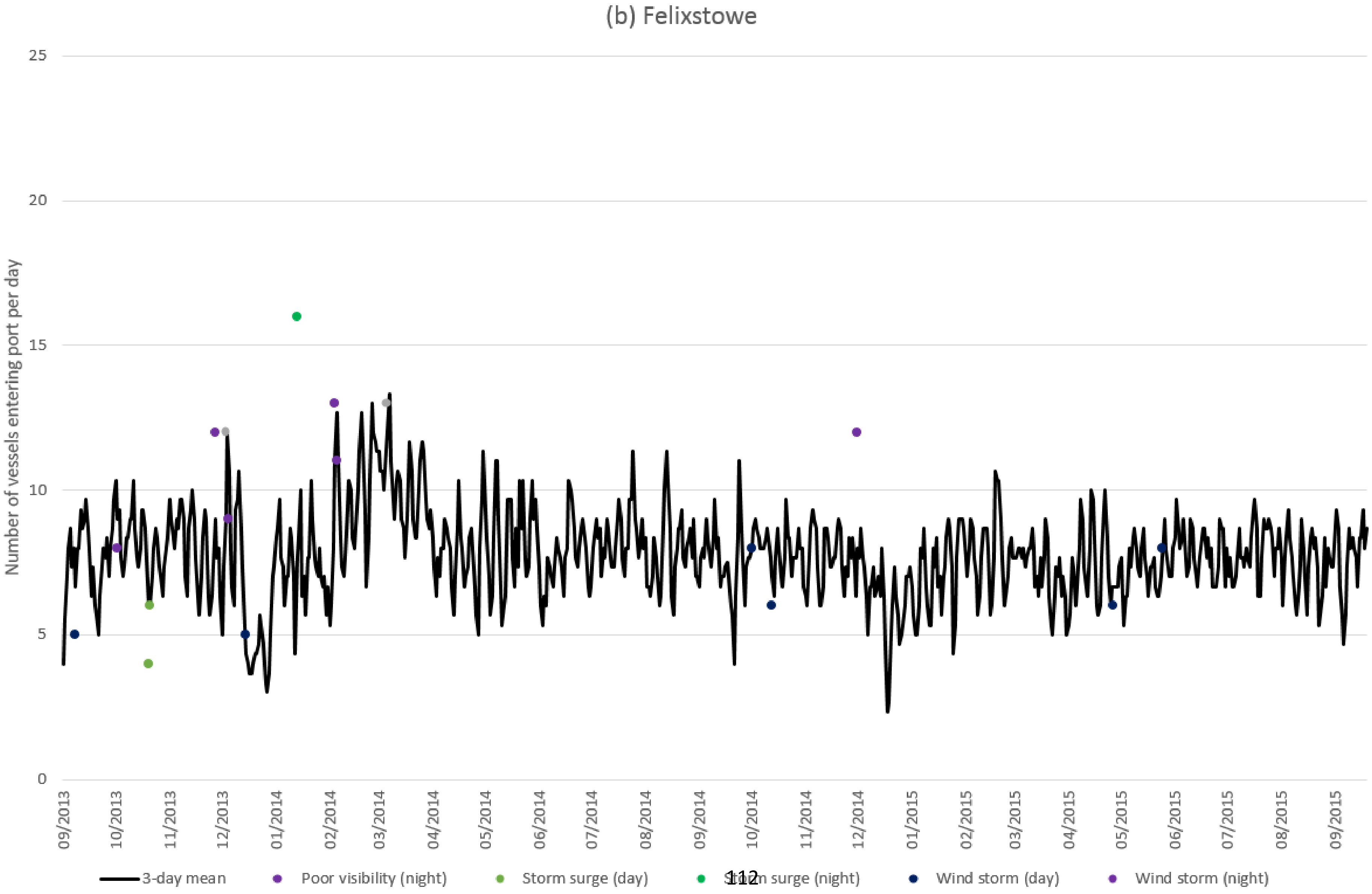
Vessel activity was most commonly affected by wind storms. The longest duration of disruption during the study arising from wind storms was identified in December 2013 where seven distinct events were recorded over a period of ten days. Five of these events occurred during the day and resulted in the lowest level of vessel activity recorded at the port during the study (Figure 4.5 (a) point (i)). Disruptions arising from this series of events continued to negatively affect the port's operations for three days after the dissipation of the final disruptive event of the sequence. This arose due to the repeated strain that the extreme events had placed on the port's safe operations, and occurred over the same period as a forecasted slowdown in vessel activity due to Christmas.

Non-weather events were also identified as affecting port operations at Dover during the study period. All identified non-weather events (in the form of industrial action) occurred during the day, as they were designed to intentionally cause maximum disruption. Despite non-weather events occurring less frequently than weather events substantial impacts on vessel operations were recorded over long time-scales and directly affected vessels and operations at multiple ports. Recovery from non-weather events was often complicated due to vessels being located in the wrong place and back-ups in the amount of cargo and passengers to be transported.

Four specific types of industrial action events were identified:



(a) Dover
Number of vessels entering port per day
60
50
40
30
20
10
0
09/2013
10/2013
11/2013
12/2013
01/2014
02/2014
03/2014
04/2014
05/2014
06/2014
07/2014
08/2014
09/2014
10/2014
11/2014
12/2014
01/2015
02/2015
03/2015
04/2015
05/2015
06/2015
07/2015
08/2015
09/2015
(i)
(ii)
3-day mean
Non-weather (day)
Storm surge (night)
Wind storm (day)
Wind storm (night)


(b) Felixstowe
Number of vessels entering port per day
25
20
15
10
5
0
09/2013
10/2013
11/2013
12/2013
01/2014
02/2014
03/2014
04/2014
05/2014
06/2014
07/2014
08/2014
09/2014
10/2014
11/2014
12/2014
01/2015
02/2015
03/2015
04/2015
05/2015
06/2015
07/2015
08/2015
09/2015
3-day mean
Poor visibility (night)
Storm surge (day)
Storm surge (night)
Wind storm (day)
Wind storm (night)

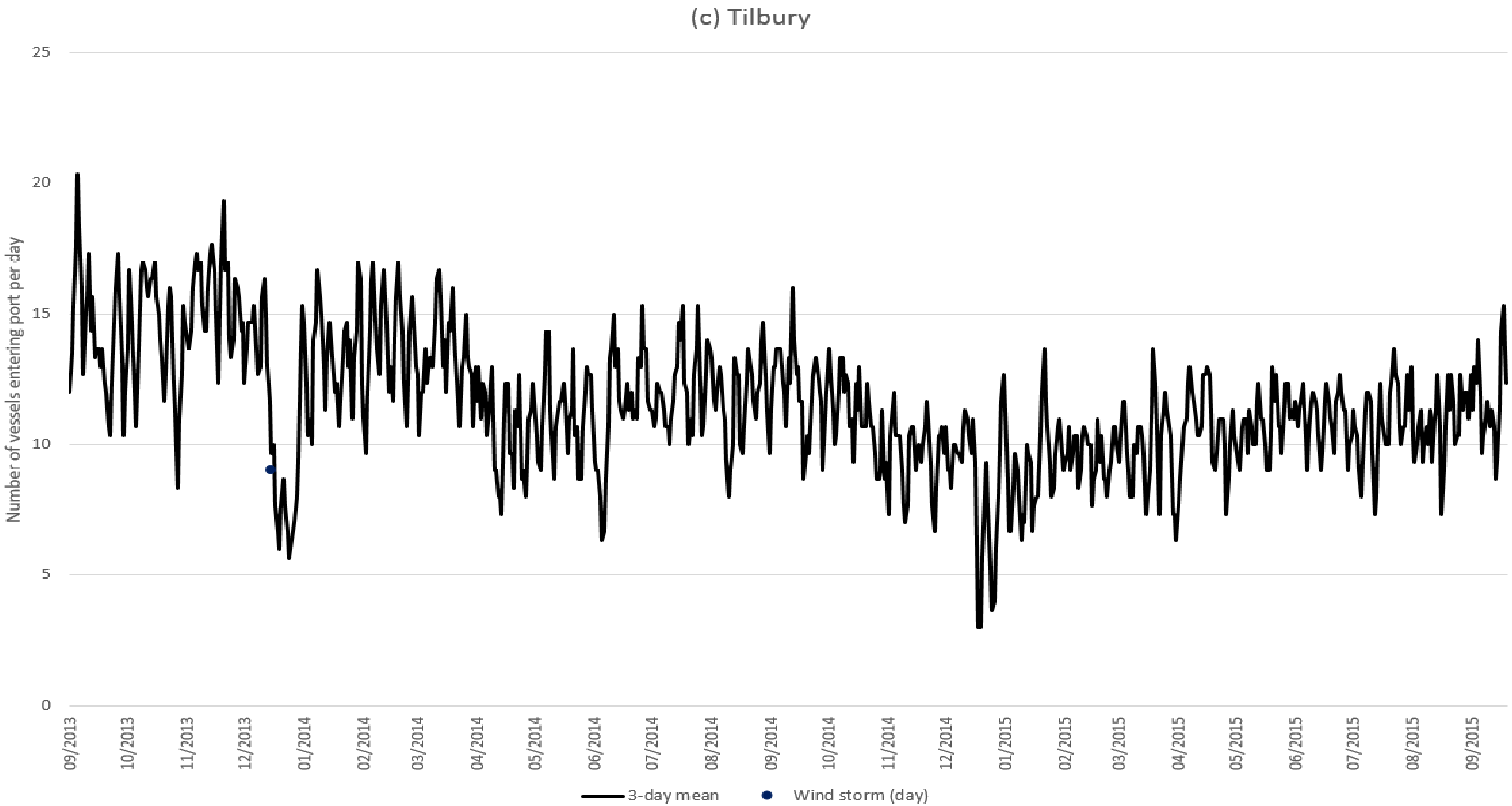


Figure 4.5: Mean number of vessels entering port (over a 3-day period) compared with vessels entering port on days of recorded disruption (a) Dover, (b) Felixstowe, (c) Tilbury. Dates of recorded extreme events are marked by a circle.

- Industrial action (in general) – MyFerryLink ferries not operating due to an industrial dispute. Delays at Dover port as passengers attempt to use an alternative ferry provider or the Eurotunnel (train service that runs in an undersea tunnel connecting the south coast of England and north coast of France).
- Blocking port – Staff operating MyFerryLink ferries positioned the company's vessels at the mouth of Calais port to prevent the entry or exit of other vessels to the port. Dover-Calais ferries were rerouted to an alternative port (Dunkirk) to reduce delays to services.
- Wilful damage – Staff employed by MyFerryLink took control of the two vessels operated by the ferry company following a dispute regarding jobs, and caused an estimated £2 million pounds of damage to the vessels (World Maritime News, 2015a).
- Company out of business – Eurotunnel's lease to operate cross-channel ferries expired at midnight on the 1st July 2015, transferring the lease to ferry company DFDS who were already operating vessels on the Dover-Calais ferry route. Following wilful damage to the vessels this transfer was delayed, reducing the number of vessels operating on the Dover-Calais route.

The extent of impacts from non-weather events depended on the type of disruption. Less severe impacts were associated with industrial action occurring on the dockside, or a destination port being temporarily closed. More severe events, which had longer durations of impacts, were associated with port blockages and vessels out of operation.

In 2015, 32 days were disrupted by four non-weather events in the form of industrial action. Between the end of June and August 2015 Dover port experienced disruptions arising from two industrial action events which had long-term impacts for the port and its operations (Figure 4.5 (a) point (ii)). These disruptions were associated with unrest within employees of the former French ferry company MyFerryLink. Recovery in vessel activity from late-July 2015 occurred due to other ferry companies that operate on the same route implementing additional vessels and services.

At Dover 97% of vessels that serviced the port during the study were ferries. A seasonal cycle, represented by a decline in the winter months, was present in the time-series of vessel activity, representing an annual cycle in demand for passenger services. Through the two-year study an increase in mean vessel activity was identified. This arose due to additional vessels being brought onto the Dover to Calais passenger vessel route to match increased public demand.

4.5.2 Felixstowe

Three extreme event types affected Felixstowe during the study: poor visibility, storm surge and wind storms (Figure 4.5 (b)). Poor visibility events occurred either at night or in the early morning and were not associated with a change in vessel activity. Two thirds of identified wind storm events affected the port at night, and were not associated with any identifiable reduction in vessel activity.

Not all identified non-weather events affected vessel operations. For example, in February 2014 at Felixstowe port a terminal was temporarily closed to export traffic due to operational issues with a docked vessel. More seriously, in August 2015 a concrete pumping machine developed a fault at Felixstowe port, resulting in the death of a site worker. Neither of these events were identifiable in vessel activity, as they reflected circumstances which primarily affected landward operations and were localised in nature.

Throughout the study mean vessel activity remained stable apart from slight dips around Christmas. A temporary increase in vessel activity occurred from March to April 2014 following the abnormally stormy winter. This temporary change was associated with short-term transfers from other ports who had experienced more severe operational disruptions.

4.5.3 Tilbury

A single extreme event was recorded as affecting the port's operations (Figure 4.5 (c)). The timing of this event (23rd of December) and a decline in port operations over Christmas resulted in vessel activity not returning to previous levels until January.

Over the two-year study vessel activity within the port declined from an average of 17 ports per day in September 2013 to 11 ports per day by September 2015. This change was attributed to the opening of London Gateway port, which is located only nine miles away. In 2014 12 vessels that used Tilbury as its UK home port, and therefore visited the port regularly, transferred their contracts to London Gateway.

4.6 Port responses to extreme events

Ports were found to respond to extreme events in two distinct forms: coping mechanisms and adaptation measures (Table 4.5). Coping mechanisms can be defined as a short-term or knee-jerk

Table 4.5: Coping mechanisms and adaptation measures implemented in response to identified extreme events during the study

	Port responses to disruptions	**Port**		
		Dover	**Felixstowe**	**Tilbury**
Coping mechanisms	Use of a “catch-up” service	✓	✓	X
	Use of a different port for connections	✓	✓	✓
	Vessels not allowed to enter or exit a port	✓	✓	✓
	Use extra vessels from other companies (ferry only)	✓	X	X
Adaptation measures	Use of backup generators	✓	X	X
	Equipment moved to sheltered locations	✓	✓	✓
	Use of additional storage zones for cargo	✓	X	X

response, where actions are taken to directly counter a negative circumstance, in this case an extreme event. In such situations the same response is implemented multiple times to respond to similar pressures or challenges. Adaptations, in contrast are decisions taken to reduce potential risk, are maintained and have longer-term benefits.

The range of identified coping mechanisms and adaptation measures were commonly implemented by multiple study ports. These responses were often generic in nature, allowing their implementation in response to a range of challenges or pressures. Often ports were found to be putting in place multiple measures in response to a single extreme event. For example, in 2013 when responding to a wind storm event Dover port combined two adaptation measures (sheltering equipment in specially designed locations and utilising additional identified cargo storage zones) and two coping mechanisms ("catch-up" service and vessels not allowed to enter the port) to reduce the impacts of the event on the port and its operations.

4.7 Discussion

4.7.1 The impacts of extreme events identified by the proxy method

Prior to this research the impact of severe singular events had been considered of importance, but cumulative minor events had not been analysed in detail. During this study port disruptions caused by these two event types were found to be of equal importance in terms of the duration of impacts on port operations and vessel activity. The impacts, and pressures, on port operations from these two event types were distinctly different, even when caused by the same type of event. Frequent nuisance events have the potential, over time, to have a greater cumulative cost than rarer severe events (Moftakhari et al., 2017).

A key finding of this research has been highlighting the interaction of multiple factors (both extreme events and business challenges – see Section 4.7.2) affecting port operations, and the challenges that ports face on a range of time-scales. Not all identified extreme events had identifiable impacts on port operations. This arose from two reasons:

- Event timing - Disruptions arising from extreme events that occurred overnight were not associated with changes to vessel behaviour. Although ports function 24 hours a day many ports, particularly those that primarily operate passengers services, have a peak in vessel activity during the day (P&O Ferries, 2015). Coping strategies, such as catch-up behaviours, are implemented to reduce the extent of disruption experienced before the port’s activities peak during the following day. Ports need to include preparedness for extreme events (particularly weather types) in their daily operations (Wright, 2013).

- Resilience and operational safety: Dover port was affected by the most extreme events (both weather and non-weather) during the study. Disruptions to operations at Dover port occurred most frequently, and port operators responded by implementing temporary port closures to reduce the risks to vessel passengers. Differences in the number of disruptions experienced per port reflects their extent of resilience to specific extreme event pressures.

Many of the identified extreme events that had impacts on vessel activity were pre-emptive closures or pauses in port operation. During extreme weather events ports implement weather policies (Thorsen, 2014a) to reduce the likelihood of damage or injury occurring (Adam et al., 2016). It is expected that some pre-emptive closures were unnecessary, particularly in situations where ports reopened for operations earlier than forecasted, and that damage or disruption would not have occurred if normal operations had continued within the port. However, port operators need to weigh up the financial costs of pausing a port’s operations for a few hours compared to the costs, and risks, to vessels, cargo and people (whether staff or passengers).

The relationship between extreme events and vessel activity differed between vessel types, and therefore the cargo or service they carry out. For example, Dover port closes if wind speeds exceed 28.3m/s (55 knots) (Port of Dover, 2015). As passenger vessels primarily transport members of the public, stricter health and safety measures are in place to ensure passenger safety. Passenger ships or cargo vessels transporting unpackaged goods, such as dry foodstuffs, were also identified as being particularly vulnerable to disruptions. Effects of extreme weather events on the operation of these vessels were associated with delays to the loading or unloading of cargo or passengers, which are more vulnerable to injury, damage or degradation from water or stormy conditions (Chhetri et al., 2016). In contrast, vessels carrying packaged goods, such as RoRo and LoLo were identified as being most resilient to disruptive conditions arising from extreme events. Published literature on ports and extreme events has not yet considered how extreme events affects ports with different operational types differently. With climate change, this need to consider ports on an individual, rather than sectoral, perspective will become more pressing (see Section 6.5).

4.7.2 Other factors affecting port operations

Port operations and vessel activity are affected by a wide range of variables and feedbacks, in addition to disruptions arising from extreme events (including seasonality, interaction between ports and complex business challenges). The interaction of these variables makes it difficult to resolve out the many signals present within port vessel activity data.

A changing demand cycle for services and goods was particularly apparent for Dover port, where a strong seasonal variation in vessel activity was identified. Reduced ferry operations at the port occur in the winter months, as the ferry companies offer a less frequent service.

Ports are also affected by knock-on effects due to disruptions occurring at other ports. This became particularly apparent for Dover port, whose primary destination port is Calais in France. Any disruption to operations at Calais, or to the vessels that service the Dover-Calais sailing route, had tangible impacts for the operations and functionality of Dover port.

In addition to extreme weather and non-weather events the study ports experienced frequent business challenges including shifts in shipping contracts between UK port (DP World, 2014). This was particularly apparent at Tilbury port (Figure 5.4 (c)) where a decline in the number of vessels entering the port per day, from 17 in September 2013 to 11 in September 2015 was associated with a loss of regularly visiting vessels to London Gateway port. The shipping industry is highly mobile and shifts in vessel contracts between ports is fairly common in an ever changing financial and supply/demand led environment. The timing of vessel shifts identified during the study, occurred following public service announcements by a newly opened deep-water port London Gateway, which began operations in November 2013, describing its purported resilience against “bad weather conditions” (DP World, 2013, 2014).

Signals from extreme events, seasonality and business challenges can be identified within the time-series of vessel activity. The average sizes of container vessels servicing ports, and the quantity of cargo they can carry, is increasing (Kidson et al., 2015). A number of ports are forecasting that the number of vessels entering port will decline, whilst the quantity of cargo on these vessels will increase. Vessel activity data would be a useful resource to identify this potential change over a range of timescales from the short to the longer-scale.

4.7.3 Port responses to extreme events and future challenges

Ports implement a number of coping mechanisms and adaptation measures in response to the impacts of extreme events. For example, port decision-makers implement weather policies (Thorsen, 2014a), such as where port operations are paused due to extreme weather events, to reduce the risk of damage or injury from occurring. Many of these responses are generic and were implemented to reduce the impacts from a range of types. The most common form of response was the development of coping mechanisms, but ports are beginning to put in place more adaptations to extreme weather. Adaptation measures tended to be developed and implemented after a port experienced severe disruption, or damage, due to extreme events (see Section 3.7).

More extreme events affected vessel activity within ports than those reported in the media (see Appendix D and compare with Figure 4.4). The study ports were found to be able to contend with the current normal range of extreme event types and severities, even during dense periods of abnormally stormy conditions (such as winter 2013/14).

Some extreme event types are predicted to become more frequent or severe with climate change (Jenkins et al., 2009), whilst with sea-level rise and rising mean temperatures new risks facing port operations may emerge. For example, combinations of event types, such as storm surge and intense rainfall, have been identified as a point of increased risk (Wahl et al., 2015), particularly if sea-level rise is taken into consideration. It is critical for the UK port sector to consider its adaptation needs in terms of climate change (see Chapter 5), as potential changes in extreme event impact frequencies and severities are expected to make coping mechanisms an inadequate response to prevent damage or extended periods of disruption.

4.7.4 Successes and limitations of the proxy method

Following the study of two years of vessel activity data for four case-study ports a number of successes and limitations of the proxy method were identified.

A number of important successes of the proxy method and analysis:

- Vessel activity data is effective at identifying disruptions to port operations at passenger ports and cargo ports that move unpackaged goods. For example, identified periods of disruption at Dover port agree well with announcements of extreme events.
- The method was able to identify three types of event: powerful singular, clustered minor and singular minor extreme events.

- Extreme events caused by both weather and non-weather events and the differences in impacts between types were identified. Non-weather events were best resolved within the time-series due to their longer duration.
- The timing, and duration, of extreme events was found to be important. Daytime events were identified as having identifiable impacts on vessel activity, whereas night-time events had little impacts due to reduced port operations and the ability of decision-makers to recover operations before peak daytime port functionality.
- The responses of ports to extreme events were found to be in the form of a combination of coping mechanisms and adaptation measures.
- This analysis has highlighted the complexity of disruptions to vessel activity and port operations. The extent of vulnerability to extreme event pressures differs between vessel types. For example, passenger vessels are most vulnerable to disruption or delay due to extreme weather types.
- A wide range of issues other than extreme events that affect vessel activity within ports were highlighted within the study, including business competition and seasonality.

Despite a number of successes of the method used, three limitations were identified. To improve the proxy method the following limitations need to be resolved:

- Vessel activity data does not effectively identify disruptions to cargo ports that move packaged goods. This is due to vessels, and infrastructure, that move packaged goods are less vulnerable than unpacked goods or passengers to extreme weather events (such as wind storms and storm surges).
- Vessel activity data highlights periods of disruption to port operations, but is unable to resolve the cause, or causes, of impacts on vessel activity.
- The two-year dataset was too short, a decade or more of data would have provided a more comprehensive perspective. A longer time-series would be beneficial in distinguishing between the multiple signals present within the time-series.

4.8 Key findings

The main findings are:

1. Vessel activity data was identified as a useful proxy for port disruptions arising from both extreme weather and non-weather events, but is unable to unpick the specific impacts of an event type. Both severe individual and cumulative minor events were found to cause

severe disruptive impacts for ports and their operations. Prior to this study cumulative minor events had not previously been considered as an important issue for port operations and vessel activity.

2. The timing of the occurrence of extreme events is an important factor in determining its severity. During this study the impacts of daytime events on vessel activity was greater, whereas events that occurred at night were found to have no impact on vessel activity. The number of vessels entering port at night, particularly passenger vessels, tends to be lower at night. For extreme events that affect a port at night decision-makers are able to implement coping mechanisms to reduce the severity, or duration, of extreme event impacts before the demand for port operations increased during the following day.
3. The exposure of ports to extreme events differed between port operations. Passenger operations experience the greatest overall exposure to extreme events, as vessel operators and port decision-makers must take action to safeguard the passengers they transport. Dockside movements of unpackaged cargo also had a high exposure to extreme events as they could not be safely transported in such conditions (such as during storm surges or wind storms).
4. The three study ports are well prepared for the current range of extreme event severities that affect their operations. Ports have developed a number of general coping mechanisms which are employed to reduce the severity and duration of extreme events. However, no “extreme” extreme events were recorded as affecting the ports during the study, and consequently how ports respond to particularly severe events was not identified.
5. This research has been an important first step in assessing the complexity of vessel activity and port disruptions, but there is still much further research needed to refine the proxy method. The next chapter assesses the climate change preparedness of the UK port sector.

Chapter 5: Assessment of the UK port sector's preparedness for climate change

5.1 Introduction

The busiest ports in England and Wales (those that move in excess of 10 million tonnes of cargo per annum – Table 5.1) were directed by the government to produce Adaptation Reports to improve governmental awareness of current weather and future climate change risks faced by the port sector. The Department for Transport classes the UK port sector as having 162 commercial ports comprising 53 major and 109 minor ports (Department for Transport, 2016a) (see Figure 1.1). The nine ports, or port clusters, located in England and Wales used by the government to assess climate change preparedness only represents 5%, or 13, of UK commercial ports. Presently the UK government considers the port sector to be making good progress in adapting to the risks of climate change (Department for Transport, 2014a). This left the majority of the UK port sector as unassessed by government organisations for climate change.

To better understand the level of adaptation preparedness of the UK port sector, a questionnaire was developed to assess how ready ports are for the challenges of extreme weather and climate change for their operations. Out of the 162 commercial UK ports (Department for Transport, 2016a) 17 "ports" were in fact closed, not a port, or not a commercial port. Over time new ports (such as London Gateway) have been more readily added to the Department for Transport database than inactive ports removed.

The research aims to assess climate change preparedness of the UK commercial port sector via an analysis of published Adaptation Reports and a questionnaire on climate change preparedness (Figure 5.1).

The chapter, and objectives, are divided into three sections:

a) The Adaptation Reports:
   1. To identify the extreme weather and climate change risks of most concern,
   2. To analyse the types and purposes of proposed and implemented adaptations,
   3. To highlight strengths and weaknesses and options for improvement in the scope and nature of the Adaptation Reports.

b) A questionnaire for the entire UK commercial port sector:

Table 5.1: Ports, as determined by Department for Transport data, who were contacted to participate as Reporting Authorities by submitting at least one Adaptation Report.

Reporting Authority	**Submitted Adaptation Reports**		**Who prepared the Adaptation Report(s)**		
	Round 1 (2010-2011)	**Round 2 (2015-2016)**	**In-house**	**Jan Brooke Environmental Consultant Ltd.**	**Royal Haskoning**
ABP (Hull, Goole, Grimsby, Immingham, Southampton)	✓	✓	✓		
Dover	✓	✓	✓		
Felixstowe	✓	✓	✓		
Harwich Haven	✓	X		✓	
Liverpool	✓	X			✓
London (Port of London Authority)	✓	✓	✓	✓	
Medway (Sheerness, Chatham)	✓	X			✓
Milford Haven	✓	✓	✓	✓	
Tees/Hartlepool	✓	✓			✓

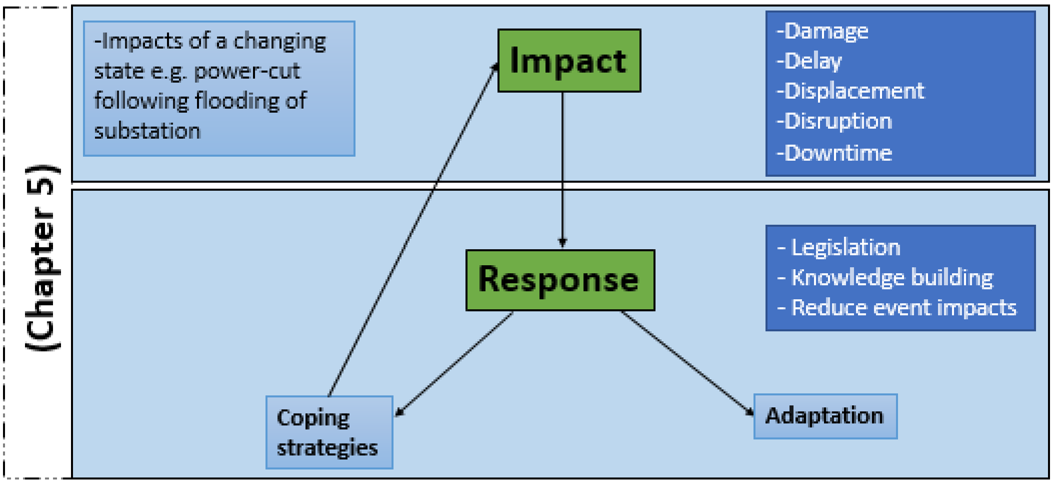


Figure 5.1: Framework of the research reported in Chapter 5

4. To assess the willingness and ability of UK ports to discuss risks associated with climate change and present-day extreme weather events,
5. To identify whether factors such as port managing body or geographical location, influence a port's climate change readiness,
6. To consider the current level of climate change adaptation taking place in the UK port sector.

c) Climate change readiness varies within the port sector:

7. To assess what guidance UK ports require for effective adaptation decisions.

5.2 Adaptation Reports and the UK's busiest ports

5.2.1 Data and methods of study

5.2.1.1 Data

In 2008 the Climate Change Act (CCA) entered into force, and was designed to provide a target reduction level for greenhouse gas emissions through mitigation, while incentivising authorities to take pre-emptive action against the predicted impacts of climate change through adaptation (see Section 2.5.3).

"Reporting authorities" were identified as nationally important organisations in the water, energy and transport sectors, among others (DEFRA, 2014b). Nine ports or port clusters in England and Wales met this criteria (Department for Transport, 2015) (Figure 5.2 and Table 5.2)) and were required to submit Adaptation Reports, which are analysed in Sections 5.2.2-5.2.6..

5.2.1.2 Methodology

Adaptation Reports produced by UK ports in 2011 and 2015 were analysed and compared to determine how well the adaptation preparedness of the UK's busiest ports is being assessed (Table 5.3). This analysis was also designed to determine whether the UK Government's perspective that the port sector is well prepared for climate change is accurate. The Reports were assessed to identify a number of important issues:

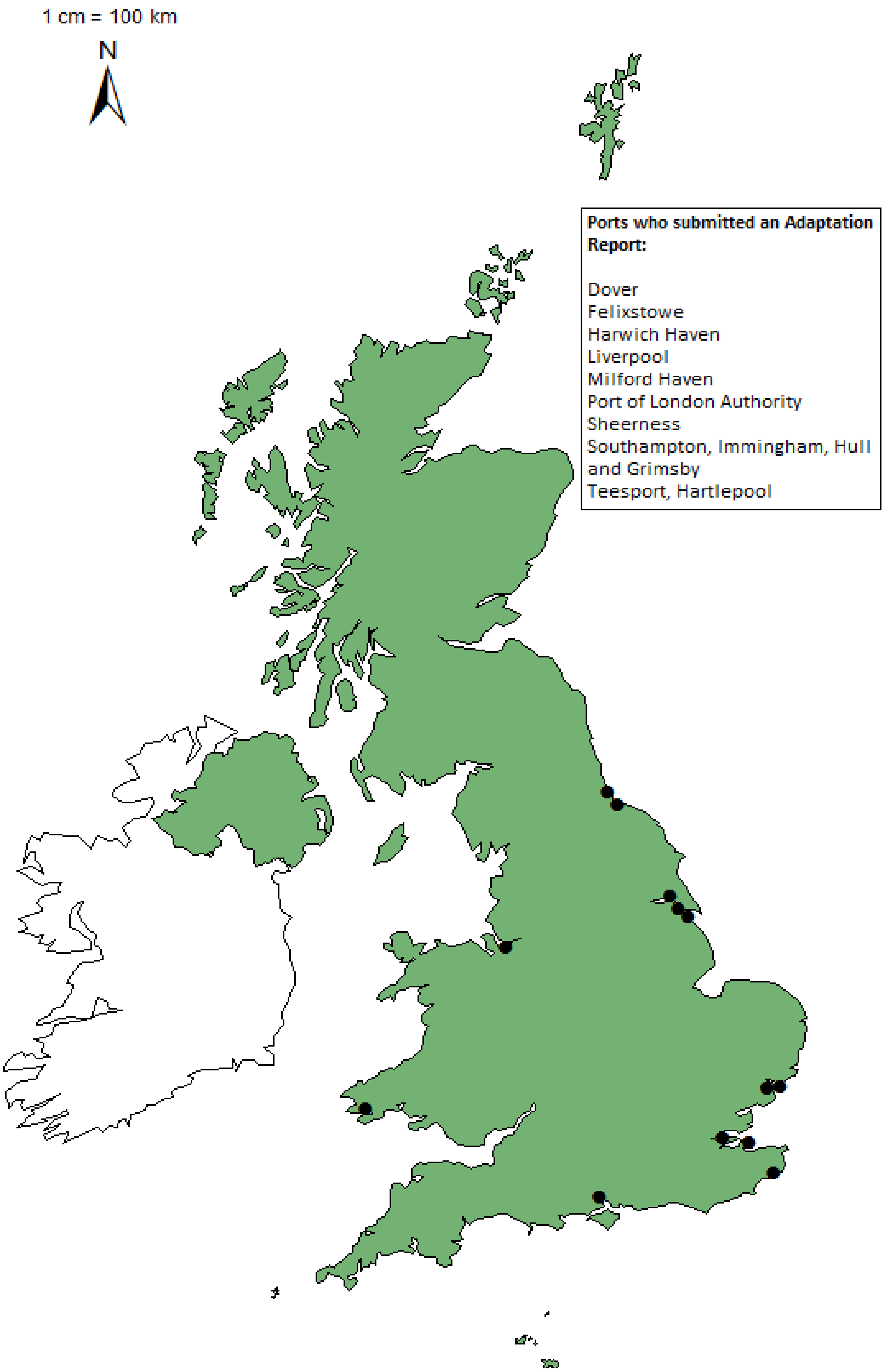


Figure 5.2: Ports in England and Wales who qualify as "reporting authorities", and submitted an Adaptation Report (in 2011) to the Secretary of State for the Department of Energy and Climate Change.

Table 5.2: Ports that move in excess of 10 million tonnes of cargo per annum, and their response to the Adaptation Report direction.

"Ports" moving in excess of 10 million tonnes of cargo per annum (Department for Transport, 2016a)	**Participated in the first round of Adaptation Reports**	**Participated in the voluntary second round of Adaptation Reports**
ABP (Hull, Goole, Grimsby, Immingham, Southampton)	✓	✓
Belfast	X	X
Clyde (Glasgow, Greenock, Hunterston)	X	X
Dover	✓	✓
Felixstowe	✓	✓
Forth (Tilbury, Burntisland, Dundee, Grangemouth, Kirkcaldy, Leith, Methil, Rosyth)	X	X
Harwich Haven	✓	X
Liverpool	✓	X
London (Port of London Authority)	✓	✓
Medway (Sheerness, Chatham)	✓	X
Milford Haven	✓	✓
Sullom Voe	X	X
Tees/Hartlepool	✓	✓

Table 5.3: Data extracted from the Adaptation Reports and the importance of each factor for determining how well the adaptation preparedness of the UK's busiest ports is assessed.

Data extracted from the Adaptation Reports	**The importance of each factor for the analysis**
Persons or companies who produced the Adaptation Reports	The level of experience and perspectives on climate change and extreme weather differs between ports
Number of Adaptation Reports produced per port	Gives an indication of how willing, or able, a port is to assess and implement adaptations
The official port perspectives on climate change and adaptation	Highlights the level of knowledge, and perspectives on, climate change.
The timescale over which climate change is perceived as an issue or challenge for port operations	
Identified extreme weather and climate change risks	The range of risks perceived as a challenge to port operations , and how this differs between ports
Climate change risks perceived as most severe	
Extreme event and climate change causes most commonly adapted to	Highlights the challenges currently experienced by ports, and climate change planning and awareness
Proposed adaptation measures	
Adaptation measures completed or underway	Progress being made by the UK's busiest ports for climate change preparedness
Motivations for proposed or implemented adaptations	Identifies whether ports are correctly attributing the motivations of improvements or enhancements to port infrastructure

- To identify the extreme weather and climate change risks of most concern for the "reporting authorities",
- To analyse the types and purposes of proposed, and underway, adaptations,
- To highlight weaknesses and options for improvement in the scope and nature of the Adaptation Reports.

5.2.2 Eligible reporting authorities

Ports who produced Adaptation Reports were eligible "reporting authorities" instructed by the Adaptation Reporting Power (see Section 2.5.3). Ports assessed within the Adaptation Reports move 89% of container traffic that passes into UK ports, and 85% of export container traffic.

The direction given to ports regarding production of Adaptation reports detailed two key topics:

1. An assessment of present-day and future climate change impacts on port operation (including the port's functions, information detailing how impacts were assessed, and the predicted impacts for their operations),
2. A summary of how and when the port will take measures to adapt (DEFRA, 2010a).

No template or additional guidance was given regarding the level of detail that should be included within the reports, which led to differences in the length, content and assessment quality of the Adaptation Reports.

The preparation of Adaptation Reports fell into three categories:

- In-house prepared reports,
- In-house reports supported by guidance from a consultancy firm,
- Reports prepared and written by a consultancy firm on behalf of the port.

In-house produced Adaptation Reports were diverse both in structure and content, reflecting in part the knowledge and perspectives of each port on the topics of climate change, extreme weather and the need for adaptation. Two consultancy firms were engaged to assist with the adaptation reporting process for five ports (Table 5.1). The involvement of these firms in multiple Adaptation Reports resulted in similarities in structure, data sources (Table 5.4) and content of reports between ports, as a common template was used.

Reports produced by two port authorities covered multiple ports: Hartlepool and Teesport, and Grimsby, Hull, Immingham and Southampton. This was found to occur due to two reasons:

Table 5.4: The report types of the Adaptation Reports and the data sources used to inform adaptation reports. UKCP09 data and Environment Agency flood risk data were recommended data sources, but additional data choices were independent decisions.

Port	Report type		Data sources									
	Bottom-up	Top-down	UKCP09 model projections	UKCP09 additional data and tools	Environment Agency flood risk maps	Local staff knowledge and records	MCCIP annual report cards	Government risk assessment reports	UK Business Areas Climate Impacts Assessment Tool	IPCC AR4	Local region climate change studies	Shoreline Management Plans
ABP (Goole, Grimsby, Hull, Immingham, Southampton)	✓		✓		✓	✓	✓	✓			✓	
Dover	✓		✓	✓								
Felixstowe	✓		✓	✓	✓	✓	✓	✓				
Harwich Haven	✓		✓				✓					
Mersey Docks (Liverpool)		✓	✓	✓		✓			✓	✓		
Milford Haven	✓		✓									
Port of London Authority (PLA)	✓		✓	✓	✓	✓	✓					
Sheerness		✓	✓					✓		✓		✓
Tees and Hartlepool		✓	✓	✓		✓		✓	✓	✓	✓	✓

- Either that the ports were geographically located closely together, and were perceived as operating at least partially in conjunction, or
- Multiple ports managed by a single port authority move in excess of 10 million tonnes of cargo per annum.

5.2.3 Identified climate change and extreme weather risks

Within the produced Adaptation Reports, ports identified and considered the causes and risks associated with climate change and extreme events which have the potential to impact their operations. Across the Adaptation Reports seven types of event were identified by UK ports as of importance, and differs from the classifications of extreme event types used in the remainder of this thesis. Therefore, to ensure consistency with the original Adaptation Report sources, within Section 5.2 the following event types will be described:

- High winds (instead of wind storms),
- High temperatures (both in terms of mean temperatures and heatwaves),
- Flooding and increased rainfall (where flooding is considered as a separate event type to storm surges),
- Storm surge,
- Sea-level rise,
- Snow and ice,
- Poor visibility,

Storm surge and sea-level rise are both risks associated with extreme sea levels, although they operate on very different time-scales. Reports that were produced by consultancies, combined these two types and considered them as a single issue. This is a key example of highlighting differences in understanding and perspective between those working in port and scientific roles.

Ports detailed whether they felt the identified event types would become more or less of an issue for their operations in future decades, by referring to UKCP09 climate projections. All reports highlighted: high winds (some ports classed this as gusts, and others as mean wind speed), rising temperatures, increased flooding and rainfall, more frequent or severe storm surges and a range of issues associated with sea-level rise (Table 5.5) as causes of particular concern. Differences in opinion were identified for snow and ice and poor visibility. Adaptation Reports produced by consultancy firms were most likely to state that they could not comment on the issues of visibility or snow due to low confidence in model data from UKCP09.

Table 5.5: Changes to event occurrences recorded in the Adaptation Report and their agreement with UKCP09 data Changes in risk expected from different types associated with climate change. Red = event types for which impacts are expected to become more severe or common, Green = no expected change, Blue = severity or frequency expected to decrease, Grey = lack of information on trends.

Event type	**Port**									**Scientific evidence from UKCP09 reports**	
	ABP	**Dover**	**Felixstowe**	**Harwich Haven**	**Liverpool**	**Milford Haven**	**PLA**	**Sheerness**	**Tees/Hartlepool**	**Change in risk (UKCP09)**	
Flooding and rainfall	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Little change in the amount of UK rainfall is expected. However winter precipitation will increase by up to 33%, and reduce in summer by up to 40%. *Higher intensity rainfall events can increase the risk of damage to cargo, drainage problems and flooding.*
High temperatures	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Mean temperatures will increase (summer - 1-9.5°C and winter 0.7-4.4°C) months. *Increasing temperatures can affect cargo, equipment and working conditions.*
High winds	Red	Red	Red	Red	Red	Red	Red	Red	Red	Green	Changes to wind speed are negligible (0 to -0.2m/s), and future storm track positions are uncertain. *Data do not suggest that wind speeds will become a greater issue for UK ports.*
Poor visibility	Green	Red	Green	Red	Green	Blue	Blue	Green	Green	Green	The occurrence of fog is expected to decline in the spring, summer and autumn months. In winter a decline is expected in most locations, with increases in London, south-east, south-west and eastern England. The uncertainty in these results are large. *Fog is not a*

											major issue for port operations due to the short-lived nature of the events.
Sea-level rise											Sea-levels are rising, although the extent of change will be influenced by emissions scenarios. Current UK predictions range from 19-59cm (5th to 95th percentile). *The rate of sea-level rise will be less in the north of the UK due to the effects of isostatic rebound.*
Snow and ice											No UKCP09 projections were released for snow and ice as the ensemble results were highly uncertain. *Snow and ice are not currently a major issue for UK ports. Rising mean temperatures is likely to reduce the incidence of such effects.*

Ports were directed to use UKCP09 as their primary data source to determine whether the impacts of identified causes of risk will change in future decades. However, UKCP09 projections do not always agree with conclusions drawn by ports (Table 5.5). For example, all ports who submitted an Adaptation Report consider high winds to become a greater issue for their operations, however, predictions suggest that changes to wind speed in the next 60 years will be negligible. This suggests that ports are concerned about an event type that is already an issue for their operations, and for which any increases in occurrence or severity would have substantial negative impacts on successful port functionality. Ports also independently inferred how they perceive changes to snow and ice and poor visibility events to affect their port. These two issues were not well resolved in UKCP09 due to large uncertainties in these results, and consequently no results on snow occurrence were included within the UKCP09 projections. The ports most concerned about these event types were those who have a history of experiencing negative impacts, and were therefore voicing concerns about an event type for which any increases in occurrence would be disruptive.

In total 77 distinct potential risks to port operations were identified within the Adaptation Reports (see Appendix H). High winds and flooding and rainfall were the event types associated with the greatest number of specific identified risks (15 each), and were identified most commonly across the Adaptation Reports (Figure 5.3). In contrast only two risks associated with poor visibility were detailed. The event types for which the most risks were identified were also those considered as most severe. Historically, using data from Chapter 3, extreme weather events arising from wind storms or resulting in flooding (whether due to storm surges or rainfall) have tended to have the most frequent impacts on port functionality.

Risks associated with high winds, flooding and rainfall and storm surge were most likely to be identified by multiple ports, whereas risks identified for snow and ice were more commonly individual to a particular port's operations. The most commonly identified risks were:

- High winds affecting pilot transfer, buoy maintenance, monitoring, mooring and dredging,
- Uncomfortably warm working conditions,
- Flooding of port land,
- Heavy rain delays and stoppages (e.g. cargo or vessel movements, pilot transfer, moorings).

Many of the most severe risks identified in the Adaptation Reports are either secondary impacts arising from an event type, or impacts arising from issues beyond the port boundary (such as disrupted utility services or delays on road or rail networks (Table 5.6)). The severity of many of

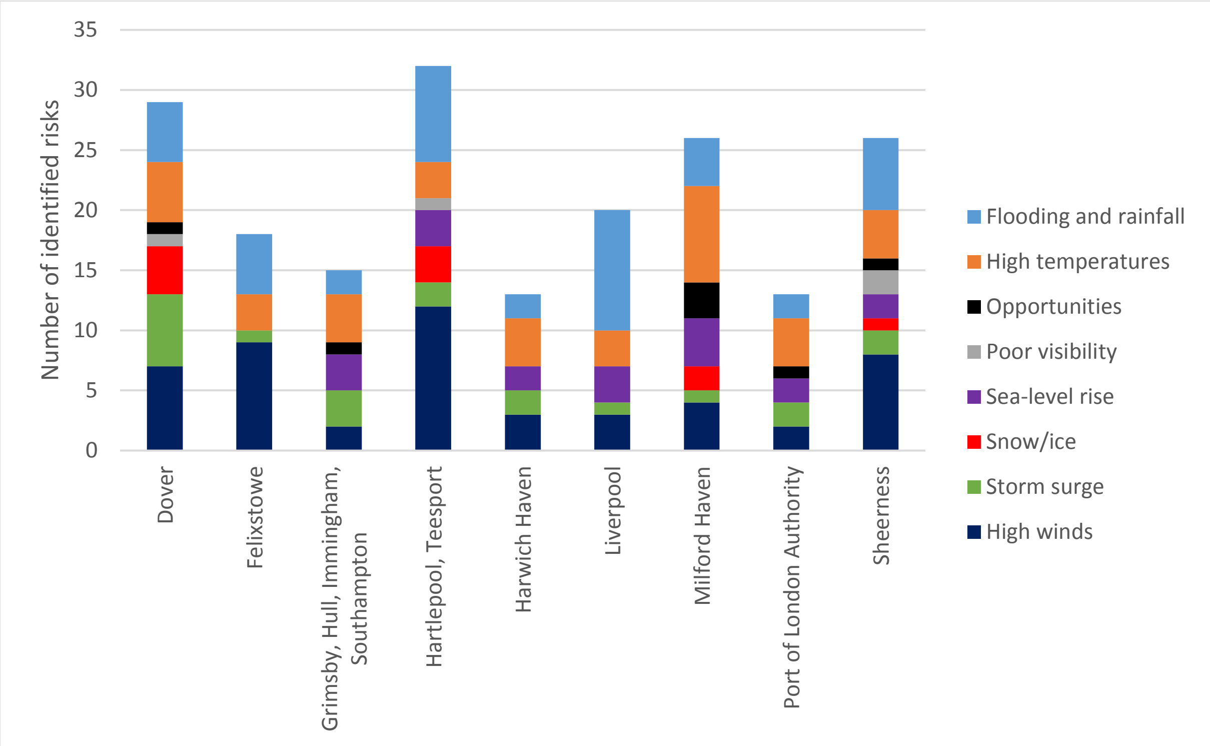


Figure 5.3: The number of climate change risks, and potential opportunities, identified for each port within the 2011 Adaptation Reports. Risks are categorised into seven distinct types, with additional positive challenges posed by opportunities.

Table 5.6: The risks recorded in the Adaptation Reports identified as most the severe or concerning for future safe and efficient port operations

	Risks	**ABP**	**Dover**	**Felixstowe**	**Harwich Haven**	**Liverpool**	**Milford Haven**	**Teesport, Hartlepool**	**Port of London Authority**	**Sheerness**
High winds	Strong winds affecting dockside operations		✓						✓	
	Port temporarily closed	✓	✓	✓			✓			
	Wind delaying vessel operations		✓							
	Wind affecting maintenance operations	✓			✓		✓			
High temperatures	Risks to staff (e.g. water shortages, sunburn)		✓							
	Increased risk from leisure activities				✓					
	Uncomfortably warm working conditions							✓		
	More alien species					✓				
	Increased up-river abstraction								✓	
	Pollution incidents								✓	
Flooding and rainfall	Flooding of port land	✓	✓		✓					
	Inadequate drainage		✓			✓				
	Substation flooded			✓	✓					
	Overtopping of flood gates or sea defences			✓		✓	✓			

	Road/rail flooded									✓
	Delays in the movement of water sensitive goods					✓				
Sea-level rise	Increased risk of flooding						✓	✓		✓
	Reduced clearance between ships and booms								✓	
	Greater variations in water depths and flow extremes								✓	
Snow and ice	Disrupting port operations		✓							
	Closures of other transport routes increasing pressure on port	✓								
Poor visibility	Delayed vessel movements		✓							
	Increased incidence of fog events								✓	
Extreme weather (in general)	Power disruption/loss of power to IT systems	✓		✓	✓		✓	✓		✓
	Travel issues for employees						✓			
	Loss of trade if unable to store goods properly					✓		✓		✓
	Rising insurance premiums							✓		
	Reputation damaged									✓
	Effects on locks and weirs								✓	

these risks are currently intangible, such as damaged reputations, rising insurance premiums and travel issues for port employees. Some identified severe risks are arguably not risks in their own right, including the increased leisure vessel activity and increased incidence of sunburn. The inclusion of intangible and unsubstantiated risks suggests that in some cases ports may potentially be suggesting severe risks for the sake of it. For the identified intangible risks ports are either able to adapt very easily, such as by changing clothing or providing sunscreen to prevent staff getting sunburnt, or by suggesting that adaptations will be required by other organisations beyond the port (such as utilities or transport networks). This suggests two questions – firstly, are ports taking the Adaptation Report directive seriously, and secondly, are ports currently able to identify the real, and potentially important, climate change risks that are facing their operations.

The Adaptation Reports did not adequately consider the importance of historical events and risks. The ports were focused on future and near-future (5-10 years from the present-day) changes to risks. A slight change in this perspective was identified in the second round of reports where five of the six submitted reports detailed the impacts of the abnormally stormy winter of 2013/14 on their port operations. In some cases the storm events increased risk awareness such as at Dover port where the storms “evidenced the potential risks of storm events” (Dover Harbour Board, 2015).

For ports to better understand the climate change risks they face it is vital for each port to fully understand their individual baseline risks and how they have been affected by extreme weather in the past. It would be beneficial for ports to keep a record of how extreme weather, and sea-level rise affects their operations on a year-to-year basis. Such records would aid clear, port-specific assessments, of how event types and associated risks affect a port, and would provide evidence to determine whether adaptation measures are effective or perhaps maladaptive.

The number of potential risks identified by a port was strongly linked to the operations they carry out. Ports who only carry out conservancy and pilotage duties identified the least number of risks. A wider range of event types, and numbers of risks, were identified by ports who have a diverse range of cargo handling operations (Figure 5.3). It is logical that ports with a greater range of operations have more variables which can potentially experience disruption or damage. However, for ports who have less diverse operations disruptions any impacts from extreme events could have widespread consequences.

5.2.4 Proposed port climate change and extreme weather adaptations

Although ports identified eight extreme event types of concern for their operations, only six of these types are currently being adapted against:

- Snow and ice,
- Sea-level rise,
- Flooding and rainfall,
- High temperatures,
- High winds,
- Extreme weather (in general) – refers to adaptations that are designed to reduce risks associated with multiple event types (such as monitoring meteorological conditions).

As of 2015 no adaptations had been proposed to adapt against poor visibility or storm surges. Poor visibility events tend to be associated with disruption rather than damage, and tend to have impacts over a short duration. The short, limited, periods of impact mean that adapting for poor visibility events are a lower priority, as many of its impacts can be reduced by temporary port closure or restrictions on vessel movement. Adaptations to prepare for storm surges, in contrast, most commonly need to occur in the form of hard adaptations, such as the raising of quay heights. Such adaptations are costly and often require long lead-in times, and would need to be carefully planned and considered by coastal engineers and port decision-makers. Currently, port decision-makers are focusing on adaptations which are easier to implement, and are often substantially cheaper to develop and put in place.

A total of 55 distinct potential adaptations to increase port resilience to risks associated with climate change and extreme weather were identified by the Adaptation Reports. The types of adaptations more commonly suggested per port, and the distribution between proposed hard and soft adaptation measures were assessed. In the context of the Adaptation Reports “hard adaptations” refer to changes or improvements to infrastructure, and “soft adaptations” to actions including changing policies and knowledge building. This analysis determined that the number of distinct adaptations actions proposed were almost equally split between hard and soft actions, 22 and 23 measures respectively. Across the Adaptation Reports submitted in 2011, 45 hard adaptations were suggested, and 66 soft adaptations, highlighting that soft adaptation measures were more likely to be suggested by multiple ports. Proposed soft adaptations were also more commonly generic in nature, reflecting changes in behaviour or health and safety policies. In contrast, hard adaptations tended to more often be port-specific, reflecting the individuality of facilities and operations for each port.

Hard adaptations, typically in the form of defences were more commonly suggested for flooding and rainfall and sea-level rise (65% and 63% of proposed adaptations respectively). Whereas adaptations for wind and storm surges and general extreme weather were dominated by soft adaptations (73% and 70% of proposed measures respectively). The differences in distribution between hard and soft adaptation measures reflects, in part, the differences in the nature and impacts between event types (Figure 5.4). For example, a critical way of protecting against storm surges or sea-level rise is to improve the resilience of defences, and to increase the effectiveness of drainage systems. In contrast, to accommodate higher temperatures proposals for soft adaptations were more prevalent, such as reviewing practices or changing behaviour.

The adaptation measures were analysed to determine whether they are motivated purely by protecting the port's operations against climate change, or whether the adaptations had multiple motivations, such as crane upgrades which would have occurred regardless of climate change. High temperature related adaptation measures were most likely motivated exclusively due to climate change, whereas adaptations to snow and ice arose due to multiple motivations (Figure 5.4). Hard adaptation measures were evenly distributed between those motivated by climate change and multiple motivations, whereas soft adaptations were more likely to occur regardless of climate change (63% of proposed adaptation measures). This difference once again highlighted the more generic nature of many soft adaptation measures, and the specific designed form of many hard adaptations. It could be argued, therefore, that it is of greater importance and a better use of resources for ports to focus on developing plans for hard adaptation measures, as many soft adaptation measures would occur naturally (such as changing health and safety regulations) as part of other wider issues that ports are already contending with.

5.2.5 Implemented climate change and extreme weather adaptations

In 2015 Dover, Milford Haven, Teesport, Felixstowe, ABP (Southampton, Immingham, Hull and Grimsby) and Port of London Authority voluntarily submitted updated adaptation reports highlighting whether new, or changed, climate change risks had been identified, and steps the port had taken to begin implementing adaptation measures.

Thirty-five distinct adaptations were, or are being, implemented, with extreme events (in general) (i.e. adaptations that would reduce vulnerability to multiple types) and flooding being the event types most commonly adapted against (Table 5.7). A full list of proposed adaptations and whether they are being implemented can be found in Appendix I. The distribution of hard and soft adaptations underway, or in place, differed dependent on the event type adapted against. For

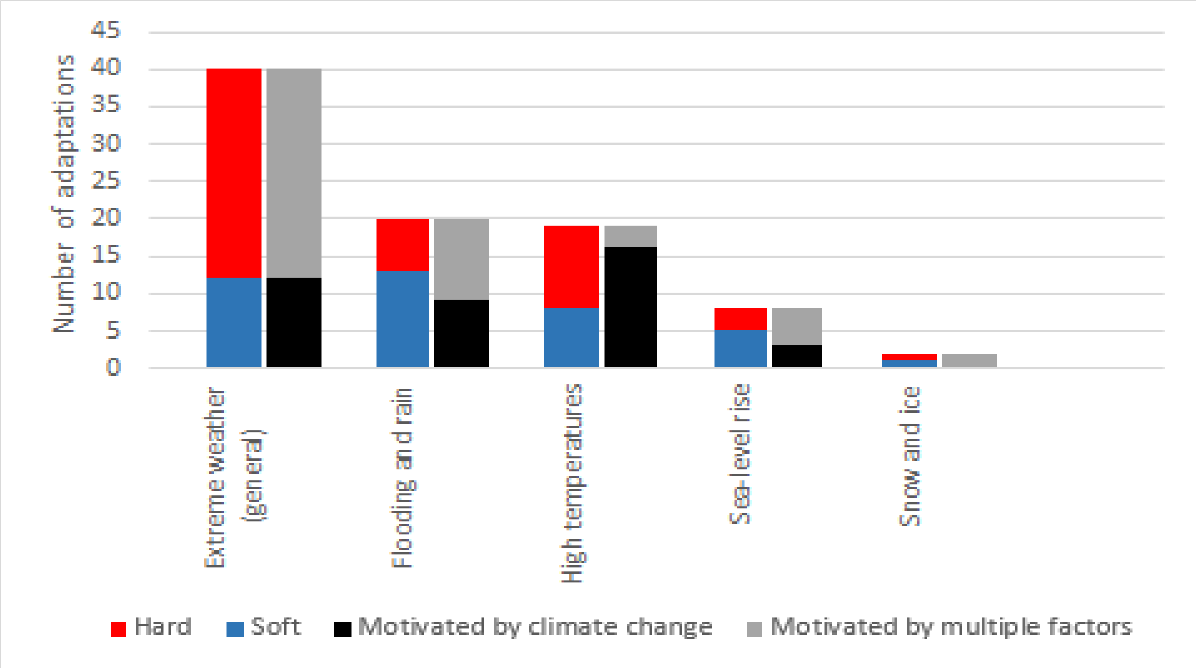


Figure 5.4: The number of proposed hard and soft adaptation measures suggested per event type in the 2011 Adaptation Reports. The second column analyses the motivation behind the adaptation decisions.

Table 5.7: Adaptations actions detailed as completed or underway within the Adaptation Reports between 2011 and 2015. Adaptations are categorised according to their type, and which types they are designed to reduce vulnerability to

Adaptation action	Adaptation type		Event type					
	Hard	Soft	Extreme weather (in general)	Flooding and rainfall	High temperatures	High winds and storm surge	Sea-level rise	Snow and ice
Relocation of facilities	✓	✓	✓	✓				
Monitoring/modelling of risks	✓	✓	✓	✓			✓	
Planning for improvements		✓		✓				
Enhance defences/infrastructure, equipment	✓	✓	✓	✓	✓	✓	✓	✓
Changes to awareness and cooperation		✓	✓			✓		✓
Increase port capacity/back-ups	✓	✓	✓					✓
Climate change considered in decisions		✓	✓					
Renewable energy initiatives		✓			✓			

example adaptations designed to aid against flooding and rainfall were strongly associated with hard adaptation measures, such as moving electrical installations to more protected locations.

The number of event types for which proposed adaptations were suggested varied between ports. Dover port is putting in place both the most, and most diverse, adaptations of the ports that submitted a progress report. There is some double counting between proposed adaptations (Figure 5.4) and underway/completed adaptations (Figure 5.5). However, some completed adaptations have been identified and implemented after the 2011 Adaptation Reports.

For example, Dover is the only port who has, to date, put in place adaptations to risks associated with snow and ice (Figure 5.6). In contrast, ports operated by ABP are presently focused on adapting to a single type of risk – that associated with flooding and increases in rainfall. Within the Adaptation Reports no ports are currently suggesting, or putting in place adaptations to tackle risks associated with poor visibility, or to take advantage of newly developing opportunities.

Adaptation measures are not necessarily equal in terms of their significance or importance. For example raising the height of a quay is a more substantial investment and long-term project than the purchase of snow blowers. Of the twenty adaptations underway or completed by Dover port the majority are minor measures that are quick and easy to implement, or involve alterations to planning documentation. This poses the question of whether some ports are currently focusing on the simplest adaptations to achieve the highest current benefits and lowest costs.

The level of adaptive success from the ports who submitted an update is questionable. An assessment of the adaptations either completed or underway identified that 71% of adaptation methods either in place or underway by one or more port had multiple motivations. The high likelihood of these so called “adaptations” being instigated regardless of whether these ports assessed their climate change readiness must be considered. These adaptations, which would have occurred regardless of climate change, and can be financially justified more easily, can make a port seem to be taking more active steps for adaptation than is truly accurate.

5.2.6 Requirement for further assessments

Ports who submitted at least one Adaptation Report move 89% of container traffic that passes into UK ports, and 85% of export container traffic. Results produced in the nine submitted adaptation reports were used to determine the preparedness of the UK port sector for the challenges of climate change. The reports were produced from 8 English ports/port clusters and 1

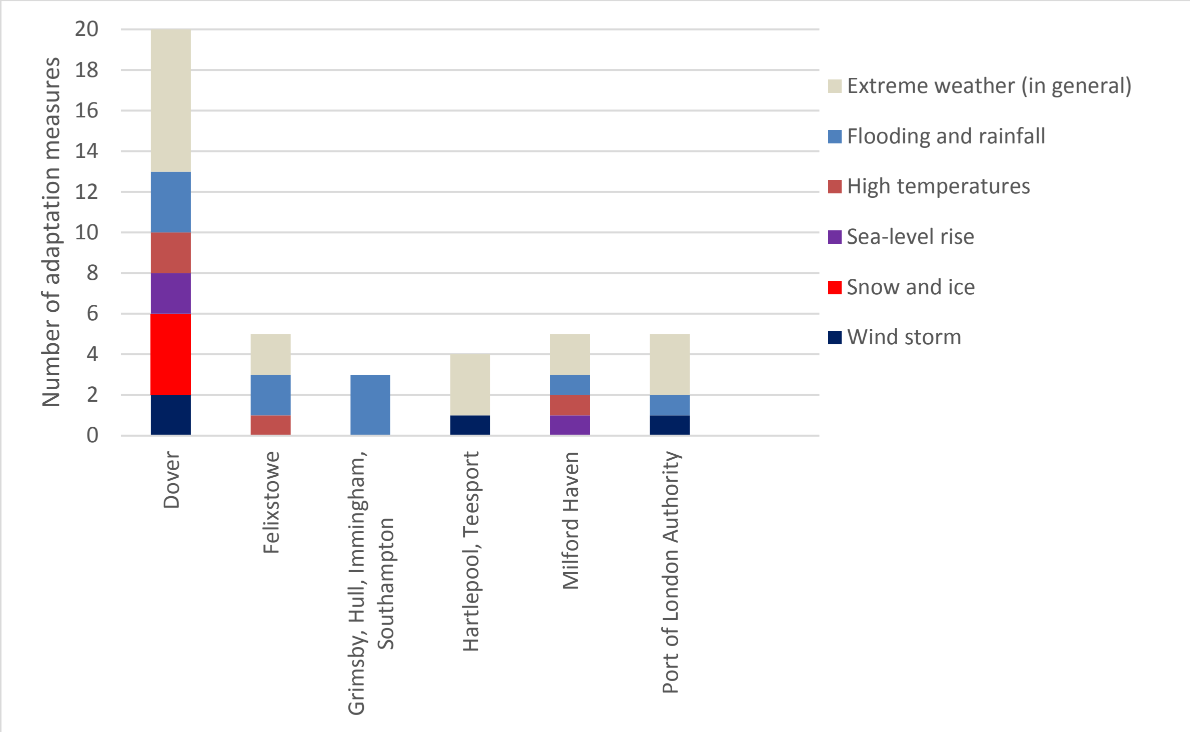


Figure 5.5: The number of adaptations either underway or completed per port and event type. Assessed using progress updates included within the second round of Adaptation Reports published in 2015.

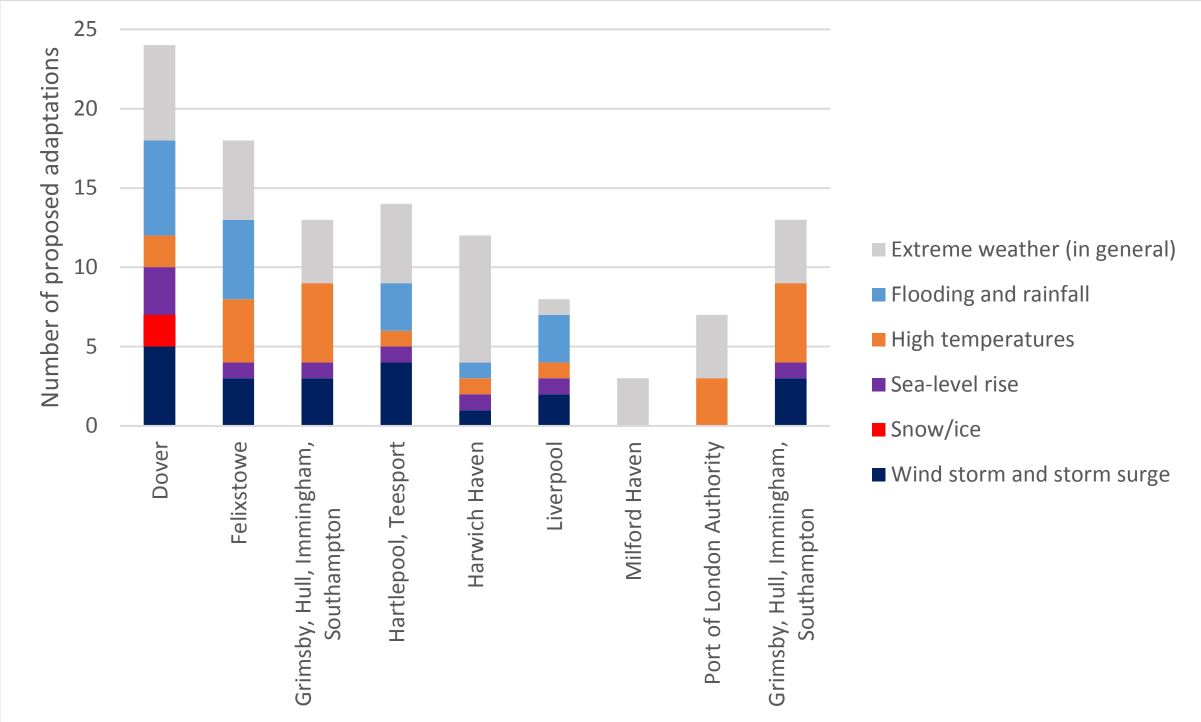


Figure 5.6: Number of proposed adaptations measures per event type for each port in the 2011 and 2015 Adaptation Reports. Extreme weather (in general) refers to adaptations that reduce risks to multiple event types. Wind and storm surge were amalgamated as the same adaptations were proposed for both event types.

Welsh port, with no input from devolved ports in Northern Ireland and Scotland (Figure 5.2). Six of the ports/port clusters who responded were located on the east coast of England.

The poor geographical and country distribution of adaptation reports introduces a data bias into the analysis of port sector preparedness. The operations of ports, and the risks they face both currently from extreme weather events, and in the future with climate change vary depending on their locations, functions and infrastructure. Therefore the results used to build a picture of the preparedness of the UK port sector is not truly representative, even of the UK's largest or busiest ports.

The first two rounds of Adaptation Reports have focused on the first stages of the adaptation process – identifying risks and thinking about what needs to be done. Future rounds of Adaptation Reports need to be directed to include a greater focus on what ports are doing to adapt, and achievements in terms of effective, completed adaptation measures.

A number of weaknesses are apparent within the Adaptation Reporting Power Direction. These issues primarily arise from the government's knowledge of the level of port awareness of climate change risks and the need for adaptation. Key weaknesses affecting the quality of the Adaptation Reports include:

- No system, or guidance, currently in place to help ports identify new or changing risks,
- Expecting port representatives (who often have no scientific training) to analyse and understand model data which has very high levels of uncertainty.
- The methodology used for the Adaptation Reports is poor from both the government and port sectors.
- Adaptation Report quality and content differed significantly between those written in house, and those produced by consultancy firms.

To tackle these issues a number of improvements could be implemented:

- Instruct ports to keep a record of extreme weather that affects their operations, to allow continued assessment of how conditions affecting their operation change through time.
- Provide more easily understood summaries of climate change risks to prevent misunderstanding. For example, in the Adaptation Reports, different results were produced by ports, despite using the same data source.
- Prepare and/or offer an Adaptation Report template with example to highlight good practice and effective assessment techniques.

The Adaptation Reports have been used as a critical data source within a number of national and sectoral government reports (including the National Adaptation Plan, Climate Change Risk

Assessment and Transport Resilience Review). A number of concerns have been raised by the Committee on Climate Change regarding published Adaptation Reports and the climate change preparedness of the UK port sector. An analysis of progress in climate change preparedness highlighted critical issues including limited data on port baseline conditions and adaptation progress. The most severe concern identified was that three ports declined to participate in the voluntary secondary round of reports (Committee on Climate Change, 2015).

Perspectives on whether the UK port sector is well prepared for climate change differ. Reports, such as those published by the independent public body Committee on Climate Change consider progress in adaptation within the port sector to be limited and are concerned that not all of the UK's busiest ports are willing to be involved in further stages of the Adaptation Reporting Power assessment (Committee on Climate Change, 2015). An independent study of port infrastructure by Jan Brooke Environmental Consultant Ltd. (2015) concluded that UK ports are well prepared for climate risks on a short to medium term time-frame. Reports produced either by, or on behalf of, government departments tended to be more positive regarding their perspectives on level of climate change preparedness underway within the port sector. The 2014 Transport Resilience Review considers ports to be well prepared for high wind events and are working on improving their resilience to other event types (Department for Transport, 2014a, b). A study of UK infrastructure adaptation considered the port sector to be highly aware of climate change risks and acts in a "conservative and risk adverse" manner putting in place "just-in-case" measures (Pricewaterhouse Coopers LLP, 2010).

The research detailed in Section 5.3 will assess the climate change preparedness of the UK port sector as a whole and determine which perspective on port sector climate change preparedness is most accurate.

5.3 UK port sector preparedness for climate change

5.3.1 Data and methods of study

5.3.1.1 Data

In 2017, the UK had 162 commercial ports comprising of 53 major ports and 109 minor ports (see Figure 1.1) (Department for Transport, 2016b). The Department for Transport defines major ports as commercial ports that move in excess of 1 million tonnes of cargo per annum, and minor ports as those moving less than 1 million tonnes of cargo in the same period. Prior to this study only those ports classed as nationally significant had been contacted regarding their preparedness for climate change representing only 8% of UK commercial ports .

A questionnaire was developed to assess the level of preparedness of all UK commercial ports for future challenges associated with extreme weather and climate change. Prior to this questionnaire only 13 of the UK's 162 ports had been contacted regarding their climate change preparedness, and did not include ports situated in Scotland or Northern Ireland. By distributing the questionnaire to all commercial ports a much fuller understanding of UK port sector climate change preparedness will be developed. A copy of the questionnaire is included in Appendix J. The questionnaire covered four key topics:

- Context/background information – Insight into the experience of the questionnaire respondent (Questions 1-5),
- Adapting against the challenges of extreme events – Analysis of any adaptive actions already being undertaken by ports (Questions 6-7),
- Preparedness for climate change – How prepared ports feel they are for climate change, and issues of concern (extreme weather or climate change risks) for their operations both now and in the 2030s (Questions 8-10),
- Guidance for adaptation – Data sources used to guide adaptations and to identify tools for improving port adaptation (Questions 11-13).

5.3.1.2 Methodology

All UK commercial ports were contacted to request that they participate in the questionnaire. Contact details for each port were collated including telephone numbers, email addresses and the names of relevant staff members. Ports were primarily contacted via telephone, to determine whether a suitable representative from each port would be able, or willing, to answer the questionnaire. Ports were contacted a maximum of five times via telephone to make initial contact, which was followed up by two emails. Ports who expressed a positive interest in completing the survey tended to elect for the questionnaire to be sent via email.

An online copy of the questionnaire was provided via the web-platform www.isurvey.ac.uk, which is hosted by the University of Southampton. The questionnaire was live between the 20th February and 31st August 2017.

Five response types were available to port respondents through telephone calls and emails:

- A representative from the port completed the questionnaire,
- No-one working from the port was able to answer the questionnaire,

- No successful contact made by either telephone or email,,
- Port is closed, no longer commercially active, or is not a port (Table 5.8),
- Unable to obtain contact with any representative from the port.

Two response types (questionnaire completed, and no-one was able to complete the questionnaire) were classed as positive responses to the questionnaire. As discussed in Section 5.3.2 62% of contacted ports responded in one of these two ways. Successful contact with port representatives occurred most commonly via telephone, where respondents, including those who were unable to answer the questionnaire, were very willing to talk in detail on the their perceptions of the topic of climate change, and in many cases, weather.

5.3.2 Port perspectives on, and readiness for, climate change

To determine whether all UK ports are prepared for climate change 162 commercial ports (Appendix G) were invited to participate in a questionnaire on climate change adaptation (the full questionnaire can be found in Appendix J). The information collected by the questionnaire was not available within the public domain. The purpose of the questionnaire was to determine:

- Background information on the respondent (including job role and time spent working in the port sector),
- Whether the port is currently adapting to extreme weather conditions,
- The port's level of climate change preparedness,
- Guidance tools for adaptation which either are, or would be, of benefit

The questionnaire was approved by the University's board of ethics as effectively ensuring the anonymity of completed responses. All identifying information, such as the port name, was separated from the rest of the questionnaire response. Port participants welcomed the anonymity of the questionnaire responses. Compared to Adaptation Reports (see Section 5.2), that are available within the public domain, potentially more honest opinions on climate change risks and adaptation preparedness were gathered through the questionnaire. Many port representatives were willing to discuss their concerns regarding climate change, and their true level of adaptation preparedness, which contradicts the stance of the UK Government, which assumes that the entire UK port sector is becoming well prepared for the many challenges of climate change.

A total of 62% of active UK ports (49% major ports and 70% of minor ports) responded either by completing a questionnaire or confirming that no-one within the port would be able to answer questions relating to climate change or extreme weather (Figure 5.7).

Table 5.8: Ports included within the Department for Transport database of port freight statistics that are not active commercial ports

Reason port is not commercially active	Port classification	Ports
Port is closed	Major	Stranraer
	Minor	Anglesey Marine Terminal Barnstaple Colchester Dean Point Quarry Dutch River Wharf Llanelli Magheramorne Penarth
Not a port/part of other ports	Major	Kilroot Power Jetty River Trent Rivers Hull and Humber
	Minor	Kilroot Larne Bank Quays Wallasey
Non-commercial port	Major	-
	Minor	Exmouth Watchet

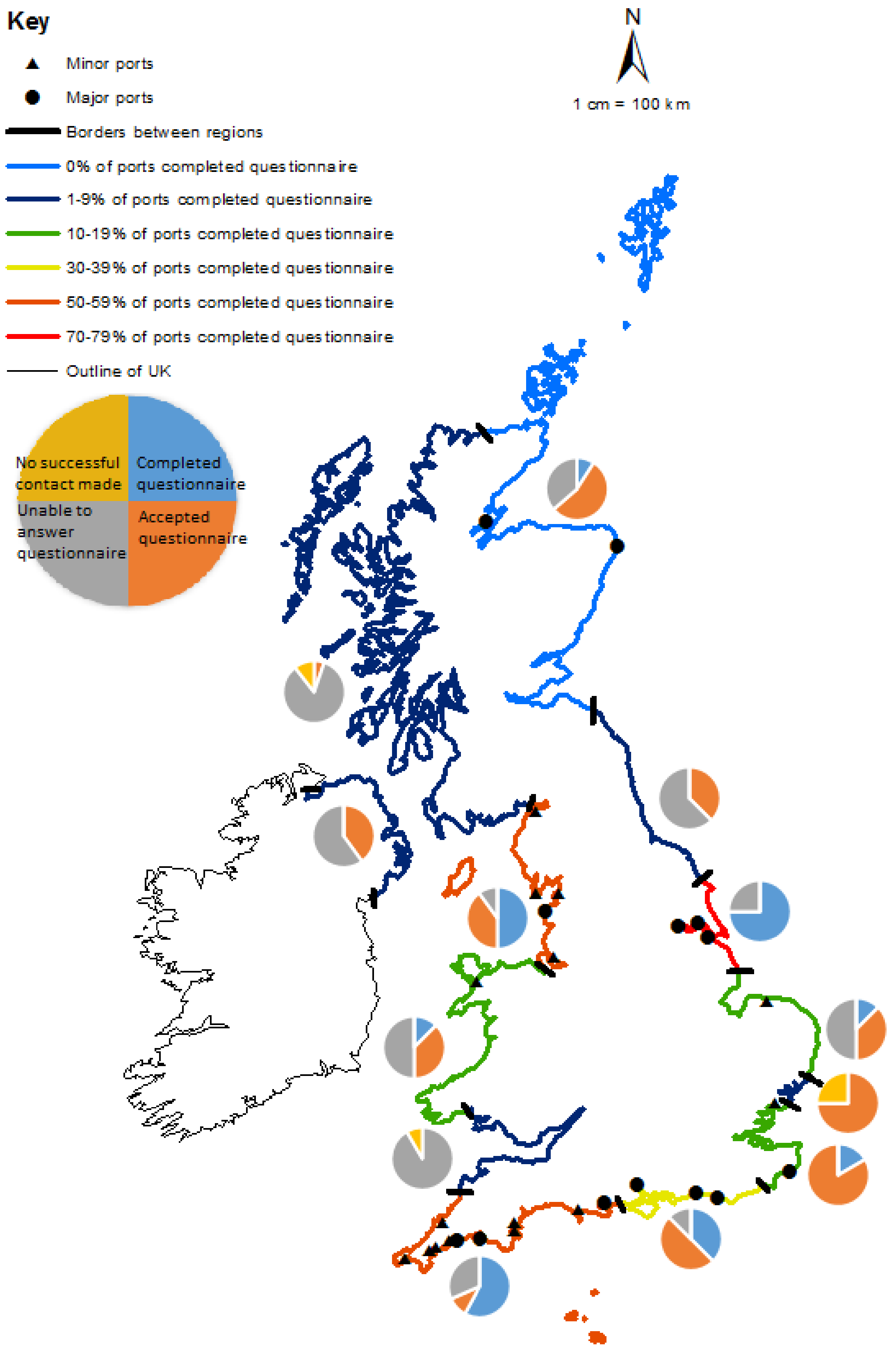


Figure 5.7: Composite image of port responses to the questionnaire, with the UK divided into 13 port regions as determined by the Department for Transport. Ports who completed a questionnaire are marked in black circles (major ports) or triangles (minor ports). The percentage of ports who completed a questionnaire per region are recorded by the colour of the coastline. The responses of ports per region are displayed as pie charts.

The responses of port representatives to the questionnaire were as follows Figure 5.7):

- Accepted, but not completing a questionnaire despite confirming that they have qualified staff – 50 ports,
- No-one within the port was able to answer the questionnaire (although respondents were often willing to discuss how they perceive the challenges of climate change in the context of their wider business operations) – 63 ports,
- Completed a questionnaire – 29 ports,
- No successful contact made with the port – 6 ports
- Closed or not a port – 14 ports

The responses to the questionnaire differed between major and minor ports. Major ports most commonly responded by accepting a questionnaire (41% of ports), whereas minor ports were most likely to be unable to answer the questionnaire (51% of ports). Ports who were unable to answer the questionnaire tended to voice a high level of uncertainty regarding the concepts and challenges of climate change, with many respondents stating that climate change was not an issue that had ever been considered within the context of their port operations and planning

5.3.3 Role of port location and management organisation

UK ports are operated by three distinct management types: private companies, trust ports or operated by local authorities. Differences both in the likelihood of preparedness for, and awareness of, climate change varied between port types. Trust ports were most likely to complete a questionnaire whereas local authority ports were found to most commonly be unable to complete the questionnaire (Figure 5.8).

A higher proportion of major than minor ports completed the questionnaire – 26% and 15% of ports respectively (Figure 5.7). Minor port were more likely to be unable to complete a questionnaire, justifying this decision as they were “too small” or had no staff who were knowledgeable on extreme weather or climate change. Multiple ports stated that there was little staff or organisational awareness of climate change or the challenges that they may face in future decades.

The likelihood of a port completing a questionnaire also varied between and within countries (Figure 5.9). Of the 30 ports who completed a questionnaire 14 were located on the south coast

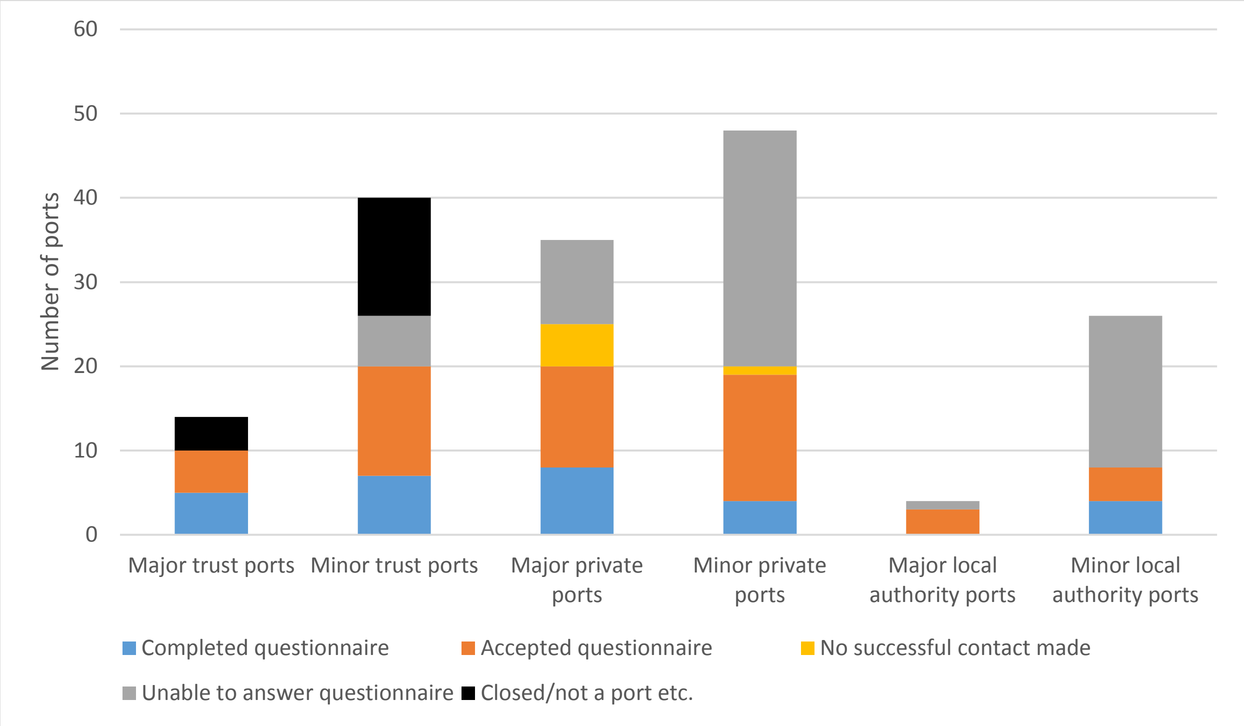


Figure 5.8: The responses of commercial UK port organisation to the questionnaire. Ports were divided into major and minor ports, and subdivided by port operating type: trust ports, privately owned ports and local authority managed ports.

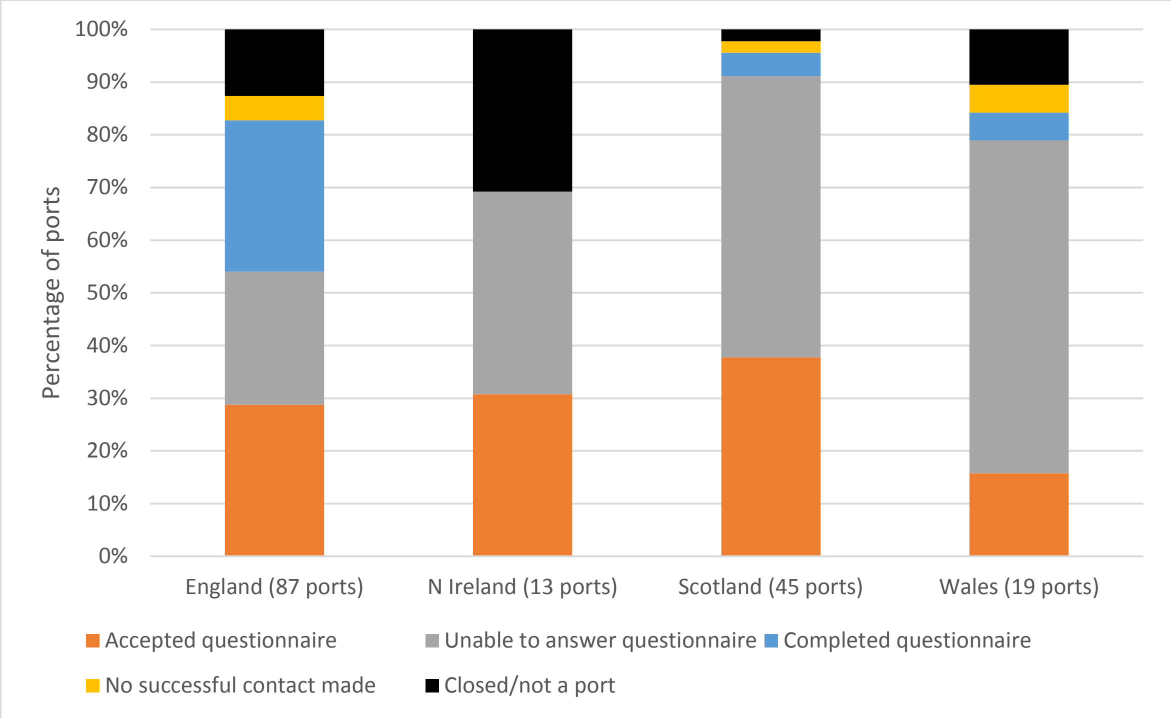


Figure 5.9: The proportional responses to the questionnaire invitation. Ports were divided by country. Absolute numbers of ports per country were recorded to give context.

of England. English ports were most willing, and able, to complete the questionnaire (33% of ports), and had the lowest percentage of ports unable to complete a questionnaire (30%). In contrast, ports in Northern Ireland, Wales and Scotland were highly unlikely to complete a questionnaire (0-5% of ports) but had a high likelihood of being unable to answer a questionnaire (54-70% of ports). Potential reasons for differences between countries and regions.

For English ports responses to the questionnaire invitation varied both regionally, and due to port management type (Figure 5.7). 52% of trust ports completed a questionnaire, compared to 25% of privately managed ports, despite 60% of English ports being managed by private companies. Ports who completed questionnaires were clustered in three regions: the Humber (east coast), West Country (south-west coast), and Lancaster and Cumbria (north-west coast). In contrast, ports situated along both the English and Welsh sides of the Bristol Channel were dominated by ports who were either unable, or unwilling, to complete a questionnaire.

Only two of Scotland's 44 ports completed a questionnaire (Figure 5.7). Ports located in Wales and Northern Ireland were least likely to complete a questionnaire – one and zero ports respectively. Major ports in Northern Ireland either accepted a questionnaire or no successful contact made, whilst all minor ports confirmed that they would not be able to answer any questions on climate change. Conversations with multiple Welsh ports determined that they would not answer questions on climate change, and in many cases that they considered themselves "too small" to be able to consider the risks of climate change for their future.

5.3.4 Port awareness of, and preparedness for, climate change

5.3.4.1 Who responded to the questionnaire?

The job roles and responsibilities of those who answered the questionnaire were varied, particularly for major ports (Figure 5.10). Received questionnaires from minor ports were, in the main completed by Harbour Masters or Port Managers. Where minor ports were unable to answer the questionnaire this was mainly confirmed by a telephone conversation with the Harbour Master who stated that no-one within the port had any knowledge on climate change. Minor ports and smaller major ports who were unable to answer the questionnaire stated that they had not previously considered climate change risks, the need for adaptation measures.

Harbour Masters and board members from minor ports were often open about how relevant they feel the issue of climate change is for their port. For example, a Chief Executive from a northern

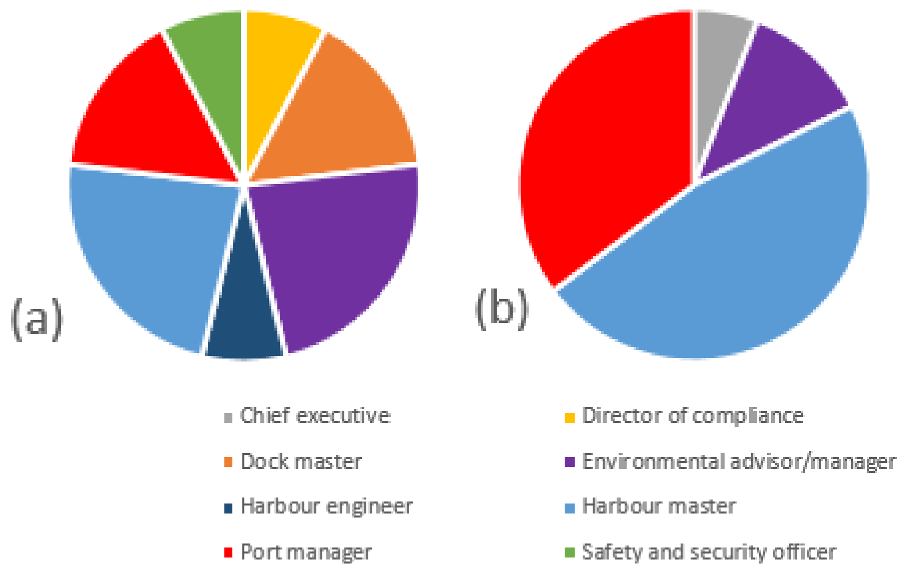


Figure 5.10: Job titles of the respondents who completed a questionnaire (a) major ports, (b) minor ports.

England port feels that in the 40 years he has worked at the port he has seen no change either in extreme weather events or sea-levels, and anticipates that climate change will have little impact on the port's infrastructure or operations. He also strongly felt that climate change will be much more of an issue for ports located on the south coast of England.

5.3.4.2 Are UK ports adapting?

Of the 30 ports who submitted questionnaires 92% of major and 81% of minor ports are already adapting. These numbers, of taken in isolation, can be misleading. Ports who were unable to answer the questionnaire verbally confirmed that they are not currently implementing or planning adaptations, which reduces the proportion of adapting ports to 50% of major and 16% of minor ports – significantly lower than the figures assumed by DEFRA. It is not known whether ports who accepted, but did not complete the questionnaire are adapting.

Out of Wales' 19 commercial ports only one, Caernarfon, completed a questionnaire. The port confirmed that it is not currently putting in place adaptations, although guidance would be welcomed. Twelve Welsh ports confirmed that they were not currently adapting, and were unable to answer the questionnaire.

Few ports use a definition of adaptation to guide their decisions. Of major ports who completed a questionnaire 38% had an in-port definition of adaptation, compared to 7% of minor ports. Interestingly, some ports who stated that they do not have, or refer to, an adaptation definition do have a definition recorded in official port documentation, such as Port Master Plans. This highlights a potential lack of staff adaptation awareness even in those ports who are beginning to take steps to prepare for climate change.

5.3.4.3 What motivates UK port adaptation decisions?

The motivations for port adaptation to climate change are broad (Figure 5.11):

- To protect infrastructure and equipment from damage,
- To meet health and safety requirements,
- To prevent or reduce damage to goods and vessels,
- To reduce downtime and stoppages,
- To reduce insurance premiums,
- To spread the financial costs of port upgrades,

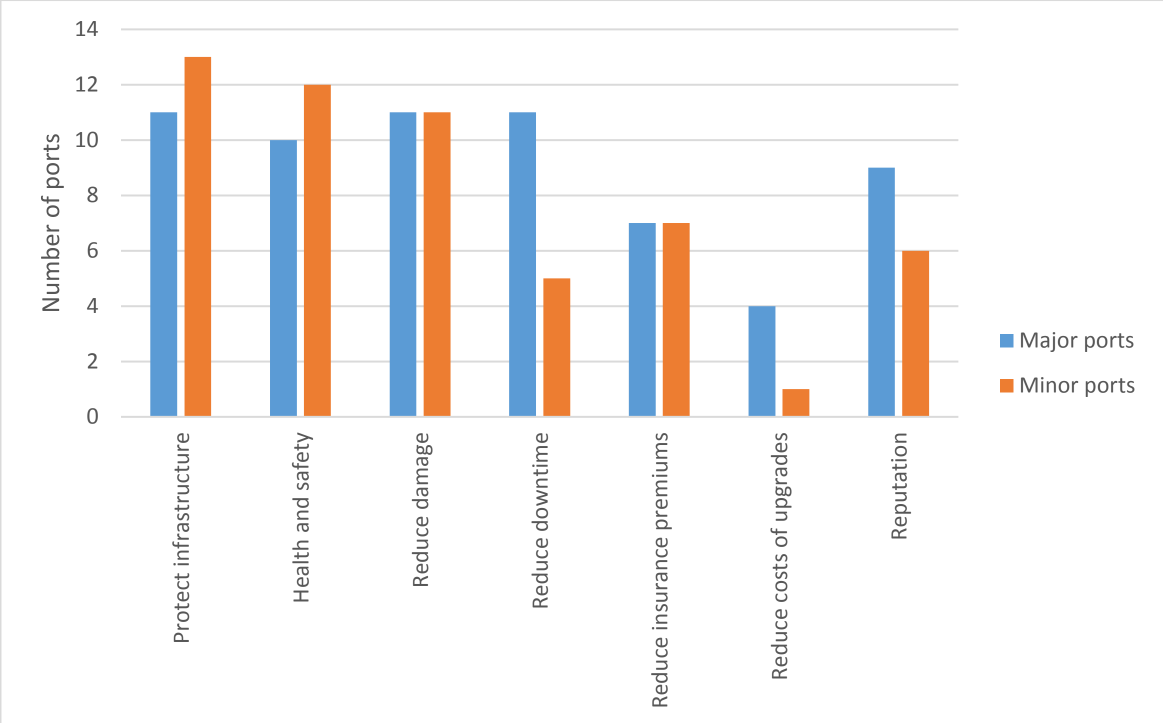


Figure 5.11: The factors that motivates whether a port puts in place adaptation measures. Major and minor ports are separated to show the different perspectives between port sizes.

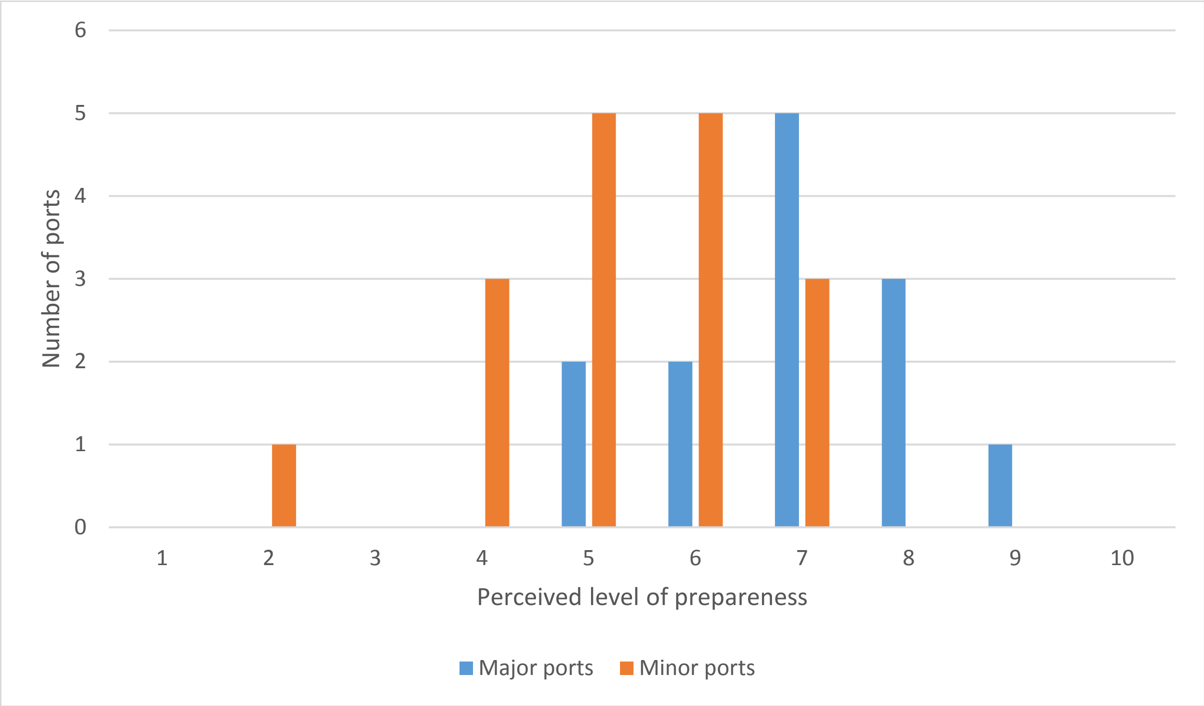


Figure 5.12 The perceived level of preparedness of ports to the potential impacts of climate change. Major and minor ports were separated to show the difference in perception of climate change preparedness between port sizes.

- To maintain or improve the port's reputation with current and future clients.

Major ports tended to be influenced by a greater number of motivations, suggesting that the larger and busier ports are either considering, or are aware of, a wider range of issues. Privately owned ports tended to be influenced by a broader range of motivations than local authority or trust ports. Interestingly, unlike privately owned or trust ports, a critical motivator for adaptation in local authority ports was to maintain or improve their reputation with current and future clients.

As well as being aware of a broader range of motivations that can be affected by climate change, major ports tended to feel more prepared than minor ports for the potential impacts of climate change (Figure 5.12). The level of confidence ranged from a positive nine (from a major port who considered themselves almost fully prepared for the challenges of climate change) to a very reserved two (a minor port). Although the level of confidence was associated with port size, no difference in perceived preparedness was identified between ports who are, and are not, currently adapting.

Differences in the awareness of potential event types of risks for port operations were apparent between major and minor ports. Major ports are concerned about potential impacts from a broader range of event types, and anticipate that risks associated with sea-level rise, storm surges and high winds will increase over the next 20 years (Figure 5.13). Less change in risks are expected by minor ports (Figure 5.14), who expect to become marginally more concerned about sea-level rise, storm surges, high temperatures and rainfall in the next couple of decades. Ports managed by local authorities are concerned about increasing risks from rainfall, perhaps reflecting the broad areas of responsibility of such authorities, where flooding of nearby promenades and coastal roads would also be of concern.

5.3.4.4 Do UK ports want climate change guidance?

UK ports would find climate change guidance beneficial. Of the ports who completed the questionnaire 77% of major and 81% of minor ports confirmed that they were interested in multiple guidance tools (Figure 5.15). Five potential guidance tools, ranging from port specific to nationally enforced legislation, were suggested to respondents:

- Risk information documentation summarising the threats of extreme weather and climate change impacts for ports,
- Decision-aiding tools to guide choices for adaptation,

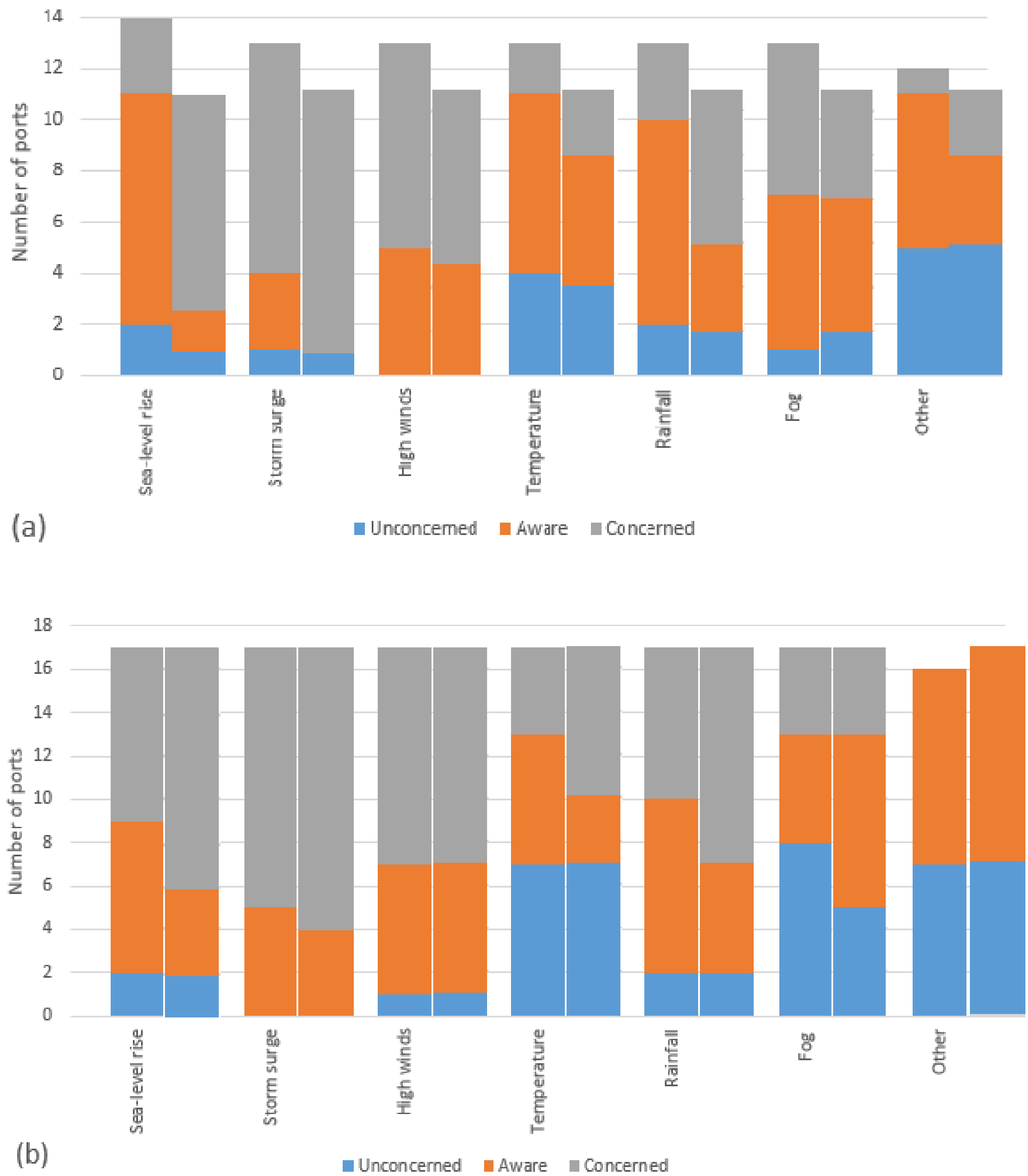


Figure 5.13: The level of perceived concern for extreme event types that (a) major ports and (b) minor ports have both in the present-day (left hand columns) and in 20 years (right hand columns).

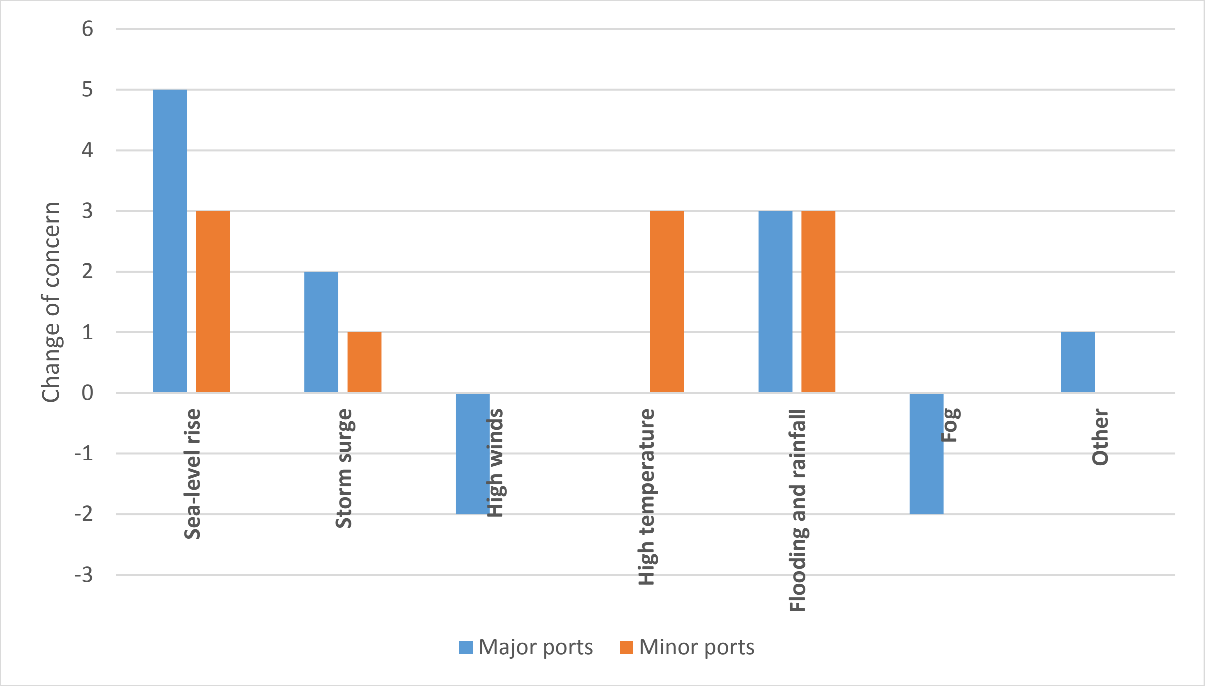


Figure 5.14: Change in the perceived level of concern for extreme event types of risk between the present day and the in 20 years. Greater positive or negative numbers represent a greater consensus in perceived changes in risk between ports.

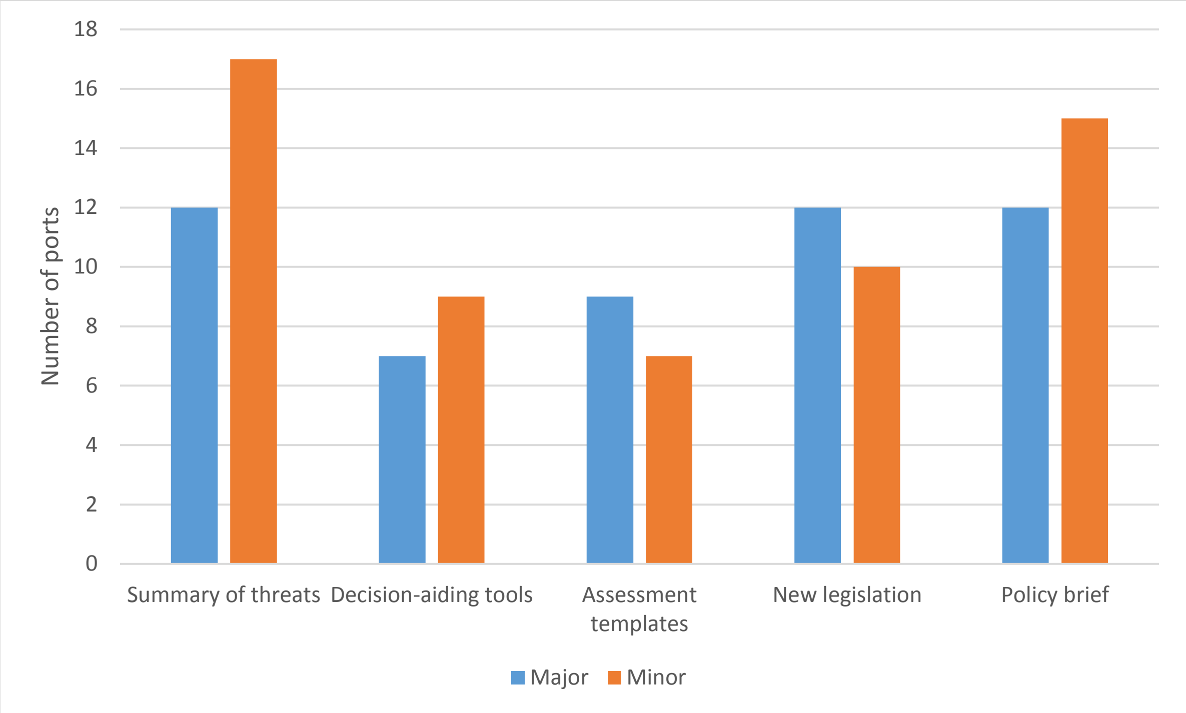


Figure 5.15: Forms of guidance that ports who responded to the questionnaire would find beneficial. Major and minor ports were separated to highlight differences in beneficial guidance tools between ports of different sizes.

- Provision of assessment templates to aid ports in determining their specific adaptation needs,
- Improved national or regional legislation or policy guidelines,
- A policy brief that explains adaptation actions available against extreme weather events and climate change, and its benefits to the wider port community.

One of the questionnaire respondents suggested a sixth potential guidance tool:

- A conservancy model which would tie climate change adaptation into the statutory duties of ports.

Port respondents most commonly viewed information on extreme weather and climate change risks and a policy brief on adaptation actions as of most benefit for their future operations. In discussion with respondents, risk information was repeatedly expressed as the most pressing guidance tool of benefit.

Minor ports most commonly considered information on the threats of extreme weather and climate change to be the guidance tool of most potential benefit. The tool was, in most cases, selected as many smaller ports felt unsure as to both the range of potential risk that they face and the likely effects on their operations. Multiple ports stated that they would appreciate any further guidance to clarify the risks of climate change for their operations, as presently climate change is not an issue that is actively considered.

5.4 Discussion

The UK port sector is a highly complex and diverse industry. When discussing climate change multiple ports took the opportunity to give detailed feedback on how they perceive climate change within the context of their current business operations. Perspectives range from those that do not recognise climate change through to those who have been adapting in recent years are detailed below:

- Global warming has not been identified as a risk by the port's board of directors.
- There are more immediate issues to be considered. Climatic events are not planned against, but other issues such as fires or oil spills are.
- Climate change is not included within the port's Environmental Policy, but the questionnaire respondent personally thinks that it is important for that to change.
- The port's Harbour Master is not concerned about climate change as the port will be forced to adapt as necessary as conditions change.

- The physical location of the port means that extreme weather and sea-level rise is perceived as a lesser threat to the port's continued operations.
- Climate change has been well addressed through Shoreline Management Plans over the past 15 years, and protection measures to defend the port against extreme weather have been in place since the 1980s.

One port also took the opportunity to voice concerns related to climate change in the context of Brexit (the colloquial term describing the exit of Britain from the European Union which is due to occur in March 2019). The Director of Compliance stated that they are concerned about how future environmental regulations and guidance may change for the port sector in a post-Brexit world. Following Brexit all European Laws which are currently proposed are to be replaced by new UK specific laws.

Minor ports were more interested in discussing the issue of climate change beyond the scope of the questionnaire. In discussion with Port or Harbour Masters, especially those that had worked in the same role for decades, these conversations were extremely frank. Topics discussed included whether they felt climate change would ever be an issue for their operations, and how they would deal with issues if, and when, they occurred. For example, some ports stated that they were not interested in adapting as they have so many other shorter term issues to consider, and would only adapt if required to (e.g. if legislation changes or conditions for the port degrade). The reasons behind this behaviour were given as:

- In their time working at the port they had not personally noticed any changes in weather issues affecting the port's operations.
- When they were in education climate change was not taught within the curriculum, and therefore, they do not have the same knowledge and experience that younger generations have.

5.4.1 Differences between large and small ports

Perspectives on, and preparedness for climate change differs distinctly between large and small UK ports, highlighting the importance of considering the sector on a port-by-port basis. The ports that are most confident about their level of preparedness for climate change are either the UK's largest ports or smaller ports who are part of a larger group (such as ports managed by Associated British Ports). This suggests that the level of perceived preparedness for climate change is at least partially influenced by organisation size. The largest ports, or port groups, were more likely to have staff qualified to communicate on the topic of climate change, and to use documentation that at least considers climate change. All other smaller ports were both less prepared for, and aware of, the risks and challenges associated with climate change.

The largest ports (those moving in excess of 10 million tonnes of cargo per annum) most commonly responded to the questionnaire request either by completing a questionnaire or by avoiding contact. A relationship was identified between decreasing port size and the likelihood of a port being unable to answer the questionnaire. Small ports were found to often be operated by a few land-based staff, including a Harbour Master, Port Manager and Receptionist. In many cases, those working in those roles have remained in the same job position for multiple decades. Management structures such as these provide little opportunity for many ports to change or improve their awareness of climate change.

The motivations for climate change adaptations differed between major and minor ports. Larger ports tended to be more financially motivated, whereas minor ports were most commonly influenced by meeting current health and safety measures. The differences in motivations reflect the two main operational types of port in the UK. Firstly, large ports who are capable of managing multiple cargo types and handling large shipping vessels. Secondly, smaller ports who tend to combine cargo operations with other services such as passenger ferries, fishing or tourism.

Larger ports, for whom cargo shipping contracts from major firms (e.g. Maersk, CMA CGM) are a significant part of their operations are under continuous pressure to keep cargo movements on schedule, particularly for just-in-time or perishable cargoes. Therefore, it is critical for ports to take steps to reduce both damage to infrastructure or cargo and to limit the amount of downtime experienced due to extreme weather events. Downtime and extreme weather can negatively impact the operations both of a port and of companies who operate on port land (such as those renting warehouses). If ports suffer damage or disruption repeatedly this can negatively affect a port's professional reputation. For example, following the abnormally stormy winter of 2013/14 Felixstowe port experienced multiple periods of downtime due to high wind or storm conditions. A number of vessels that were due to call at the port during these periods of disruption adjusted their routes to call at the nearby new deep-water port London Gateway which had only opened in November 2013. DP World, who operate London Gateway, had published multiple advertisements stating that its state of the art equipment meant that, unlike its rival ports, it was able to continue operating despite challenging weather conditions.

Operations in minor ports more commonly combine cargo and passenger operations with services of benefit to the local economy. These minor ports are most commonly motivated to adapt to meet health and safety requirements. From discussions with these small ports, who are often run individually (rather than part of a larger port group), it is apparent that they are not aware of the full range of climate change risks and impacts that may affect their operations. Currently, many of these ports are only adapting minimally, responding to specific instructions, such as those included within health and safety policies. However, even if smaller ports identify the need to adapt it is likely such changes will be piecemeal. As they do not have the financial resources of a larger organisation smaller ports are likely to be unable to justify the costs of large-scale adaptation measures alongside other shorter-term business costs.

5.4.2 UK port sector preparedness for climate change

The majority of UK ports are not well prepared for climate change. Responses to the questionnaire highlighted that few ports currently employ staff who have knowledge on how climate change risks, such as extreme weather or sea-level rise, will potentially affect their port. Even fewer ports (only some of the UK's largest and busiest) actively employ staff in environmental roles. This lack of knowledge could potentially put ports at an increased risk of damage or disruption arising from climate change. For example, if ports do not consider adaptation until after they have experienced damaging impacts to their infrastructure or operations the financial costs of such upgrades and adaptive measures may be too costly. For smaller ports these costs may be financially impossible to contend with, particularly when combined with lost revenue due to the damaging circumstances itself.

Few ports refer to a definition of adaptation to aid their decision-making process even, in some cases, if a definition is available within port documentation. If decision-makers do not fully understand how to effectively adapt this could result in negative impacts including: adaptation not being viewed as an important issue, an increased likelihood of maladaptive decisions being taken, and the implementation of more costly reactive, rather than proactive, adaptations.

It is very clear that the UK port sector would greatly appreciate, and benefit from, improved guidance. Ports responding to the questionnaire were interested in both informative and enforced methods of guidance. Small ports in particular would find basic guidance which would prepare them to begin incorporating climate change into their port policies and decision-making processes. It is critical that the mind-set of being "too small" to be able, or important enough, to adapt is changed for smaller UK ports.

The importance for ports to have a good understanding of the climate change risks they is likely to face is critical. Currently these risks are poorly understood by both major and minor ports. Comparisons of Adaptation Reports identified potential misunderstandings of scientific predictions of risk between ports. Limited awareness of the risks ports face from climate change were also highlighted within the questionnaire responses. Provision of a clear summary of likely risks associated with climate change is therefore a critical gap in available knowledge for the UK port sector. Provision of clear risk information to ports who have benefits including the quality of future rounds of Adaptation Reports, encouraging adaptation, and reducing the likelihood of maladaptive decisions.

Ports that are already putting in place adaptation measures were most likely to have identified the climate change related issues of greatest concern for their operations. A concern raised by multiple ports is that regardless of how well they adapt they remain vulnerable to disruptions experienced by external utilities or connective services (such as the surrounding road network). This concern highlights that it is critical to have continuity for adaptation guidance across multiple sectors.

5.4.3 The role of devolution in port sector climate change preparedness

A greater percentage of major and minor English ports completed a questionnaire than ports located in Northern Ireland, Wales or Scotland. English ports tended to have a greater overall awareness of the concept of climate change. In English legislation, following the passing of the 2008 Climate Change Act reporting bodies (including the UK's busiest ports) were directed to produce a report detailing assessing how well they are preparing for climate change. This request only applied to the nine busiest UK port groups located in England and Wales, devolved ports in Northern Ireland or Scotland were not affected. To date the governments of Northern Ireland and Scotland have not yet carried out an assessment of the adaptation preparedness of the port sector in their countries. This poses the question of whether devolved ports, even the largest ports in these regions, are as aware of the importance of climate change issues for their future operations as ports in England.

The perspectives of ports on the importance of climate change adaptation for their operations also differed per country. Welsh ports broadly considered themselves as "too small" to be able to consider adapting to climate change, and that such actions should be considered only by larger ports who have the experience, qualified employees and financial resources to tackle such a challenging issue. Ports located in Northern Ireland most commonly stated that they were unable to answer a questionnaire as they did not have qualified staff who were able to address the issue of climate change. In contrast Scottish ports had a more positive viewpoint, in many cases that they were currently unconcerned about the risks of climate change, as they felt that their operations were already robust, and that certain risks, such as sea-level rise, were not of great importance. For example, some smaller Scottish ports are not worried about sea-level rise because they expect that isostatic rebound, whereby the landmass of Scotland is rising, will counteract the effects of rising sea-levels.

The differences between countries were particularly marked when comparing Scottish ports with those English ports located in the West Country or Humber regions – three areas that experience regular, and severe, stormy conditions. Ports situated in the West Country and Humber were those most likely in England to complete a questionnaire, and are currently putting in place adaptation measures. In contrast, Scottish ports did not complete the questionnaire, with many ports stating that they are not currently, or considering, implementing adaptation. That decision was justified by port representatives who stated that due to their geographical location they are used to rough coastal conditions and storms. When comparing historical records of extreme weather events affecting ports (Adam et al., 2016) events affecting Scottish ports were more commonly associated with disruptions (such as vessel delays), whereas impacts for West Country and Humber ports were more commonly in the form of flooding or damage to vessels or infrastructure.

5.5 Key findings

The main findings are:

1. The UK port sector is not as currently well prepared for the challenges of climate change as government reports suggest. This is due to a combination of:
   - Ports framing normal upgrades as adaptations to provide an inaccurate perspective on the extent of measures being implemented to prepare for climate change.
   - Many ports are unsure about the likely future risks, or the extent of potential impacts, they may face due to climate change.
   - Few ports feel certain about how, or when, to begin putting in place adaptation measures.
2. Successful responses to extreme weather events are being put in place due to damage and disruption experienced, such as during the stormy winter of 2013/14. Ports have relabelled existing developments and upgrades as climate change adaptations, whereas in reality they are putting in place few preparations for climate change. Both the awareness of risks associated with climate change, and the quantity of ports currently putting in place adaptation measures are low.

3. The UK port sector would appreciate additional guidance on the topic of climate change, whether in the form of information to improve knowledge through to new enforced legislation on adaptation. The most commonly requested form of guidance was a simple summary of the risks that ports are likely to face due to climate change, highlighting that ports are unsure even as to how climate change will affect them, let alone how to best and effectively adapt.
4. The preparedness of the UK's port sector to climate change varies between and within countries. English ports are currently best prepared for climate change compared to Northern Ireland, Wales and Scotland. Ports who are actively adapting are more commonly either the UK's busiest ports or multiple ports managed by a single parent port company (such as Associated British Ports).

Chapter 6: Discussion

6.1 Introduction

This research analysed the vulnerability to, effects of, and responses to extreme weather events affecting UK ports, and determined how well the port sector is currently prepared for the pressures and challenges of climate, in the form of extreme weather events, and climate change.

Four stages of research were carried out to address the objectives of this thesis:

1. To determine the historic nature, and extent, of impacts of extreme weather and non-weather events on UK ports and the use of coping mechanisms as responses to disruptions.
   Outcome: An analysis of extreme events that affected UK coastal areas, EEZ and ports between 1950 and 2014.
2. To examine disruptions to dock-side port operations due to extreme weather and non-weather events under present conditions.
   Outcome: Vessel activity was developed as proxy for disruptions to port operations due to extreme events. The types, impacts and responses to extreme events that affected the operation of three case-study ports between September 2013 and September 2015 were identified.

3(a) To assess how well UK port infrastructure and operations are prepared for the current and future challenges of extreme weather and climate change.

3(b) To propose measures for enhancing the adaptation preparedness of the UK ports sector for climate change.

Outcome: The climate change preparedness of the UK port sector was assessed via an analysis of published Adaptation Reports and a questionnaire on climate change preparedness. Potential measures designed to increase the adaptation preparedness of UK ports were identified.

This chapter builds on the earlier chapters (see Chapters 3, 4 and 5) to synthesise how well prepared the UK port sector is currently for extreme weather events and climate change, and how sector-wide preparedness can effectively be improved.

6.2 The UK port sector, extreme events and climate change

Both awareness of and responses to the risks of extreme weather and climate change has improved in UK ports in recent decades, although much further progress is required (see Chapters 3, 4 and 5). Improvements to advice and guidance, and how they in turn affect the management of extremes, can be represented by a risk reduction cycle (Figure 6.1). Cycles of risk reduction are periods of transition that are dynamic and complex in nature (Park et al., 2012) where actions or responses are taken to reduce the severity or duration of impacts from identified risks. In the context of this research the cycle of reduction builds on the Driver Pressure State Impact Response model (see Figure 2.2). This cycle is initiated by the occurrence of a trigger, which sets the cycle in motion. Trigger is being used as a new term to amalgamate two previously used terms: driver and pressure, and is proposed as a broader term which will allow global (e.g. climate change) and local (e.g. extreme events) stresses to be considered together.

For this thesis three timescales are considered within the risk reduction cycle: past (mid-20th Century to 2010), present (2010 to 2018 – incorporating the UK Government's adaptation cycle which finished its first round in 2011) and future (2020 to 2100). Within Figure 6.1, two futures are considered: optimistic (climate change impacts for ports are limited, with a focus on sea-level rise) and pessimistic (climate change has a broad range of potentially severe impacts for ports and their operations).

The five parts of this cycle are:

- **Trigger** – In terms of this thesis, triggers are either sudden shocks (extreme events) or creeping change (climate change) and potentially result in negative circumstances. Triggers are global and regional stresses that can affect, or put pressure on, the condition or operability of an asset or resources Historically, triggers experienced by the UK port sector has been in the form of extreme events (see Section 3.3.1), and can arise from a range of types, including storm surges and wind storms. Extreme events are the primary trigger currently facing UK ports, and climate change is making these extremes worse, such as through rising sea-level.
- **Exposure** – A variable which has the potential to be affected by a disruptive event (e.g. port infrastructure or equipment). Historically the exposure of port operations to potential disruptions has been high, reflecting a combination of poor sea-defence quality and vulnerable infrastructure (e.g. pre-fabricated buildings) (see Section 3.7.3.1). Changes to port operations (such as increased mechanisation/containerisation and the development of new trades and services) has affected both the types and severities of impacts from extreme events. The exposure of the port sector to disruptive events is

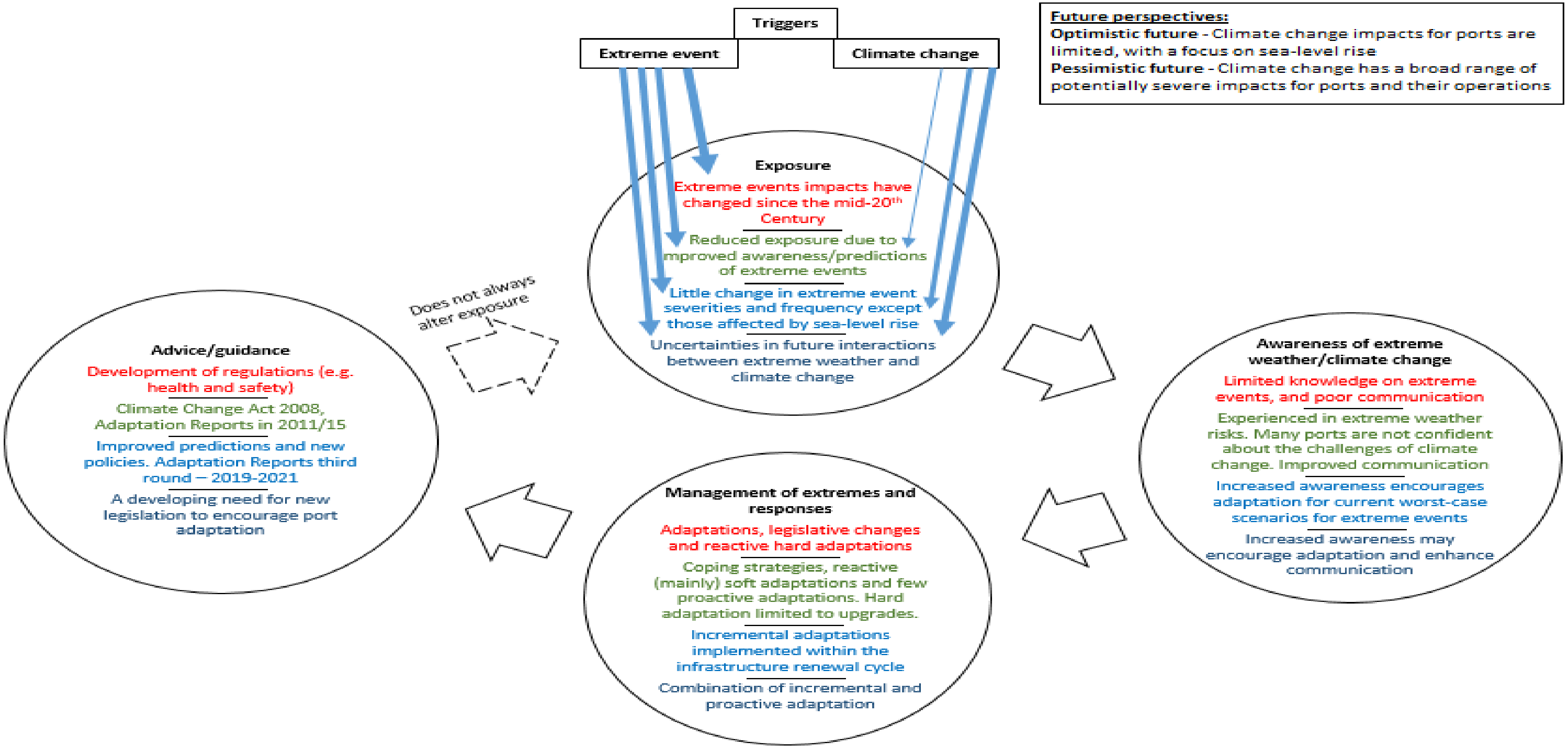


Figure 6.1: Cycle of knowledge development and risk reduction for extreme events and climate change in UK ports. The weighting of importance of extreme evens and climate change alter through time. Three time periods are included: red – past, green – present-day and blue – future (split into light blue – optimistic future and dark blue – pessimistic future).

forecasted to increase due to climate change through a combination of changes in the frequency and intensity of extreme weather events, and the emergence of new causes of potential disruption (such as sea-level rise).

- **Awareness of extreme weather/climate change** – Awareness of the risks associated with extreme weather has increased substantially in recent decades through improvements to weather prediction technology and communication (see Section 3.6). Ports are now much more aware of how different event types can affect their operations (see Section 4.6). There is still much room for improvement in terms of awareness of climate change risks, and what these changes will mean for the port sector.
- **Management of extremes and responses** – UK ports have a history of acting reactively (Preston et al., 2011) to causes of damage or disruption (Tompkins et al., 2008). Most commonly ports have responded to events with the most severe, damaging or lasting impacts (see Section 3.3.2). These responses are not always wise in the long-term, particularly when new knowledge becomes available. For example, decision-makers at Dover port purchased snow blowers to reduce the duration of impacts from snow events. However, the effectiveness of the blowers were found to be limited and instead contractors will be used to clear snow in the future (Dover Harbour Board, 2015).
- **Advice/guidance** – Since the 1950s a number of new policies have been implemented (such as enhanced health and safety regulations) to increase the safety of operations in ports both on a day-to-day basis and under times of pressure (see Section 3.7.3.1). There is a vital need within the port sector for additional guidance both on potential causes of future disruption and a need for timely and effective adaptation. It is likely that adaptation within the UK port sector will not significantly improve until this gap in knowledge is appropriately filled.

6.2.1 Historical port extreme event risk reduction

Through history, the cycle of risk reduction from extreme events for the UK port sector has changed (Figure 6.1), and reflects a number of shifts including in infrastructure, equipment, society and finance.

6.2.1.1 Changing awareness of risks and impacts for port operations

In recent decades the awareness of risks, and impacts, facing port operations due to extreme events has increased due to a number of key factors:

- **Experience** - Repeated exposure to extreme events have led to increased knowledge on how events can disrupt port operations (see Chapters 3 and 4). It is important that ports continue to learn from extreme events by making connections between the impacts of past events and how to manage them (Department for Transport, 2014b). Effective learning can help ports improve their responses to potentially disruptive events, and reduce impacts.
- **Forecasting** – Scientific and technological developments, particularly over the past 30 years, have greatly improved the accuracy and reliability of weather forecasting techniques (see Section 3.7). Many UK ports employ weather forecasting services to provide regular updates and warnings of any potential disruption (Sayers et al., 2002) or risk of damage to their operations.
- **Technology/infrastructure** – Enhancements to technology used on vessels and within ports have helped to reduce the range, and severity, of risks faced by those working in marine environments. Developments to infrastructure have reduced the exposure of port operations to potential disruptions (e.g. storm surges). However, changes in technology can also be associated with new or increased risks. As cargo containerisation has increased, the use of high-level cranes has become widespread. An identified drawback of high-level crane equipment is that due to their height they are vulnerable to high-wind gusts, and can become dislodged from their rails, or can even be blown over.
- **Policies/legislation** – Policies guiding port operating procedures have been developed through recent decades to increase the safety of those working or being transported through ports.
- **Business focus** – Operators of UK ports are explicitly aware of the range of current issues that could potentially disrupt their operations, cost them money or damage their professional reputation (such as their attractiveness to clients - (Stenek et al., 2011)).

6.2.1.2 Changing causes and impacts of extreme events through time

Historically, actions to reduce exposure to existing infrastructure have been in the form of hard adaptation, such as the installation of sea defences during general port upgrade programmes. Reducing port exposure to extreme events can be further complicated if there are uncertainties over land ownership or responsibility. For example, at Tilbury port the East Dock sewer, for which the Environment Agency and the port was jointly responsible, was unable to cope with storm waters experienced in 2012 and 2013 (Thurrock Council, 2013). Maintenance of this sewer was delayed due to the Environment Agency having to ask the port for permission to carry out the remedial works. Although many ports are considering reducing such risks when developing plans for new infrastructure (such as quays or berths) new developments cannot always be considered wise. For example, in 2009 a proposed expansion of Leith Docks was contested by the local council due to concerns that with climate change the development, and nearby housing, could be at risk of flooding within the next 20 years (The Scotsman, 2009).

6.2.1.3 Historical management of, and responses to, extreme events

Historically management of extreme events has tended to occur in three ways within the port sector:

- **Port upgrades** - To date port upgrade programmes have focused on expansions, in line with the UK, and global, booming shipping industry. Assumptions made within such developments are that baseline conditions will remain constant throughout the design lifetime of the infrastructure or technology.
- **Reactive adaptations** – Past adaptation to extreme events, particularly weather, has tended to be in the form of reactive hard adaptations (Dilling et al., 2015), most commonly occurring in response to the most severe, or media-worthy, extreme events. These reactive, knee-jerk, responses most commonly returned a port environment back to its previous standard of conditions (Berrang-Ford et al., 2011).
- **Policies/legislation** – Multiple legislative changes have affected UK ports and the vessels that they service in recent decades. The reasoning behind these developments has largely been to increase safety, and to reduce the likelihood of injury.

UK ports are currently well prepared for the common range of disruptions they have experienced. In contrast, the port sector is not as well prepared for less common, but more severe, events, at the extreme end of the event spectrum, such as the December 2013 storm surge, where the flood gate at Immingham port was overtopped. The impacts from this severe event, which included the flooding of 75% of port land (including the port’s substation), was not forecast and has acted as a catalyst for adaptive change by the port operator, ABP.

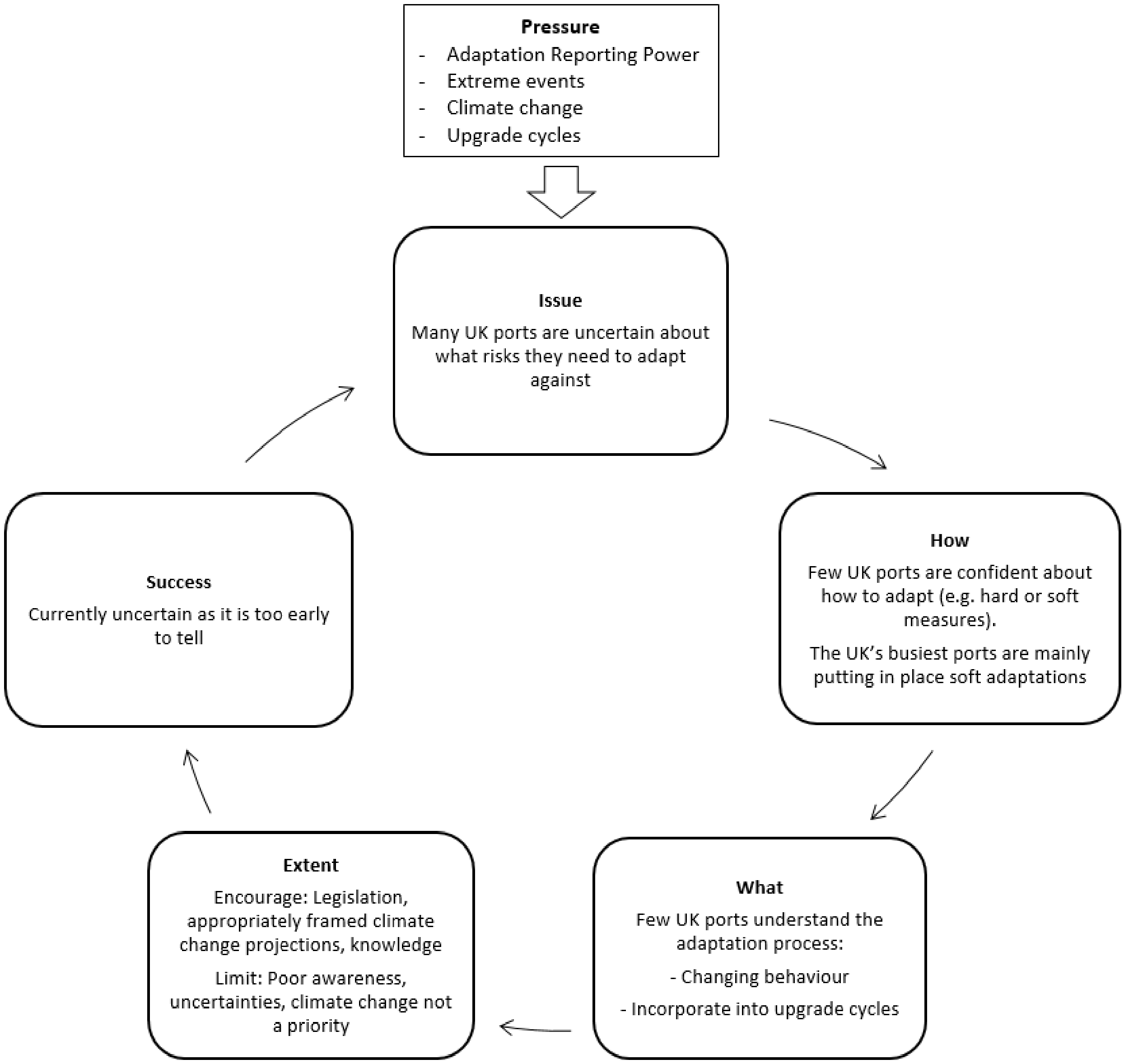


Figure 6.2: The present state of the UK port sector's climate change adaptation assessment cycle (building on Figure 2.3).

6.2.2 Present-day extreme event risk reduction

6.2.2.1 Changing awareness and preparedness for risks and impacts to port operations

The development of "just-in-time" deliveries within ports, and efficient cargo and vessel turnaround times has led to some UK ports attempting to reduce disruptive impacts for their clients by providing announcements of likely service delays. This behaviour is more apparent for passenger services as there are more repercussions, such as from the media (Beniston and Stephenson, 2004), if the public are negatively affected.

The 2009 UK Climate Projections project has acted as an important assessment of the likely challenges that will arise from climate change (Wright, 2013). However, few people working in port environments have to date been able to apply scientific projections to their future planning (Vogel et al., 2007), and this represents an ineffective use of currently available resources to guide adaptation.

Currently ports are not as well prepared for extreme events that are at the far, or most severe, end of the spectrum. Due to the rarity of these events and their low likelihood of occurrence, ports may be inadequately prepared for their occurrence (Section 6.6). With climate change, currently low frequency but high-impact, extreme events may become more common – or even the norm.

Port sector awareness of climate change, and its risks, is poor, which is limiting the extent of adaptation (Figure 6.2). The Government has only, to date, considered the climate change adaptation preparedness of the UK's busiest ports. Beyond the scope of interest from the Government, few other smaller ports are presently adapting (Jan Brooke Environmental Consultant Ltd., 2015) (see Section 5.3). A number of factors have contributed to this limited climate change awareness:

- There is little sharing of adaptation knowledge, particularly between ports, due to their competitive business nature. This contradicts a statement included within the Transport Resilience Review (Department for Transport, 2014b) where sectors, including ports, were advised that sharing of adaptation successes with their "peers" should become an accepted practice.
- Scientific data on likely climate change risks is not in a suitable, non-specialist, form for port decision-makers to easily understand and apply to their planning process. The language used within the scientific world and the port and shipping business environments is very different.

- Ports are misunderstanding what scientific projections will be able to provide in the future. A number of ports are mistakenly waiting for scientific research to be able to provide specific climate change projections for their individual operations (see Section 5.3.4).
- Limitations in current port climate change legislation, where ports are instructed to take adaptive action with no further guidance or time-scales, is not enough to encourage effective and timely adaptive action (see Section 5.3.4). Few ports currently understand the importance of putting in place proactive adaptive measures (Tobey et al., 2010), rather than adapting when climate change issues become evident or of concern. New and improved legislation is required to better address, and encourage, adaptive action. A step towards this is currently being undertaken by DEFRA whose third round of Adaptation Reporting Power is being developed to address a low response rate to the voluntary request to submit Adaptation Reports (DEFRA, 2018).

6.2.2.2 Managing extreme events

To date primarily only the UK's busiest ports are putting in place adaptations, a step largely instigated by a Government-led assessment of climate change readiness (see Section 5.2.2). Few other ports are considering either the importance or role of climate change adaptation for their future operations. To encourage adaptation due to climate change risks, it is important to develop the mainstreaming of adaptation measures (Berrang-Ford et al., 2011) into port sector operations, which could be encouraged by new legislation. The port sector may be adapting less than it is suggesting, so it is important to determine the true level of climate change adaptation that is currently being undertaken. To encourage adaptive action it is important that the perspectives of the Government and the port sector are aligned, removing current misunderstanding on how well prepared the entire port sector currently is for climate change.

Most UK ports are not currently preparing for climate change, but of the few ports implementing adaptations, port decision-makers tend to favour soft adaptations, largely in the form of planning documentation (Dover Harbour Board, 2015; Felixstowe Dock and Railway Company, 2015). This has arisen due to their lower costs, shorter lead-in times, and can often be easily reversed or altered if new knowledge comes to light, or even if the measure is found to be maladaptive.

Many ports are currently unwilling to put in place hard adaptations (which are often expensive and take a long time to install) due to current uncertainties in climate change projections. The few hard adaptations implemented to date have tended to be incorporated into usual upgrade or expansion programmes (such as the installation of articulated walkways). Exceptions occur if substantial damage or disruption is noticeable in the public eye, such as following the overtopping of the flood-gate at Immingham port in December 2013 when a new higher gate was installed to repair any damage to the port's reputation (ABP, 2017).

6.2.3 Future extreme event and climate change risk reduction

6.2.3.1 Extreme events and climate change in the short and longer-term future

From February to March 2018 DEFRA undertook an open consultation to gather opinions for the third round of climate change adaptation reporting on topics such as whether the Adaptation Reports should be a voluntary or compulsory request (DEFRA, 2018). This third round of reports, slated to be received between 2019 and 2021, will be used to, hopefully, guide integration of climate change risk management into planning documentation. Appendix L reports the consultation response detailing findings from this thesis of benefit, to improve the standard of the third round of adaptation reporting.

A challenge for decision-makers will be to contend both with climate change impacts and current operational pressures (such as business risks) (McEvoy and Mullett, 2013; Tompkins et al., 2008). It would be beneficial for the port sector to begin implementing a combination of proactive planned (e.g. upgrades to quays incorporating sea-level rise projections) and incremental adaptation measures (e.g. end-of-life replacement of high-level cranes with newer models able to function in higher temperatures). Adaptations, if well planned, can reduce the risks that will be faced by the UK port sector due to both extreme weather events and climate change, and will alter the current risk equation for the port sector (see Figure 2.1), particularly by altering a port's exposure to identified risks. To encourage such behaviour a combination of improved climate change projections and enhanced targeted legislation to guide port adaptation is needed. If adaptations are effectively included within port upgrades, such as improvements to quays or equipment, the impacts and financial costs of such projects can be more easily justified, and the disruptions caused by the installation of such works minimised.

6.3 Port sector climate change preparedness

Becker et al. (2011a) assessed 342 of the world's most important commercial ports (see Section 2.4.2.6) to assess perspectives on new infrastructure developments, and the extent that climate change is considered within operational decisions (Becker et al., 2011a, b). Becker et al.'s research focused on how climate change adaptation is being considered at a port scale by the ports who move the greatest volumes of cargo by weight globally. Although the study was global in nature, 46% of respondents were from North American ports. This study was followed by a further paper by Ng et al. (2018) who assessed the perspectives of 67 ports on the perceived effectiveness of the concept of climate change adaptation.

The questionnaire developed as part of this thesis was designed to improve on Becker et al.'s research (Table 6.1 and Appendix J). To increase the representative nature of questionnaire responses all UK ports were contacted regardless of their size, operational type or operator (whether privately owned, managed by a local authority or a trust port). Becker's study provided an important overview of global port adaptation perspectives. In contrast, the questionnaire developed within this thesis has been designed as a targeted national-scale analysis.

The strength of results from Becker et al.'s study was limited by a low response rate – just 26% of contacted ports. This low response rate likely occurred due to two primary reasons: that ports were only contacted once (no follow-up contact or reminders) and that the questionnaire was written in English which would not be a known language for all questionnaire recipients. This is compared to a 62% response rate (ports that completed a questionnaire, or confirmed that they were unable to answer the questionnaire) for the UK's 162 commercial ports. These responses have allowed the development of a much more complete picture of port adaptation across the different characteristics of UK ports. This higher return-rate was achieved by using follow-up measures and by contacting people by telephone, which achieved more positive feedback.

Prior to the findings of the questionnaire the viewpoint of the majority of the UK commercial ports had not been considered. Reports produced, to date, by the UK Government view ports on a sectoral scale, and have not interpreted the unique perspective of individual ports. The analysis presented in Section 5.3 represents the most complete, and detailed, analysis of port sector perspectives on climate change preparedness, and how great an influence they expect climate change to be on their operations in future decades.

6.4 Current perspectives on the UK port sector and climate change

When assessing the current and future challenges of extreme weather events and climate change for the UK port sector a number of different perspectives are available. Contradictory perspectives are particularly apparent between:

Table 6.1: Comparison between Becker et al. (2011b) and UK port questionnaire studies

	Becker et al. (2011b)	**UK port questionnaire**	**Differences between Becker et al. (2011b) and the UK port questionnaire**
Contacted ports	5% of global ports (Lloyd's List, 2015b)	Contacted all UK commercial ports	• Becker: Broad study, and the first to assess port climate change globally. • UK questionnaire: A detailed UK assessment.
Types of ports included within the study	Only contacted members of International Association of Ports and Harbors or the American Association of Port Authorities	All commercial UK ports were contacted regardless of their port organisation or operator	• Becker: Only the busiest ports were contacted across the globe, with a bias towards ports located in North America. • UK questionnaire: All UK ports were contacted regardless of size, which removed a bias in the sampling method. Smaller ports were also contacted as the importance of their preparations for climate change had not previously been considered.
Size of ports contacted	Globally commercially important	All commercial ports (both major and minor)	
Questionnaire response rate	Low response rate (26%), and no follow-ups were carried out	62% response rate (respondents either completed, or were unable to complete, a questionnaire) and a range of follow-up measures	• Becker: A poor response rate arose due to issues with contacting ports, and a lower response rate from respondents for which English was not their first language • UK questionnaire: By using follow-up measures and making contact by telephone, respondents were more likely to be willing to discuss the topic of climate change adaptation in the context of their operations.
Contact style	Questionnaire was emailed, no specific contact with respondents	Non-respondents were contacted by telephone to discuss adaptation	

Table 6.2: Differing perspectives of ports, UK Government and researchers on the perceived future of the UK port sector under the challenges of climate change. Summary of findings from Section 6.4

Identified in this thesis	**Perspectives on the perceived current and future challenges for the UK port sector agree with the findings of this thesis**			
	UK Government	**Major ports**	**Minor ports**	**Published literature**
Extreme weather events are an important issue for UK ports	X	X	X	X
Climate change is not viewed as a pressing issue for UK ports	X	✓	✓	X
There is limited port-sector awareness of the need for climate change adaptation	X	✓	✓	X
Most UK ports are not yet adapting for climate change	X	✓	✓	✓
The UK port sector is not well prepared for climate change	X	X	X	✓
Current climate change legislation and policies is not enough to help the port sector adapt	X	✓	✓	X
The motivations of many port adaptations is often not climate change	X	X	X	X

- Publications produced by the UK Government, or on its behalf,
- Reports and statements provided by major, and minor, ports,
- Research published within the scientific literature.

A missing, yet important, perspective is from industry reports which are not in the public domain. Table 6.2 highlights and compares the differences in perspectives for a number of issues critical to the UK port sector and climate change. The findings from this thesis disagree with many published perspectives on how the UK port sector will fare under climate change, particularly if impacts arising from climate change begin to affect the port sector sooner than current projections suggest. Publications by the UK Government provide a very positive perspective on how well prepared UK ports are, and will continue to be, under climate change. Extreme weather events are considered as a known business risk, for which ports are well prepared due to their diverse and detailed experience of contending with such challenges. Government reports views the port sector as actively considering and preparing well for climate change, by assessing the likely risks they will face in future developments and by putting in place adaptation measures. The Government views the port sector as both willing and able to put in place effective and timely adaptations without further guidance (Department for Transport, 2007). The Government's very positive perspective on port sector climate change preparedness contradicts many of the findings of this thesis, and are discussed in the following sections.

Differences in perspectives between those published by commercial ports, and the findings of the research in this thesis are largely due to framing and can act as a barrier to effective adaptation. The complexity of the challenges facing ports from climate change can also act as a barrier for adaptive action (Tobey et al., 2010). As the UK port sector is not economically regulated there is less available information on its resilience (Dawson et al., 2016). Ports confirmed within completed questionnaires that they are poorly prepared, and most importantly are not well informed about how climate change is likely to affect their future successful operations. However, reports published by ports in the public domain provide an optimistic perspective on how well ports are currently prepared for climate change, and that they are implementing more adaption measures than is strictly accurate. This positive framing reflects ports taking steps to maintain a good reputation with clients, and to show no signs of potential weakness to ports with which they are in business competition.

Limitations of much of the published literature is that the primary source of data used in these reports are those published by the Government and ports. This has introduced a bias as statements by the Government and ports are largely accepted without the motivations behind them being investigated. The most significant exception to this is research published by the

Committee on Climate Change who state that the limited involvement of ports to provide updates on their adaptation progress is an issue which needs to be taken into consideration (Committee on Climate Change, 2015), and that it is vital for effective sector adaptation that this perspective changes.

6.4.1 Extreme weather events are an important issue for UK ports

Extreme weather events have been an important issue for UK ports both historically and in the present day (Table 6.2). The findings from this thesis contradict the perspectives of the UK Government, ports and published literature who state that extreme weather events are an accepted risk for port operations, and are not an issue of concern.

It is important that extreme events, and how they affect port operations, is well understood. The potential impacts of extreme events are diverse and have financial implications for ports (Scott et al., 2013a). Recovery from extreme events can be a long process, especially if infrastructure or specially designed equipment (such as high-level cranes) is damaged (Shafieezadeh and Ivey Burden, 2014).

It is predicted that extreme events will become a more pressing issue in the future due to changing baseline conditions and risks due to climate change. The Driver-Pressure-State-Impact-Response model (see Figure 2.2) can express changing the risks for UK ports from extreme events and climate change.

With climate change, ports may need to contend with extreme event types and impacts for which they are not currently well prepared. To respond to climate change risks port decision-makers will need to develop new responses, such as implementing adjusted operating limitations or improving air conditioning and drainage facilities. It would be of particular benefit for UK ports to learn from ports who already experience the likely challenges they may face in the future (Department for Transport, 2014b). For example, some Australian ports use equipment which is able to function safely at higher operating temperatures than those currently used in the UK.

6.4.2 Climate change is not viewed as a pressing issue for UK ports

Communications with UK ports confirm that climate change is not currently an issue of major concern for successful port operations (Table 6.2). This contradicts publications in the published literature, and within Government reports, which instead assume that the port sector is very aware of the concept of climate change and is giving due consideration to the need to put in place adaptation measures.

The major difference in perspective between time-scales of port planning and climate change projections is an important issue (Scott et al., 2013a). Port planning is focused on short-term business risks (United States Environmental Protection Agency, 2008), such as shifts in supply and demand, the increased focus on "just-in-time" deliveries and competition between ports for shipping contracts (Wang et al., 2007). The primary operational focus of ports ranges from the day to day through to approximately a year in advance. This perspective has arisen largely due to the fact that ports are a profit-driven business where any loss of trade could have devastating impacts. Major infrastructure developments have long design lifetimes, and if climate change knowledge is not effectively incorporated at the design stage the development may not continue to be effective throughout its intended lifetime.

The long time-scale and gradual changes makes climate change an intangible issue for many port decision-makers to contend with. Other issues, such as those associated with trade and business, which are known current risks, tend to be seen as more important as their effects can be measured for the present day. Ports are also more likely to put in place "green" mitigation measures which are attractive to clients, and are not considered such a business risk (Knatz, 2015).

As a number of climate change risks are in many ways uncertain regarding their extent or nature of impacts, ports are unwilling to put in place measures that may result in overcompensating for climate change. In such circumstances finances which could have been invested elsewhere would be potentially only providing limited benefits.

6.4.3 Limited port sector awareness of the need for climate change adaptation

UK ports have limited awareness of the need to begin considering, and implementing, adaptation measures (Table 6.2). Published literature, and Government reports, assume that the port sector's extent of awareness for adaptation is greater than is strictly correct. Climate change adaptation is not an active topic of conversation in many UK ports, and port sector understanding of adaptation is poor. A common misunderstanding is confusing "adaptation" and "mitigation" where actions to green a port by reducing its $C0_2$ emissions are framed as a type of adaptation. Many adaptation measures will have beneficial impacts decades earlier than the effects of mitigation will begin to be felt (Fussel, 2007).

From conversations with ports it is clear that more guidance from the Government and scientists would be welcomed as ports are unsure about the challenges they are likely to face from climate change (Berrang-Ford et al., 2011). This is not an issue that exclusively affects the UK port sector as studies by Scott et al. (2013a), McEvoy et al. (2016) and Smith (2015) found that Australian and North American Naval ports would also appreciate guiding information on how extreme weather event risks may change due to climate change.

6.4.4 Most UK ports are not yet adapting for climate change

Many ports (both major and minor) are not yet putting in place climate change adaptations due to uncertainties in current projections. These uncertainties provide a key barrier for current port sector adaptation (see Table 2.4), and it is imperative that such uncertainties do not encourage inaction (Drew et al., 2010). The limited extent of current port sector adaptation is a confirmed issue both within ports themselves and is reported upon in the published literature, although the UK Government assumes that the entire port sector is taking active steps to prepare for climate change.

Ports are profit-driven businesses, and any investment needs to be justifiable to maximise their economic success (Wiltshire, 2014). It is very difficult when the extent and severity of potential impacts from climate change are uncertain to justify the costs (Adger et al., 2009) of infrastructure adaptation measures that have both long life-times and high costs (Vellinga and De Jong, 2012), particularly when uncertainties are present in climate projections (Zhang et al., 2017). This perspective is echoed by many UK ports, who confirmed within questionnaire responses (see Section 5.3) that they are unwilling to begin considering adaptation before being provided with a range of information and assurances, including the extent of likely climate change impacts for their future operations. In situations where ports are part of a larger company information (such as on adaptation needs or successes) are often not shared within all members of the company group (Gerrard, 2016).

The most common type of adaptation currently either underway or completed within the UK port sector tends to be soft adaptations, which provide ports with an opportunity to build their adaptive capacity (Smith, 2015). Other areas of the UK transport sector (road, rail and air) have similar perspectives on adaptation, and are focused on implementing mainly soft adaptation measures. Hard adaptation measures are detailed within the port sector Adaptation Reports but are largely limited to the future, in the context of proposed conceptual long-term projects such as the relocation of moorings to prevent storm damage or movement of IT systems to areas with low flood risk (see Appendix I).

6.4.5 Current climate change legislation and policies are not enough to help the port sector adapt

Many UK ports do not know where to begin when it comes to climate change adaptation. These ports are waiting for the Government or the scientific community to provide additional guidance and advice. The UK Government has only provided general guidance for ports, advising that they should adapt to climate change. This guidance does not:

- Advise ports when they should begin to consider putting in place adaptations,
- State whether climate change should be prioritised alongside other known business risks,
- Provide advice on resources that can inform ports how to begin the adaptation process,
- Provide advice on the likely risks or challenges the sector will face due to climate change,
- Provide any discussion on what climate change is likely to mean for the continued operational success of the port sector.

6.4.6 Port adaptations are often not purely motivated by climate change

The commercial port sector is a business for which success is greatly reliant on a good reputation with clients. Within Adaptation Reports published in the public domain by the UK's busiest ports framing is used to give the appearance that they are achieving a higher standard of climate change adaptation than is accurate.

To date UK Government papers and published literature accepts reports of proposed adaptations by ports without assessing their underlying motivations or suitability to contend with the challenges of climate change. It is important that the true motivations behind so-called adaptations are identified to develop a more true representation of the extent of "real" climate change adaptations which are being undertaken by the UK port sector.

6.4.7 The port sector is not well prepared for climate change

Publications by the UK Government and ports consider the port sector to be, or rather – will be soon, prepared for the many challenges and risks associated with climate change. Conversations with representatives from ports have highlighted that the port sector is in fact unsure about how well prepared they currently are, with this uncertainty stemming from a poor understanding of the likely risks they will face from climate change.

Research by the Committee on Climate Change (2015) has raised concerns regarding the lack of participation, and willingness, of the UK's busiest ports to participate in assessing their adaptation needs. Effective port sector adaptation has the potential to improve both the efficiency of port operations, and improve the quality of planning decisions (Ng et al., 2016).

6.4.8 Comparisons between the benefits of proactive and incremental adaptations

It is advised within, both the published literature and Government reports, that UK ports should put in place adaptation measures (Climate Change Act, 2008). However, there is no suggestion within the Climate Change Act of when, or how, the port sector should begin to put into place adaptation measures. Many UK ports are not confident about beginning adaptation until they become more aware of the likely risks they will face from climate change.

If ports take adaptive action two main types of action can be considered: either focusing on acting in a proactive manner, or taking a more cautious approach in the form of incremental adjustments. Port decision-makers need to carefully consider the extent of adaptation that will be required to prevent the likelihood of risks to the safety of those working in, or visiting, port environments (Thorsen, 2014c) from increasing in future decades. The need for adaptation differs between the design life of the particular infrastructure, or equipment, in consideration. Regular renewals of infrastructure or equipment with short design lives, such as those associated with asphalt surfacing or straddle carriers, are expected to incorporate improved climate change awareness within usual upgrades. In contrast, consideration of future climate change risks for infrastructure or equipment with longer design lives, such as breakwaters or berths would be of greater benefit.

Proactive adaptation options have the potential to provide great benefits for ports and their successful future operations. By acting in a proactive manner ports have the opportunity to reduce the risk of future damages to their operations. If ports do not act in a proactive manner they are likely to, at some point in the future, experience a range of costs including damage (to infrastructure, equipment and cargo), loss of trade and potential profit, and a dented business reputation (at least temporarily). Although the costs of proactive adaptations can be substantial this needs to be weighed against the costs of not adapting, and port decision-makers need to be able to justify this choice. Proactive adaptation is particularly important for major ports who provide a unique vital service for the UK, especially if their processing equipment and operations cannot be taken over temporarily by an alternate port. Many smaller commercial ports may find proactive adaptation to be a financially unsuitable option.

Incremental adaptations allow ports to adapt and transition gradually (Kates et al., 2012) to changing baseline conditions and provide a number of opportunities to spread the costs (in terms of finances or time) of adaptation measures. The concept of incremental adaptations has the potential to become an attractive option for many UK ports, and can benefit ports by gradually developing a culture of resilience. By adjusting in an incremental manner ports will be able to focus the majority of their resources on present-day pressures (such as business competition), and implement further stages of adaptation when climate change becomes a more pressing operational issue.

Gradual adaptations can incorporate improvements in climate change projections, and reduce the likelihood of either maladaptation or overinvestment from occurring. Multi-stage adaptations, where changes and upgrades incorporate the best knowledge available at the time, may be more easily financially justified, and can be framed from a port operator’s perspective as potentially a more effective use of financial resources. Incremental adaptation would be particularly beneficial for minor ports as it provides an opportunity for them to spread the costs of their adaptation needs. For ports that have specialised cargo handling facilities (Thorsen, 2014b) incremental adaptation may be of particular benefit due to the fairly rapid rate of technological advancements in such environments.

The findings from an analysis of the Adaptation Reports and Questionnaire suggest that a third option – a combination of proactive and incremental adaptations – would best prepare the UK port sector for climate change. Proactive adaptation can focus on adapting to known climate change (and extreme event) risks whereas incremental adaptation can aid preparations to risks for which the extent of changes are currently less certain. Port sector adaptation, whether in the form of hard or soft adaptation measures, should incorporate flexibility. The incorporation of flexibility into adaptation decisions can help to contend with uncertainties in current climate change projections and impacts for the UK port sector.

6.5 The UK port sector and adaptation planning

6.5.1 The role of Government in promoting port adaptation

Although implementing adaptation measures remains the responsibility of port decision-makers the supporting role of the Government has not yet been considered or addressed. This is a missing perspective and acts as barrier to effective port sector adaptation. Currently, the port sector (in the form of statements from port decision-makers – see Section 5.3) considers the Government as not providing suitable support to facilitate adaptation. Effective, and appropriate, guidance for adaptation (such as requiring all UK commercial ports to assess their adaptation needs) could significantly improve sector-wide climate change preparedness. The Government has the potential to provide three critical roles for the port sector:

- Guidance – Encouraging, and facilitating, ports to take appropriate adaptive action,
- Providing knowledge – Direct ports as to how they can access relevant scientific information and projections,
- Advice/legislation – Encourage, or require, the port sector to consider and act on their adaptation needs.

Through these three roles the Government has the ability, and the opportunity, to initiate adaptation throughout the entire port sector. A significant change in port behaviour and priorities, can be instigated by a combination of new legislation and advice on how adaptation needs to be addressed.

To be able to initiate adaptation, a major barrier – ineffectual communication between the port sector and the Government – first needs to be overcome. A change in behaviour needs to occur within both the Government and ports however. Currently the Government views ports on a sectoral, rather than an individual, scale. Its viewpoint is focused on ports identified as of particular importance to the UK trade network (due to being the busiest commercial ports) (DEFRA, 2018). However with climate change it will become more important for the Government also to consider the adaptation preparedness of the UK's smaller commercial ports. It would be beneficial for a confidential dialogue (which would prevent any weaknesses or concerns being communicated to competing ports) to be opened between the Government and ports to discuss the true extent of their climate change readiness and needs for adaptive guidance.

The Government is currently focused on the adaptation preparedness of the UK's busiest commercial ports. However, many smaller commercial ports carry out unique operations that are important on a regional, or even national, scale. It would instead be beneficial for all commercial ports, regardless of their size, to be provided with generic sector appropriate guidance by the Government to aid adaptation.

6.5.2 The relationship between ports and their surrounding areas

6.5.2.1 Ports and the port-city relationship

Ports exist as part of a wider landscape, and network, of businesses and communities. Historically, the UK's port sector have considered many of their actions and operations in isolation to the wider community.

Currently, ports located within, or near, cities have a complex relationship with the surrounding land, businesses, public and local government. Through their location and physical infrastructure ports provide a number of services to stakeholders in their local area (both on and beyond the boundary of port land). Ports are located on the interface between the land and sea, and can protect the surrounding city from extreme event risks, such as flooding and associated damage.

Protection provided by ports for the wider port-city has particular benefits for local councils through reducing flood risk to businesses, homes and transport infrastructure (such as road and rail links) adjacent to port land. However, any failure to uphold these services can lead to negative media attention, particularly focused on local councils, or even national Government rather than ports themselves. Negative press can encourage councils to take action to reduce future risks to local populations and businesses (Pigna, 2014). The port sector, being private businesses, currently isolate themselves from the wider port-city, and do not always put in place maintenance or upgrades which would reduce extreme event risks for the wider area. For example, following the repeated flooding of multiple properties in Tilbury, sediment blockages were identified in the local sewerage system (Thurrock Council, 2013). Despite this blockage being located on land owned and managed by the port of Tilbury the port took no action, and the Environment Agency was required to liaise with port decision-makers to enable their staff access and allow maintenance to be undertaken. Also, following the flooding of Immingham port, and neighbouring businesses during the December 2013 storm surge, a grant of £4.5 million was provided by the Environment Agency to North East Lincolnshire Council to invest in new outer lock gates and to raise sea defences at the port (Watson, 2017).

Some of the UK's busiest ports are beginning to integrate port operations with that of port stakeholders by developing emergency forums where businesses can act in tandem in response to periods of disruption or damage (see Appendix I). Ports need to develop a fuller understanding of their interconnectivity within the wider community beyond the port boundary – including the port-city, transport networks and power supplies (DEFRA, 2009a). Some of the UK's busiest ports have expressed concern regarding how potential disruptions to their wider connections, such as road and rail networks and power supplies, can affect their operations (Dover Harbour Board, 2015; Felixstowe Dock and Railway Company, 2015; Milford Haven Port Authority, 2015; Royal Haskoning, 2011a). This issue has the potential to become particularly important in future decades as climate change risks become more pressing. It would be beneficial for local councils to facilitate, and encourage, ports in integrating their preparedness for climate change and extreme weather events in conjunction with neighbouring businesses and operators. Effective integration of climate change assessment and preparedness between ports, local councils, city stakeholders and non-statutory bodies (such as DEFRA and the Environment Agency) has the potential to enable sharing of successful adaptation experiences and the development of cost-effective adaptation measures.

Climate change may alter the relationship between ports and the port-city, and the nature of this change may depend on the extent, and nature, of adaptation measures implemented by the port sector. It is possible that the proximity of ports to their port-cities may act as an additional motivation in two particular ways for ports to put in place adaptations. Firstly, the close spatial positioning of ports to the port-city can develop an opportunity for ports to adapt in conjunction with local authorities (such as local councils or the Environment Agency), such as improvements to sea defences or enhancements to drainage systems. Secondly, if extreme event impacts, such as flooding, are felt beyond the port boundary, or affect non-port businesses or buildings, ports may be encouraged to put in place improvements to reduce the re-occurrence of unacceptable risks to the local community. Lastly, if the port-city experiences multiple damaging or disruptive events (such as the flooding of local homes and businesses) and suitable adaptation measures are not implemented by port decision-makers, local councils make be required to consider whether compulsory land purchase, to allow the development of sea defences or other protection measures, would be a wise course of action.

6.5.2.2 Comparisons between Government perspectives on port and coastal adaptation

Current Government perspectives on adaptation between port and coastal areas are substantially different. This is despite similarities in the types of adaptation measures which could be implemented to defend ports and coastal areas, and the life-spans of protective infrastructure (such as sea-defences).

Local councils, Government agencies (such as the Environment Agency) and national Government lead national adaption of coastal areas to flooding and associated damage. Funding for coastal flood protection is nationally allocated according to need (DEFRA, 2017), and spending is justified to the public through the media and Government reports. Public accountability of any failure of coastal defences has aided development of a longer-term perspective, on the scale of the infrastructure's lifespan. The national interaction of organisations, such as the Environment Agency, aids the sharing of adaptive experiences and knowledge between regions.

In contrast to coastal flood defences the Government views ports on a sectoral scale (DEFRA, 2014a), rather than considering differences on a regional level. The only exception to this is if a port which carries out unique operations of national importance experiences severe disruption or damage to its operations. Port upgrades and adaptations have a short-term perspective, focusing its resources on more tangible business risks. This short-term view, and broad-scale Government perspective, makes port adaptation less easy to plan for than adaptation of coastal areas.

6.5.3 Low cost port adaptations to current conditions

The UK port sector is currently well prepared for the range of extreme event challenges they experience on a semi-regular basis. Most common current impacts of extreme events on ports are in the form of disruptions to day-to-day operations or more severely, pre-emptive shutdowns of part or all of a port during an extreme event.

Ports are currently less well prepared for rare, more severe, extreme events. Such low frequency high-impact events are the worst-case scenario that currently face the UK port sector. The extreme weather event types that most commonly have the potential to cause the most severe impacts for ports are currently storm surges, wind storms and extremes in temperature (including snow and ice), and their impacts for port operation can be diverse. The widest range of current risks facing the UK port sector is from storm surges, with impacts from a combination of seawater inundation and damage to port infrastructure and equipment.

It would be beneficial for all ports to assess what the impacts of a worst-case scenario event (such as a storm surge or wind storm) would be likely to have on their operations and infrastructure. A suitable extent would be to consider a 1:1000 return period, for which over the next 100 years (a typical design life for port infrastructure – see Section 6.6) there would be only a 9% chance of a greater than 1:1000 year event occurring. Some of the UK's largest ports are carrying out assessments, such as through flood mapping (Dover Harbour Board, 2015; Felixstowe Dock and

Railway Company, 2015), but few smaller ports are considering the worst-case scenarios potentially facing their operations. A 1:1000 return period (or 1:1000 event plus high tide for storm surges), compares with the tidal storm surge that flooded Immingham port on the 6th December 2013 which had a 1:760 return period event (French et al., 2017a, b).

The most severe risks from, and impacts of, extreme events currently facing the port sector as identified by the UK's busiest ports (see Section 5.2.3):

- Infrastructure damage,
- Flooding of port land,
- Supply issues,
- Cargo damage,
- Dangerous working conditions.

To effectively contend with the potential risks to port operations a range of low-cost measures can be developed, particularly if incorporated into renewal cycles (Table 6.3). Some of the UK's busiest ports have begun to implement adaptation measures (see Appendix I) which can reduce risks from current extreme event conditions (including flood mapping, enhanced maintenance schedules and the implementation of new TEU stacking techniques to increase resilience to wind gusts) (ABP, 2016; Dover Harbour Board, 2015; Felixstowe Dock and Railway Company, 2015).

6.6 Port planning timescales

6.6.1 Conventional port planning timescales

Current port planning horizons are typically split into short (0-5 years) and long-term (5-25 years) timescales (Peel Ports, 2011). These timescales are designed to primarily implement infrastructure upgrades (by replacing worn infrastructure and to meet updated design specifications) (Figure 6.3) or to expand port operations to take advantage of business opportunities. Beyond 25 years in advance there is little or no port planning. Port upgrade schedules depend greatly on the expected design lifespan of infrastructure and equipment, ranging from the short-term (e.g. road surfacing) to the long-term (e.g. breakwaters) (Thorsen, 2014b). Examples of common port infrastructure and equipment types are detailed in Table 6.4 and can be split into two main groups: maintenance (upgrades and replacements) and new developments.

Table 6.3: Low cost adaptation options to defend against current conditions, and whether they are being implemented by UK ports.

Extreme event impacts	Event types	Low cost adaptation options	Currently being implemented
Infrastructure damage	• Storm surge • Wind storm	Build flexibility into infrastructure during renewal cycles	
Flooding	• Storm surge	Improve drainage efficiency through improved maintenance	
		Flood mapping	✓
		Use temporary defences or flood proofing to protect key systems	
		Identify back-up power sources	✓
		Waterproof coating for overland power cables	
		Enhanced maintenance schedules	✓
		Use new surge prediction technology (e.g. Artificial Neural Network forecasts - (French et al., 2017b))	✓ (tested at one port – Immingham)
Supply issues	• Snow and ice • Storm surge • Wind storm	Building stores of resources (e.g. water, fuel)	
		Allocate additional storage zones	✓

Damage to cargo	• Storm surge • Wind storm	Stacking techniques to prevent TEUs being dislodged	✓
		Relocate cargo to less wind sensitive areas	
		Investigate methods for increasing crane stability in high winds	
		Model wind gusts across port land	
		Develop new regulations for tug use to reduce collisions	
Dangerous working conditions	• High temperatures • Snow and ice • Wind storm	Under-ramp heating for key access points	✓
		Enhancements to port grit supplies and spreaders	✓
		Consider methods to de-ice crane rails	
		Re-paint buildings white to reflect heat	
		Retrofit port crane air conditioning	

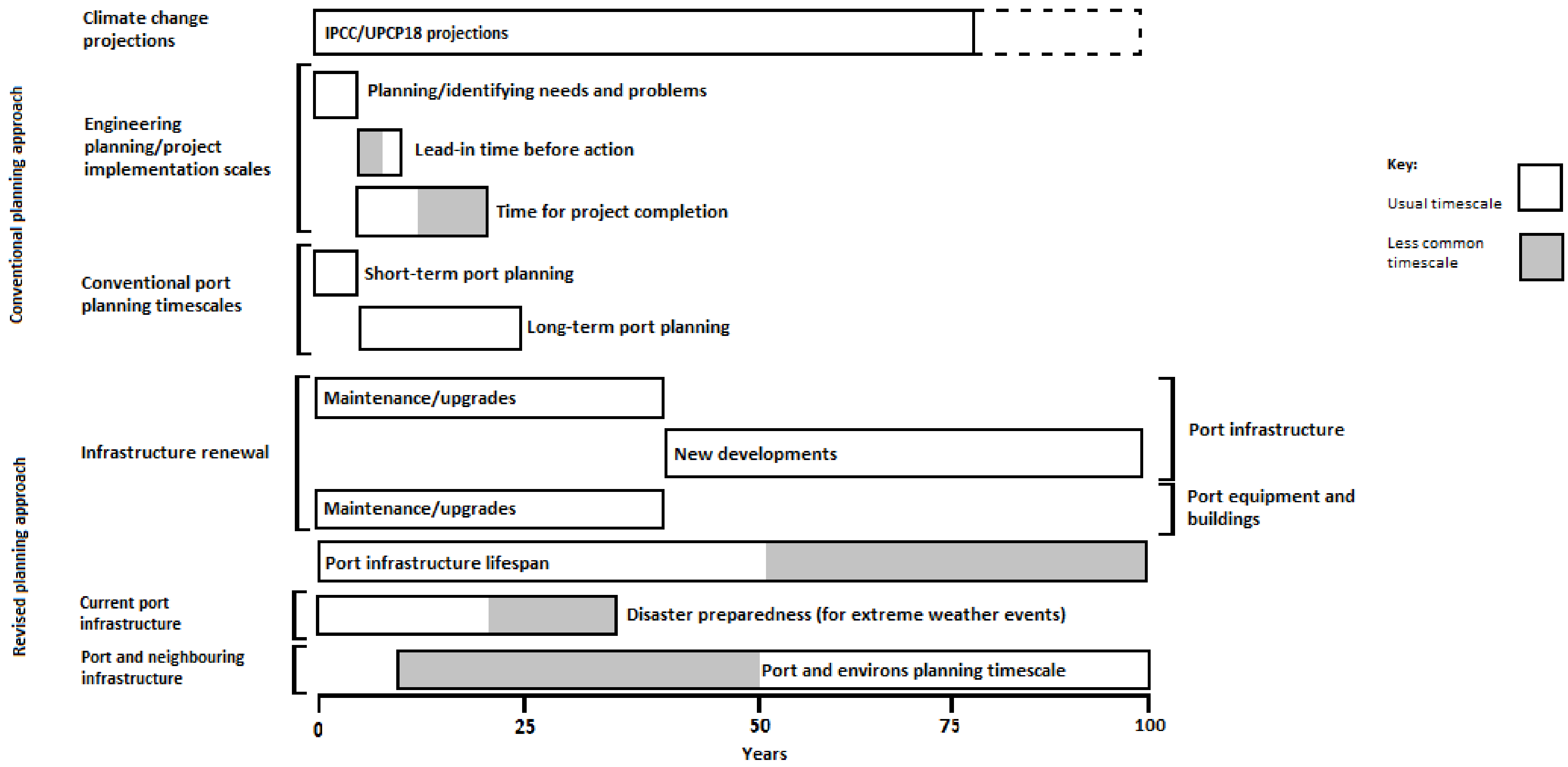


Figure 6.3: Comparisons between conventional port planning and the new port planning timescale. Conventional port planning timescales are adapted from Savonis et al. (2012).

Table 6.4: Design life of common port infrastructure and equipment, and are split into maintenance/upgrades (normal text – 0-40 year lifespan) and new developments (italics – 40-100 year lifespan). Whether the infrastructure and equipment are more likely to be affected by extreme events or climate change are detailed. Adapted from Thorsen (2014b).

	Estimated design life (years)	**Impacts throughout their lifespan**	
Port infrastructure		**Extreme events**	**Climate change**
Asphalt surfacing	10	✓	
Breakwater	100		✓
Concrete aprons and roads	20	✓	
Reinforced open berth structure	50-100		✓
Rubber fenders	10	✓	
Steel sheet pile berth structure	50		✓
Port equipment and buildings			

Container gantry cranes	20	✓	
Fork lift and reach stackers	10	✓	
Mobile container cranes	15	✓	
Road tractors	10	✓	
Straddle carriers	5-10	✓	
Warehouses and sheds	40	✓	

In recent decades UK port planning decisions have tended to occur as a result of four distinct motivations: port upgrade, reactive adaptation (to extreme events), policies/legislation and changing business needs. These motivations have evolved in recent decades and reflects changing technologies and behaviours in the UK port sector. Experienced disruption and damage from past extreme weather events have encouraged developments in ports in the form of technological upgrades, equipment and behaviour, alongside new national policy and legislation developed to address environmental and health and safety issues.

There is a major mismatch between current port planning and climate change timescales, and this is a significant barrier to timely and effective adaptation. The two time-horizons currently used (short-term – 0-5 years – and long-term – 5-25 years (ABP, 2010; Peel Ports, 2011)) are incompatible with known port infrastructure life-spans which for infrastructure (such as berths) can extend from 50-100 years (Table 6.4) (Thorsen, 2014b). It is therefore, important for port decision-makers to consider how the conditions port infrastructure will be situated in during its intended life-time will potentially alter with climate change.

To date few ports have begun to consider their relationship to their surrounding area, and even less are considering the benefits of adapting to climate change in conjunction with local cities and authorities. If ports continue to act in isolation to the challenges, including climate change, that they face ports will potentially be physically cut off by cities located behind the port who will be actively adapting to protect their local populations and businesses.

The following section proposes a new port planning timescale which has been designed to consider the full range of life-spans of port infrastructure and equipment, particularly in terms of considering how conditions will likely to alter due to climate change before their renewal is due.

6.6.2 Port planning including climate change

Responses from questionnaires sent to all of the UK's 162 commercial ports (see Section 5.3.2) identified the perspectives of port decision-makers on current planning timescales, and their preparedness and concerns for the developing challenges of climate change. Twenty-nine port confirmed that they are uncertain regarding how to begin adaptation and are, in fact, unsure about what risks climate change will likely have for their operations. The UK port sector is currently most aware of risks associate with sea-level rise, but are uncertain as to how other risks (such as the occurrence of storm surges, wind storms or rising mean temperatures). They also would be fully able and willing, if given more direction, to prepare their operations and infrastructure for the multiple challenges of climate change. A new port planning timescale has been developed to resolve these uncertainties, and to highlight that port sector adaptation can occur in a gradual, more certain, form.

Not all infrastructure, equipment and building renewals are equally at risk from climate change (Stenek et al., 2011). Some infrastructure and equipment is common between most ports and represent risks that should be considered by the port sector in general (Stenek et al., 2011). Many smaller developments have shorter lifespans and will be altered or replaced before climate change impacts, such as sea-level rise or changing frequencies or severities of extreme weather events, become an important issue. Instead, it is more important for port decision-makers to focus on long-term infrastructure, with life-spans exceeding 50 years, which will experience environmental changes and pressures due to climate change during its lifetime.

It is likely that the business priorities, technology and infrastructure used within ports will alter through time. This new planning timescale has been designed to remain appropriate despite such changes, combining an understanding of the importance of flexibility in adaptation, and the awareness of key factors (such as port location and trade types) that will almost certainly remain constant for decades.

To effectively contend with gradual changes due to climate change and new associated risks ports will need to consider a broader planning horizon which includes the entire lifespan of its infrastructure and the importance of recognising its connectivity to neighbouring areas (especially cities, transport links and utility services). To accommodate both sudden shocks in the form of extreme weather events and creeping change (changes in extremes such as under sea-level rise) due to climate change it would be beneficial for ports to consider upgrades and planning on three general timescales (Figure 6.3). The new port planning timescale balances shorter-term disaster preparedness for extreme weather events and the longer-term view of port and environs planning through the entire lifespan of port infrastructure and equipment. These are detailed below:

- **Infrastructure renewal (0-100 years):** A continual cycle, the regularity of renewal depends on the lifetime of infrastructure (Lo Bianco and Giddings, 2010). Infrastructure renewal is split into port equipment and buildings and port infrastructure (Figure 6.3). Port equipment and buildings tend to have short to medium-term lifespans (up to 40 years) and renewal tends to occur in the form of maintenance or upgrades. Port infrastructure lifespans ranges up to 100 years, and renewal occurs as a combination of maintenance or upgrades (up to 40 years) and new developments (from 40-100 years). The benefits of adapting to sea-level rise has been an identified issue within the literature through recent decades, such as by Dronkers et al. (1990) who considered the potential benefits of hard or soft structural solutions, whilst also recognising the need to tailor adaptations to the specific needs of the coastal zone in question. Current port design specifications for new infrastructure developments require the consideration that between 2010 and 2060 sea-level rise for between 0.25 and 0.30 meters is expected (Thorsen, 2014b), although future sea-level rise may be large and is currently highly uncertain (Nicholls et al., 2014). Therefore, recent infrastructure developments and infrastructure located within the UK's newer ports have been built to withstand predicted sea-level rise during their lifetime. If ports are aware of the spectrum of extreme events impacts for their operations areas where enhancements during upgrades would be particularly beneficial can be identified. Infrastructure or equipment upgrades need to be designed to meet projections of the severity of risks (e.g. from storm surges) expected to affect their functionality throughout the infrastructure lifetime (Thorsen, 2014c). This is of particular importance for infrastructure with long life-spans (such as berths) as often maintenance is assumed to not be required before renewal occurs.

- **Disaster preparedness for extreme weather events (0-20 years):** The port sector is both well aware of, and prepared for, the current range of risks from extreme weather events. To reduce both the severity and duration of extreme event impacts ports have in place multiple health and safety measures to reduce the likelihood of damage or injury. When preparing for current extreme weather events actions taken by port decision-makers consider current equipment and infrastructure in the context of short-term planning. In recent decades improvements in port awareness of risks from extreme event drivers, and their range of impacts, has greatly reduced the damages ports experience. For example, the severity of impacts from storm surge events have declined since the 1950s due to a combination of improved even forecasting techniques, the development of a national tidal gauge network and enhancements to sea defences (Adam et al., 2016). However, further improvements need to be made, and it would be beneficial for ports to consider the potential impacts of worst case scenario extreme weather events. The abnormally storm winter of 2013/14, which included the December 2013 storm surge (during which Immingham port's flood gate was overtopped), highlighted how multiple ports can experience damage or flooding during a single event. A total of 21 UK ports experienced damage, or flooding, during the winter storm events (Fenn, 2017). Where port decision-makers put in place coping measures and adaptations designed to contend with known or anticipated risks from extreme weather events. Recently, a number of UK ports (including Belfast and Dover) have acted to reduce the risk of flood damage to cargo by carrying out flood mapping for the port and reallocating cargo storage locations (Belfast Harbour Authority, 2013b; Dover Harbour Board, 2015).

- **Port and environs planning timescale (50-100 years):** Current port design guidelines are limited in terms of climate change consideration, and the only risk explicitly considered is sea-level rise (Thorsen, 2014b). It will become important for UK ports to consider how conditions will likely change due to climate change in future decades, and to develop a longer-term planning perspective which considers port infrastructure or equipment which has a greater lifetime (such as berths or breakwaters) and the relationship between the port and neighbouring areas. Traditionally ports have not considered this relationship and yet climate change and adaptation to climate change could have effects on the ports, particularly as sea-levels rise and new risks to their operations arise.

It would be beneficial for ports to consider these three parts of the planning timescale in conjunction, as they balance shorter-term disaster preparedness for extreme weather events and the longer-term view of port and environs planning through the entire lifespan of port infrastructure and equipment. This longer-term view will allow consideration of how baseline risks will shift with climate.

It would be beneficial for the port sector to add flexibility into port decision-making through:

- Grouping of port infrastructure, equipment and buildings into those that will be covered by maintenance or upgrades, and those that will need to have adaptations put in place in the form of new developments.
- Improvements or refinements to port infrastructure as new, improved climate change projections and knowledge becomes available.
- Strategic port planning incorporating how ports interact with their surrounding environment (including coastlines, cities, transport networks and utility services).

6.7 The future of UK port sector adaptation

The UK port sector is well prepared for the current common range of extreme event types, and their impacts, that can affect their infrastructure, equipment and operations. The current level of disaster preparedness (see Section 6.5 and Figure 6.3) for most extreme events is good, apart from “extreme” extremes which represent present-day worst-case scenarios.

Recognising, and preparing for, worst-case scenario events have the potential to act as an important bridge between present-day conditions and future risks associated with climate change. In many cases some of the first identifiable climate change impacts for ports may be a shift in the occurrence of worst-case scenario events from the rare to a more “normal” occurrence. By identifying the worst-case scenario of current extreme event impacts for their operations ports will be both preparing for known risks whilst also beginning to prepare for the likely future impacts that will arise due to climate change. Such preparations, if effectively implemented, will be particularly beneficial over the short to medium-term and improve both port disaster preparedness and the resilience of infrastructure as it is renewed. For example, the new flood gates installed at Immingham port following the December 2013 storm surge (a 1:760, or 12% chance of exceedance event at the port) have been designed to protect the port from flooding up to a 1:1000 year event. It would be beneficial for the Government to advise all ports, regardless of their size or location, to consider worst-case scenarios, especially in terms of infrastructure which has a long design life.

Current port planning timescales (from 0-25 years) contradict known port infrastructure life-spans which can be up to 100 years. With climate change it is expected that port infrastructure with life-spans exceeding 50 years will experience changing conditions during their life-time. It would be beneficial for the port sector to consider the renewal or adaptation needs of individual port infrastructure and equipment. The new planning timescale developed in Section 6.6.2 has been developed to assist ports in identifying their adaptation and renewal needs, especially in terms of longer-term infrastructure developments. With climate change and shifts in interactions with neighbouring areas it will become more pressing for ports to ensure that infrastructure upgrades are designed to incorporate the extent of projected risks expected to affect their functionality throughout their design life-time.

Chapter 7: Conclusion

7.1 Structure of the research problem

This thesis has assessed the vulnerability to, effects of, and responses to extreme weather events affecting UK ports, and determined how well the port sector is adapting to the pressures and challenges of climate and climate change. The research was split into three time-frames: the past (1950-2014), present (2013-2018) and future (2020 to 2100). Four objectives were addressed within the thesis:

1. To determine the nature, and extent, of impacts of extreme weather and non-weather events on UK ports and the use of coping mechanisms and adaptations as responses to disruptions.
2. To examine disruptions to dock-side port operations due to extreme weather and non-weather events under present conditions.
3. To assess how well UK port infrastructure and operations are prepared for the current and future challenges of extreme weather and climate change.
4. To propose measures for enhancing the adaptation preparedness of the UK port sector for climate change.

Five main outcomes were produced from the research included within this thesis:

- A database of historical recorded disruptive extreme events that affected UK maritime zones between 1950 and 2014.
- A new proxy method for identifying extreme event driven disruptions to UK port operations. Using this a fuller understanding of the types, duration, impacts and responses of UK ports to extreme events was developed.
- A detailed, critical, analysis of the Adaptation Reports produced by the UK's busiest commercial ports.
- A questionnaire to assess the level of preparedness for extreme weather and climate change of the entire UK commercial port sector.
- A new, climate change ready, port planning timescale was developed.

7.2 Key findings

7.2.1 UK port sector disruptions due to extreme events

The complex interaction of exposure, impacts and responses of UK port operations to extreme weather and non-weather events was investigated (objectives 1 and 2), and identified that:

- Extreme event types of particular importance for port operations have altered through time, and both extreme weather and non-weather event types have the potential to disrupt port infrastructure, equipment and operations (see Figure 3.3). Historically storm surges have been the cause of the most severe recorded extreme events for ports. The severity of the impact of identified storm surge events have declined due to national improvement in sea defence standards, improved technology (such as weather forecasting) and awareness that pre-emptive action (such as temporary port closure) can reduce the likelihood of damage or injury occurring. In contrast, both the frequency and severity of the impact of recorded wind storms has increased in response to the mechanisation of the port sector (such as the installation of wind gust vulnerable high-level cranes). The changing exposure of the port sector to these extreme event types in recent decades highlights how developments in technology and knowledge can potentially change the severity of risks faced by the port sector, or even develop new, unexpected, risks.
- The timing of impacts from extreme events has not previously been considered as a factor of importance when determining, or even predicting, the likely impacts of extreme events (see Section 4.7.4). The distinct differences in impacts of daytime (potentially severe) and night time (little impact on operations) events highlighted the complexity of interactions between port activity and the impacts of extreme events. Port decision-makers need to focus their resources on contending with day-time extreme events to reduce the extent, and duration, of impacts from such events. Streamlining resources to primarily contend with the potentially most disruptive timings of extreme events can reduce the financial and time costs of responses. With climate change the frequency and severity of extreme events may change, and it will become more pressing for ports to develop responses (whether in the form of coping mechanisms or adaptation measures) to contend with these pressures and risks for their successful operations.
- The complexity of port interactions alongside extreme events is highlighted by its changing exposure to different event types since the mid-20th Century. Developments and shifts in knowledge and technology applied to port environments have altered port exposure (for example, the implementation of high-level cranes has increased risks

associated with wind storms and lightning). Exposure to extreme events is further altered by a combination of coping mechanisms that have been developed by port decision-makers to reduce both the extent and duration of impacts.

The challenges currently facing the UK port sector from extreme events are complex. However, ports are well prepared for the current “normal” range of extreme events due to detailed learning from experiences of past events. Despite being well prepared for extreme events no port can be fully able to protect their operations from potential disruptions. With climate change both the frequency and impacts of extreme events are predicted to alter. It would be beneficial for ports to prepare for current worst-case scenarios for extreme weather events. Preparation for rare “extreme” extreme weather events will be an important starting point for adaptation to identified climate change risks.

7.2.2 UK port sector preparedness for climate change

The extent of the UK port sector readiness for climate change is more limited than commonly assumed. Multiple reports produced by ports actively label business-as-usual upgrades and developments as adaptation measures. This thesis includes the most detailed and thorough analysis of the UK commercial port sector’s extent of preparedness for climate change (objectives 3 and 4):

- Future risks from climate change are only one of many pressing issues and challenges currently facing the UK port sector, and are currently a low priority issue for most port decision-makers. Climate change, and the need for adaptation, is an uncertain issue for the port sector, as it is indeed for many UK business sectors, due to concerns regarding the cost, timing and extent of needed adaptations. These uncertainties are further compounded by low confidence in many projections of risk for extreme event types.
- The English port sector is currently leading the rest of the UK in terms of port sector adaptation. Ports that are adapting are most commonly those that were required to assess their adaptation needs by UK legislation (Climate Change Act, 2008). Governance and legislation is an important tool to initiate adaptive action, and even the consideration of adaptation as a relevant issue, within the UK port sector.
- Poor port sector awareness of the likely risks facing their operations due to climate change, and miscommunication between the port sector and Government, is limiting the current extent of port sector adaptation.

- Conversations with all UK ports (see Section 5.3) have highlighted that the port sector is not well prepared for climate change and does not understand what is needed. It would appreciate the provision of additional guidance – particularly very basic guidance in the form of summaries of likely future risks to face their operations – to aid them in taking their first steps towards implementing effective adaptation measures. These findings highlight an important gap in knowledge within the UK port sector. To encourage port sector adaptation either climate change awareness needs to be improved or specific legislation must be put in place providing frameworks to guide timely adaptive action.

These findings show that much further work, and action, is required to encourage and enable climate change adaptation within the port sector. Combined action is required between ports, the Government and the scientific community. Port sector adaptation is important on both a local and national scale:

- UK trade greatly relies on the port sector. Any severe damage to port infrastructure, and equipment, has the potential for long-term repercussions on UK trade – particularly for those ports that carry out nationally important, or specialised, operations.
- Delayed port sector adaptation action has the potential to negatively affect the business reputation between ports and their shipping clients.
- Incremental and proactive planned adaptations can be designed to spread the cost of investment. Although the UK Government considers ports on a sectoral rather than individual basis it will become important to recognise the importance, even of smaller ports, to local populations and businesses.

7.2.3 Current UK port perspectives on extreme events and climate change

The UK port sector's perspective on the challenges of both extreme events and climate change is complicated:

- Extreme events have been, and continue to be, an important issue for UK port operations. The spectrum of event types and severities range from minor nuisance events through to events that have severe damaging impacts, such as in the winter 2013/2014 storms (and the December 2013 storm surge in particular) (see Figure 3.8). With climate change extreme events will progressively become a more pressing issue for port operations, although on longer timescales than used for current port planning. Changes in baseline conditions, such as those associated with sea-level rise and rising mean temperatures, may develop new extreme event types and impacts which will need to be adapted for.

- Currently the threat of climate change is not a pressing issue for port operators. This has largely arisen due to the conflicting time-scales of current port planning and climate change projections. Shifts in conditions due to climate change are gradual in nature, which makes this an intangible issue for many port decision-makers to consider. Currently port planning horizons focus on the time-frame of 0-25 years, although it would be beneficial for ports to begin considering how conditions and risks from climate change will alter throughout the entire design lifetime of new infrastructure developments (see Figure 6.3 and Section 6.6.2). The long timscales and the uncertainties in climate change projections has led to the cautious port sector being unwilling to put in place adaptation measures (see Section 5.4.2). The few UK ports currently putting in place adaptation measures are largely limited to the UK's busiest ports (in England and Wales) who have been instructed by the Government to assess their adaptation needs.
- Limited available guidance for port sector climate change adaptation has helped to restrict port-sector awareness of the need for timely adaptive action. To date sector-wide guidance advises that UK ports should take steps to adapt for climate change, but includes no further specifics (Climate Change Act, 2008). Only nine UK ports (8 in England and 1 in Wales) have been required to assess their adaptation needs, and have been advised to use UKCP09 projections as a key resource for how likely risks to their operations may change. However, for many working in ports this resource is not presented in an accessible and useful format.
- There is a sector-wide need for further guidance from the Government and scientists to assist ports in identifying the likely challenges they will face from climate change, and how best to reduce the impacts they will experience (see Figure 5.15). The Government currently considers the port sector to be on track to become well prepared for climate change, and has produced a number of reports stating that the UK's transport sector (including ports) are adapting to long-term climate change. Although the Government perceives the port sector to be taking good adaptive steps further work (in the form of full integration of adaptation needs into business models) will be needed. The findings of this thesis contradict the Government's viewpoint as, following discussions with all UK commercial ports, it was found that port sector adaptation is at present very limited. Conversations with many commercial ports found that current port sector knowledge on how climate change is likely to affect their future operations or how and when they begin implementing adaptation measures is poor. A number of UK ports, both major and minor, want additional climate change guidance from the Governement and scientists in place before beginning to integrate adaptation into their business plans. However, their need

for further guidance is obscured by some of the busiest ports stating that they are putting in place more climate change adaptations than is strictly true.

- The framing of port sector adaptation measures needs to be carefully considered. Many of the adaptation measures proposed or underway by the UK's busiest ports (see Section 5.2) are part of normal upgrade and expansion projects. This means that these changes would have occurred regardless of whether climate change was an issue (see Section 5.3.4.4). It is important that further assessments of port sector adaptations consider the motivations behind the decisions to develop a more true representation of the extent of undertaken climate change adaptation. Ports need to begin carefully integrating adaptation within their business plans.

- How and when to adapt to climate change is an issue of concern for the UK port sector. Also, due to uncertainties in a number of current climate change projections (e.g. changes to wind gust velocities) it would be beneficial for the port sector to develop a combination of proactive and incremental adaptation measures. Proactive adaptation measures are currently most appropriately applied to reduce future impacts from known climate change risks, whereas incremental adaptations can be developed for less certain risks, reducing the likelihood of maladaptation occurring.

7.2.4 The future of UK port adaptation preparedness

The mismatch between current port planning and climate change timescales is a major barrier to timely adaptation. Current port planning timescales are split into short (0-5 years) and long-term (5-25 years) timescales and does not, at present, incorporate climate change awareness. The current short-term perspective of port decision-makers makes port adaptation challenging to plan for:

- A new three part port planning timescale (infrastructure renewal, disaster preparedness and port and environs planning) is proposed for ports to allow them to effectively prepare both for extreme weather events and climate change (see Figure 6.3). Infrastructure renewal (0-100 years) is a continual cycle within ports, and the rate of renewal depends on the design life-time of infrastructure and equipment. Infrastructure renewal is split into port equipment and buildings, and port infrastructure. Equipment and buildings tend to have shorter lifespans, and renewal occurs as maintenance or upgrades. The lifespan of port infrastructure can extend up to 100 years. Disaster preparedness (0-20 years) is where port decision-makers can respond to known or anticipated risks through a combination of coping mechanisms and adaptation measures. Ports are well prepared for the current normal range of extreme weather events apart from so-called "extreme" extremes or worst-case scenarios. A new long-term planning timescale, port and environs planning (50-100 years) has been developed to assist ports in assessing how conditions may alter due to climate change and interactions with neighbouring areas through the life-span of longer-term infrastructure developments, such as berths or breakwaters. With climate change it will become more pressing for ports to ensure that infrastructure upgrades are designed to incorporate the extent of projected risks expected to affect their functionality throughout their design life-time.

- Port sector responsibility for adaptation is with port decision-makers, although the role of the Government in supporting climate change preparedness has not yet been considered. The Government has the ability to instigate significant changes in port behaviour and priorities through new legislation and advice on how best the sector can address their need for adaptation. However, to achieve this the current ineffectual standard of communication between the Government and the port sector needs to be overcome.
- The port sector needs to alter their perspective on how they are connected to the wider city community. Many ports operate in an isolated manner, not considering their interdependence and connectivity to the wider community beyond the port boundary (such as the port-city, transport networks and power supplies). Effective integration of climate change adaptation across ports, local authorities and city stakeholders would be beneficial in developing cost-effective adaptation measures and encourage the sharing of successful adaptation experiences.
- The port sector is uncertain as to how climate change is likely to affect their future operations, which is currently limiting the extent of adaptations being implemented. Consideration of worst-case scenario impacts from known extreme event types represents a useful starting point for ports to prepare both for known risks and some likely future impacts from climate change.

7.3 Contribution to knowledge

Within this thesis a number of new, and unique, contributions to knowledge have been developed:

- A database of extreme weather and non-weather events that affected UK ports, coastal areas and EEZ between 1950 and 2014.
- A severity scale to enable comparisons between maritime zones, event types and through time.
- Developed and tested the benefits and limitations of vessel activity data (in the form of AIS) and social media (Twitter and blogs) as a proxy for port disruptions due to extreme weather and non-weather events.
- A critical analysis of Adaptation Reports submitted to DEFRA by England and Wales' busiest commercial ports.
- Developed, distributed and assessed responses from a questionnaire to assess climate change awareness of the entire UK commercial port sector. The questionnaire represented the first consideration of climate change for many of the UK's commercial ports.
- Developed a new port planning timescale which will aid ports in preparing their infrastructure and equipment for the challenges of climate change.

7.4 Further research

This research has highlighted that there are a number of important avenues for further study and action, and can be grouped into three key categories:

- Governance – Multiple representatives from the UK port sector consider the Climate Change Act as incomplete governance for climate change adaptation. Many ports are currently awaiting further guidance from the Government before beginning to identify, and implement, adaptation measures.
- Guidance – The UK port sector, as a whole, is unsure as how to begin preparing for the challenges of climate change. Improved scientific guidance would benefit adaptation across both major and minor ports.
- Adaptation pioneering – Currently few UK ports are implementing, or even considering, climate change adaptations. It would be beneficial from ports to learn from experiences of adaptation success within other, potentially competing, ports.

Governance

1. **New legislation on climate change adaptation**

New and improved legislation incorporating climate change adaptation is necessary to encourage ports to start considering adaptation in their planning decisions. Many UK ports have stated that climate change adaptation is an uncertain concept, and that they will begin adapting when they are required to, either legally or due to climate change impacts.

Guidance

2. **Improve the UK port sector's understanding of risks they face**

   Outcomes of communication with many UK ports concluded that the port sector would both benefit from, and welcome, guidance on the likely risks and challenges they will experience due to climate change. Few UK ports are currently aware of the likely impacts of climate change for their operations, or have considered how important a business issue climate change will become in future decades. Results detailed in Chapter 6 highlight that many ports do not feel that they have a good knowledge of how climate change is likely to affect their future operations and profitability. The development of a tool, or resource, that can help each port to better understand the risks they face will be beneficial in aiding the sector in adapting to climate change.

3. **Development of an Adaptation Report template**

   Many UK ports are unsure as to their adaptation needs, and when they should begin putting in place adaptation measures. Many representatives of the UK port sector have found the Climate Change Act 2008 an inadequate first step on the topic of adaptation preparedness, and are currently awaiting further guidance from the Government before beginning to put in place adaptation measures.

   Inconsistencies between Adaptation Reports submitted to DEFRA highlight how an Adaptation Report template would be beneficial in aiding ports to identify both their adaptation needs, and potential effective adaptation measures. An Adaptation Report template would significantly increase consistency between reports submitted by ports, and would allow DEFRA, and other Government departments, to effectively compare the extent of adaptation awareness and preparedness between ports.

   An adaptation template would aid the port sector by encouraging consistent adaptation across multiple ports. It would be particularly beneficial for such a template to be disseminated to all UK ports, to guide them in identifying their adaptation needs.

   The format of an Adaptation Report template can easily be adjusted to be beneficial for other sectors, such as aviation or utilities.

Adaptation pioneering

4. **Monitor UK port climate change adaptations**
   The UK port sector is only just beginning to adapt against the challenges of climate change. It is important to monitor the implementation and effectiveness of adaptation measures. Suggestions for future work includes to analyse whether implemented adaptations are either effective or ineffective. The types and amount of adaptations put in place are expected to increase if and when legislation becomes stricter, or when the impacts of climate change become more apparent for the port sector.

Of the four detailed areas for further study or action the most pressing is to improve the UK port sector's understanding of risks they face. This is critical as a lack of knowledge on climate change risks is hampering the UK port sector's ability to take active and effective adaptive steps. In the next few decades, timely adaptation will be vital to allow ports to contend against the many challenges of climate change.

Appendix A Summary of extreme event types that have affected port operations (data from Chapter 4)

Disruption type	Nature of the disruption relevant to the port's operations, equipment and infrastructure	Extreme weather	Non-weather		Historically affected UK ports
			Natural	Human induced	
Coastal flooding	Flooding arising from infiltration of seawater, such as during a storm surge or wind-storm event. The impacts of such an event could increase if local sea defences are breached, or are in poor condition.	✓	X	X	✓
Earthquake	Seismic shaking of the ground caused either by volcanic activity or a tremor within the crust of the earth.	X	✓	X	X
Fire	The severity of such events vary greatly dependent on multiple variables such as its location, and type. Both landward (e.g. fires affecting port buildings or power substations) or seaward (e.g. fire aboard a vessel docked at a port) fires can have impacts on port operations.	✓	✓	✓	✓

Fluvial flooding	Flooding arising from rivers bursting their banks is often caused by rainfall events occurring far upstream. Fluvial flooding events can have long-term impacts, particularly depending on the effectiveness of port drainage.	✓	X	X	✓
Fuel shortages	Can severely disrupt port operations. Much of port equipment, including many high-level cranes, is reliant on diesel as a fuel source.	X	X	✓	✓
Hailstorm	A storm of solid balls of ice that fall from the sky which can range in size from 5mm to 4.5cm.				
Human error	Poorly chosen or timed decisions or actions that result in disruptive impacts (e.g. misjudging vessel movements resulting in a collision between a vessel and the dockside).	X	X	✓	✓
Hurricane (or cyclone, tornado or typhoon)	An exceedingly strong storm characterised by wind exceeding 120 kilometers per hour.	✓	X	X	X
Industrial action	Circumstances where staff take protest action such as strikes, often motivated by pay or working condition disputes.	X	X	✓	✓
Inland transport breakdown	Disruptions to other transport routes, such as road, rail or air can have multiple implications for ports. They can either act to isolate the	X	X	✓	✓

	port, preventing the movement of goods both landwards and out of the port, or to choke the port with additional trade.				
Mechanical or structural fault	Weakness or fault in infrastructure, vessels or equipment that directly results in damaging or disrupting circumstances (e.g. a vessel taking on water, or a high-level crane unable to operate).	✓	✓	X	✓
Pluvial flooding	Flooding arising from rainfall occurring directing on the port's land. The severity of impacts depend strongly on the standard of port drainage.	✓	X	X	✓
Poor visibility (fog and mist)	Where visibility is reduced far enough to prevent safe port or vessel operations	✓	X	X	✓
Power disruption	Power disruptions from transformers, or from a power station, lead to a shutdown, or delay to, many port operations. The extent of disruption depends on whether back-up generators are available to supplement the electricity supply within the port.	✓	✓	✓	✓
Rough seas	Where wave heights are high enough to cause damage to vessels or port structures.	✓	X	X	✓
Sandstorm	Clouds of wind or dust carried by the wind that can cause erosive damage.	✓	X	X	X

Snow and ice	Where snowfall and/or icy conditions prevent safe working practice (e.g. causing slip hazards or preventing the safe operation of equipment).	✓	X	X	✓
Storm surge	Atmospheric and wind conditions raise sea-level leading to coastal flooding and damage to infrastructure, equipment or vessels.	✓	X	X	✓
Subsidence	Caving or sinking of land, often occurs following groundwater extraction or building on unconsolidated material.	X	✓	X	X
Temperature extremes	High and low extremes of temperature can lead to unsafe conditions for people working in port environments, such as for those operating high-level cranes. In some conditions temperature extremes can also increase the likelihood of equipment failure or poor reliability.	✓	X	X	✓
Thunder and lightning	Thunder strikes can have damaging implications for ports, particularly if tall equipment, such as high-level cranes, are struck.	✓	X	X	✓
Tsunami	A seismic sea wave, often caused by a submarine earthquake or landslide.	X	✓	X	X
Wind storm	Where strong wind gusts disrupt working conditions by exceeding safe working limits. For example high-level cranes may become unstable.	✓	X	X	✓

Appendix B Data sources for Chapter 4

Flood Disasters (1953) vol. 511, cc1456-1580, http://hansard.millbanksystems.com/commons/1953/feb/19/flood-disasters

Scotland (Flood damage) (1967) vol. 743, cc 1956-1972, http://hansard.millbanksystems.com/commons/1967/mar/23/scotland-flood-damage

Anchors and Chain Cables Act (1967) vol. 757, c170W, http://hansard.millbanksystems.com/written_answers/1968/jan/25/anchors-and-chain-cables-act-1967

Drilling Rig "Ocean Prince" loss (1968) vol. 760, cc659-60, http://hansard.millbanksystems.com/commons/1968/mar/07/drilling-rig-ocean-prince-loss

Scotland (Storm damage) (1968) vol. 758, cc401-526, http://hansard.millbanksystems.com/commons/1968/feb/07/scotland-storm-damage

"Torrey Canyon" (Agreement on claims) (1969) vol. 791, cc199-206, http://hansard.millbanksystems.com/commons/1969/nov/11/torrey-canyon-agreement-on-claims

North Sea Installations (1974) vol. 867, cc669-696, http://hansard.millbanksystems.com/commons/1974/jan/16/north-sea-oil-installations

Sea Defences (1976) vol. 903, cc1501-1512, http://hansard.millbanksystems.com/commons/1976/jan/21/sea-defences

Floods (East Coast) (1978) vol. 944, cc203-214, http://hansard.millbanksystems.com/commons/1978/feb/13/floods-east-coast

Scottish Highlands (Storm Damage) (1978) vol. 943, cc249-256, http://hansard.millbanksystems.com/commons/1978/jan/31/scottish-highlands-storm-damage

Flooding, North Wales (1990) vol. 170, cc769-770W, http://hansard.millbanksystems.com/written_answers/1990/apr/05/flooding-north-wales

Oil Pollution (Devon Coast) (1990) vol. 172, cc899-905, http://hansard.millbanksystems.com/commons/1990/may/16/oil-pollution-devon-coast

Sea Defences and Flood Damage (1990) vol. 176, cc188-226, http://hansard.millbanksystems.com/commons/1990/jul/10/sea-defences-and-flood-damage

Appendix B

Sikorsky helicopter crash (1990) vol. 177, cc463-467, http://hansard.millbanksystems.com/commons/1990/jul/25/sikorsky-helicopter-crash

MV Braer (Oil Pollution) (1993) vol. 216, cc609-624, http://hansard.millbanksystems.com/commons/1993/jan/11/mv-braer-oil-pollution

Otal Investments Ltd. v. M. V. Tricolor (2012) United States Court of Appeals for the Second Circuit, 08-3031-cv(L), 08-3032-cv(XAP) & 08-3324-cv(CON), p. 18

AAIB (1983) Report on the accident to Westland Wessex 60 G-ASWL 12 miles ENE of Bacton, Norfolk on 13 August 1981. p. 41.

AAIB (1991) Report on the accident to Sikorsky S-61N, G-BEWL at Brent Spart, East Shetland Basin on 25 July 1990. p. 2.

AAIB (2008) Accident involving Aerospatiale SA365N, registration G-BLUN near the North Morecambe gas platform, Morecambe Bay. p. 94.

ABP (2013) Situation update - tidal surge issued 11:20 Fri 6th Dec., http://www.abports.co.uk/News/2013/Dec/06/SITUATION_UPDATE_TIDAL_SURGE_issued_1120_Fri_6th_Dec/

ABPmer (2014) Ensuring flood resilience: An overview of 5/6 December 2013 UK storm surge.

Aon Benfield (2014) Costliest EU Windstorm/Winter Storm Events. p. 2.

Association of British Insurers (2014) £6.7 million a day in insurance claims from customers hit by the recent flooding, https://www.abi.org.uk/News/News-releases/2014/03/6-7-million-a-day-in-insurance-claims-from-customers-hit-by-the-recent-flooding

Association of Drainage Authorities (2014) Coastal flooding December 2013, http://www.ada.org.uk/news_detail.php?id=527

Baxter PJ (2005) The east coast Big Flood, 31 January-1 February 1953: a summary of the human disaster. Philosophical transactions. Series A, Mathematical, physical, and engineering sciences 363:1293-1312.

BBC (12th January 1999) Another Empress before long, http://news.bbc.co.uk/1/hi/sci/tech/253614.stm

BBC (12th January 1999) Assessing the oil spill impact, http://news.bbc.co.uk/1/hi/uk/253856.stm

BBC (12th January 1999) Port pleads guilty over Sea Empress, http://news.bbc.co.uk/1/hi/uk/253324.stm

BBC (24th August 1999) Liner damaged in Channel collision, http://news.bbc.co.uk/1/hi/uk/428545.stm

BBC (24th August 1999) Q&A: Investigating the collision, http://news.bbc.co.uk/1/hi/uk/429110.stm

BBC (31st October 2000) Chemical fears after tanker sinks, http://news.bbc.co.uk/1/hi/world/europe/999852.stm

BBC (6th February 2001) Sea sickener for ferry passengers, http://news.bbc.co.uk/1/hi/scotland/1156511.stm

BBC (12th December 2001) Ships collide during pilot strike, http://news.bbc.co.uk/1/hi/england/1705582.stm

BBC (16th December 2001) Eight rescued as cargo ship sinks, http://news.bbc.co.uk/1/hi/wales/1714096.stm

BBC (15th December 2002) £30m cargo 'lost' as ship sinks, http://news.bbc.co.uk/1/hi/world/europe/2576179.stm

BBC (26th October 2002) Mini tornado hits town, http://news.bbc.co.uk/1/hi/uk/2363425.stm

BBC (26th October 2002) Russian ship edges back to safety, http://news.bbc.co.uk/1/hi/uk/2363237.stm

BBC (27th October 2002) Seven dead as gales batter UK, http://news.bbc.co.uk/1/hi/uk/2365319.stm

BBC (28th October 2002) Britain counts storm damage cost, http://news.bbc.co.uk/1/hi/uk/2367089.stm

BBC (28th October 2002) Small boats warned of timber threat, http://news.bbc.co.uk/1/hi/england/2367119.stm

BBC (28th October 2002) UK storm costs escalate, http://news.bbc.co.uk/1/hi/business/2367733.stm

BBC (14th December 2002) Ship sinks after Channel collision, http://news.bbc.co.uk/1/hi/world/europe/2575009.stm

Appendix B

BBC (7th January 2005) Rain and winds causing problems, http://news.bbc.co.uk/1/hi/scotland/4153757.stm

BBC (8th January 2005) Severe gales cause havoc on roads, http://news.bbc.co.uk/1/hi/england/4157069.stm

BBC (12th January 2005) Three killed as storms batter UK, http://news.bbc.co.uk/1/hi/uk/4164613.stm

BBC (18th January 2007) Crew rescued from stricken ship, http://news.bbc.co.uk/1/hi/england/cornwall/6274625.stm

BBC (18th January 2007) Nine dead as storms hit England, http://news.bbc.co.uk/1/hi/england/6274041.stm

BBC (18th January 2007) Nine dead as UK struck by storms, http://news.bbc.co.uk/1/hi/6272193.stm

BBC (18th January 2007) Severe storms batter the country, http://news.bbc.co.uk/1/hi/england/suffolk/6277103.stm

BBC (20th January 2007) Stricken ship shelters off coast, http://news.bbc.co.uk/1/hi/england/devon/6277651.stm

BBC (21st January 2007) Stricken cargo ship run aground, http://news.bbc.co.uk/1/hi/england/devon/6283455.stm

BBC (22nd January 2007) Scavengers grab what they can, http://news.bbc.co.uk/1/hi/uk/6288845.stm

BBC (23rd January 2007) Police crack down on scavengers, http://news.bbc.co.uk/1/hi/england/6290887.stm

BBC (29th January 2007) Napoli's cargo removal under way, http://news.bbc.co.uk/1/hi/england/6309747.stm

BBC (16th March 2007) Council is to hold Napoli inquiry, http://news.bbc.co.uk/1/hi/england/devon/6457971.stm

BBC (8th May 2007) High winds close container port, http://news.bbc.co.uk/1/hi/england/suffolk/6636817.stm

BBC (9th July 2007) Stricken container ship refloated, http://news.bbc.co.uk/1/hi/england/devon/6283102.stm

BBC (13th July 2007) Attempts to break Napoli in two, http://news.bbc.co.uk/1/hi/england/devon/6895899.stm

BBC (17th July 2007) Charges break Napoli's deck plate, http://news.bbc.co.uk/1/hi/england/devon/6901922.stm

BBC (20th July 2007) Ship split after new explosions, http://news.bbc.co.uk/1/hi/england/devon/6905365.stm

BBC (7th August 2007) Napoli towed away for recycling, http://news.bbc.co.uk/1/hi/england/devon/6935009.stm

BBC (5th January 2008) 1993: Oil tanker runs aground off Shetland, http://news.bbc.co.uk/onthisday/hi/dates/stories/january/5/newsid_2506000/2506223.stm

BBC (18th January 2008) Napoli leaves Devon out of pocket, http://news.bbc.co.uk/1/hi/england/devon/7195422.stm

BBC (31st January 2008) 1953: 130 die in ferry disaster, http://news.bbc.co.uk/onthisday/hi/dates/stories/january/31/newsid_2505000/2505913.stm

BBC (1st February 2008) Ferry aground as storms batter UK, http://news.bbc.co.uk/1/hi/uk/7219492.stm

BBC (10th March 2008) Storm leaves 3,000 without power, http://news.bbc.co.uk/1/hi/england/7287003.stm

BBC (10th March 2008) UK storm causes 14 flood warnings, http://news.bbc.co.uk/1/hi/uk/7287662.stm

BBC (11th March 2008) Repairs start on storm-hit wall, http://news.bbc.co.uk/1/hi/world/europe/jersey/7289021.stm

BBC (12th March 2008) UK pounded by second severe storm, http://news.bbc.co.uk/1/hi/uk/7291170.stm

BBC (18th March 2008) 1967: Supertanker Torrey Canyon hits rocks, http://news.bbc.co.uk/onthisday/hi/dates/stories/march/18/newsid_4242000/4242709.stm

Appendix B

BBC (29th March 2008) 1967: Bombs rain down on Torrey Canyon, http://news.bbc.co.uk/onthisday/hi/dates/stories/march/29/newsid_2819000/2819369.stm

BBC (6th July 2008) 1988: Piper Alpha Oil Rig Ablaze, http://news.bbc.co.uk/onthisday/hi/dates/stories/july/6/newsid_3017000/3017294.stm

BBC (4th September 2008) The big freeze of 1963, http://www.bbc.co.uk/london/content/articles/2008/09/04/bigfreeze63_feature.shtml

BBC (6th November 2008) 1986: Oil workers die in helicopter crash, http://news.bbc.co.uk/onthisday/hi/dates/stories/november/6/newsid_2538000/2538505.stm

BBC (17th November 2008) 1953: Twenty die in Channel collision, http://news.bbc.co.uk/onthisday/hi/dates/stories/november/17/newsid_3190000/3190340.stm

BBC (14th November 2009) Floods as UK faces storm gales, http://news.bbc.co.uk/1/hi/8358530.stm

BBC (16th November 2009) Heavy rain and winds across Wales, http://news.bbc.co.uk/1/hi/wales/8361820.stm

BBC (4th December 2009) In detail: The Sea Empress disaster, http://news.bbc.co.uk/1/shared/spl/hi/picture_gallery/06/uk_the_sea_empress_disaster/html/1.stm

BBC (6th January 2010) High winds and snow closes Felixstowe container port, http://news.bbc.co.uk/1/hi/england/suffolk/8443480.stm

BBC (7th January 2010) Drivers stuck in Operation Stack at Port of Felixstowe, http://news.bbc.co.uk/local/suffolk/hi/people_and_places/newsid_8446000/8446969.stm

BBC (18th February 2010) Looking back at the Towyn floods of February 1990, http://news.bbc.co.uk/local/northwestwales/hi/people_and_places/history/newsid_8516000/8516287.stm

BBC (31st March 2010) Bad weather causing NI distruption, http://news.bbc.co.uk/1/hi/northern_ireland/8594268.stm

BBC (1st April 2010) Thousands without power overnight, http://news.bbc.co.uk/1/hi/scotland/8596090.stm

BBC (14th September 2010) Wild Weather: The perfect storm, http://news.bbc.co.uk/local/cambridgeshire/hi/people_and_places/nature/newsid_8940000/8940413.stm

BBC (15th September 2010) Storms and the sea - the nature of Sussex weather, http://news.bbc.co.uk/local/sussex/hi/people_and_places/nature/newsid_8974000/8974393.stm

BBC (20th September 2010) Storms and snow: Dorset's wild weather, http://news.bbc.co.uk/local/dorset/hi/people_and_places/nature/newsid_8997000/8997380.stm

BBC (1st December 2010) Snow and ice causes disruption as cold spell continues, http://www.bbc.co.uk/news/uk-11883714

BBC (8th December 2010) Scotland storm blackout hitting thousands, http://www.bbc.co.uk/news/uk-scotland-16079849

BBC (3rd January 2012) Severe weather causes damage around UK, http://www.bbc.co.uk/news/uk-16390088

BBC (3rd January 2012) Two men die as storms hit England, http://www.bbc.co.uk/news/uk-england-16392074

BBC (30th August 2013) Super Puma crash not due to technical problems, says CAA, http://www.bbc.co.uk/news/uk-scotland-north-east-orkney-shetland-23896479

BBC (14th October 2013) Firm admits failures over River Clyde Flying Phantom tug deaths, http://www.bbc.co.uk/news/uk-scotland-glasgow-west-24518260

BBC (28th October 2013) Four die as storm hits southern UK, http://www.bbc.co.uk/news/uk-24699748

BBC (28th October 2013) Winds of 60mph winds force closure of Dover port, http://www.bbc.co.uk/news/uk-24705614

BBC (6th December 2013) Lethal storm and tidal surge sees thousands out of homes, http://www.bbc.co.uk/news/uk-25220224

BBC (6th December 2013) Tidal surge hits east UK coastal towns after storm, http://www.bbc.co.uk/news/uk-25253080

BBC (24th December 2013) UK storm: Damage disrupts travel as more severe weather hits, http://www.bbc.co.uk/news/uk-25502730

Appendix B

BBC (3rd January 2014) Storm surge brings flooding chaos moving up Wales' coast, http://www.bbc.co.uk/news/uk-wales-25591305

BBC (6th January 2014) Flood warning for parts of Belfast and Ards peninsula, http://www.bbc.co.uk/news/uk-northern-ireland-25616864

BBC (6th January 2014) Pagham's new flood defences to be rebuilt, http://www.bbc.co.uk/news/uk-england-sussex-25618719

BBC (7th January 2014) UK storms: Giant waves hit amid fresh flooding fears, http://www.bbc.co.uk/news/uk-25618080

BBC (24th September 2014) Environmental impact of MSC Napoli, http://www.bbc.co.uk/devon/content/articles/2007/01/24/napoli_oiled_birds_feature.shtml

BBC (29th September 2014) Clydeport fined £650,000 after Flying Phantom tug deaths, http://www.bbc.co.uk/news/uk-scotland-glasgow-west-29410685

BBC (1st October 2014) No fatal accident inquiry into Flying Phantom tug deaths, http://www.bbc.co.uk/news/uk-scotland-glasgow-west-29446617

BBC (21st October 2014) UK storms: woman dies and others injured in high winds, http://www.bbc.co.uk/news/uk-29701560

BBC (2nd December 2014) Flood defences: Treasury unveils £2.3bn for schemes to protect homes, http://www.bbc.co.uk/news/business-30282701

BBC (10th December 2014) 'Weather bomb' hits power and travel in northern UK, http://www.bbc.co.uk/news/uk-30407295

BBC (11th December 2014) Power restored as 'weather bomb' storm subsides, http://www.bbc.co.uk/news/uk-scotland-30402293

BEAmer (2002) Supplementary report to the inquiry into the collision between the car carrier Trocolor and the container vessel Kariba. in Ministère des Transports dlE, du Tourisme et de la Mer (ed.).

Belfast Telegraph (9th December 2011) Northern Ireland weather alert as gales down trees and power lines, http://www.belfasttelegraph.co.uk/news/local-national/northern-ireland/northern-ireland-weather-alert-as-gales-down-trees-and-power-lines-28690656.html

Belfast Telegraph (6th February 2014) Northern Ireland weather: Prepare for another two fierce weeks of battering, http://www.belfasttelegraph.co.uk/news/local-national/northern-ireland/northern-ireland-weather-prepare-for-another-two-fierce-weeks-of-battering-29984984.html

Belfast Telegraph (10th December 2014) Weather bomb: Two people swept into sea at Portstewart as storm batters north coast, http://www.belfasttelegraph.co.uk/news/local-national/northern-ireland/weather-bomb-two-people-swept-into-sea-at-portstewart-as-storm-batters-north-coast-30812400.html

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.

Blue and Green Tomorrow (11th January 2013) On this day in 1963: big freeze hits the UK, http://blueandgreentomorrow.com/features/on-this-day-in-1963-big-freeze-hits-the-UK/

Boston Borough Council (9th September 2013) Tragic flood remembered 60 years on, http://www.boston.gov.uk/index.aspx?articleid=4931

Burke L (2013) The Sea Gem: A story of material failure. Journal of Undergraduate Engineering Research and Scholarship.

Burnham on Sea (13th December 2011) 30 years ago today: Major 1981 storm hits Burnham-On-Sea, http://www.burnham-on-sea.com/news/2011/1981-storm-anniversary-13-12-11.php

Burt S (2007) The Lowest of the Lows … extremes of barometric pressure in the British Isles, part 1 – the deepest depressions. Weather 62:4-14.

Chatterton J, Clarke C, Daly E, Dawks S, Elding C, Fenn T, Hick E, Miller J, Morris J, Ogunyoye. F., Salado R (2016) The costs and impacts of the winter 2013 to 2014 floods. p. 36.

Coll J, Woolf D, K.,, Gibb SW, Challenor P, G., (2013) Sensitivity of ferry services to the western isles of Scotland to changes in wind and wave climate. Journal of Applied Meteorology and Climatology 52:1069-1084.

Commercial Motor (17th February 2014) Poor weather sees Operation Stack and delays for trucks accessing Dover port, http://commercialmotor.com/latest-news/poor-weather-sees-operation-stack-delay-trucks-accessing-dover-port

Cornwall Council (2014) Cumulative impact of severe weather in Cornwall: Winter 2013/2014. p. 43.

Appendix B

Cosco (29th January 2013) Port of Felixstowe weather warning, http://www.coscon.co.uk/news/port-of-felixstowe-weather-warning/

Crochet M, Cuq F, Ralph FM, Venkateswaran SV (1990) Clean-air radar observations of the great October storm of 1987. Dynamics of Atmospheres and Oceans 14:443-461.

Cruise and Maritime Voyages (14th February 2014) Friday 14 February 2014 (2200hrs), http://www.cruiseandmaritime.com/media-statement-friday-14-february-2014-2200hrs

Cruise and Maritime Voyages (15th February 2014) Important passenger notice (1300h Sat 15 February 2014) Marco Polo incident, http://www.cruiseandmaritime.com/important-passenger-notice-1300h-sat-15-february-2014-marco-polo-incident

Cruise and Maritime Voyages (15th February 2014) Saturday 15 February 2014 (1200hrs), http://www.cruiseandmaritime.com/media-statement-saturday-15-february-2014-1200hrs

d'Andremond K (2003) From disaster to Delta Project: The storm flood of 1952. International Association of Dredging Companies, pp. 1-10.

Daily Mail (9th August 2002) Crash helicopter pilot may have tried emergency landing, http://www.dailymail.co.uk/news/article-128298/Crash-helicopter-pilot-tried-emergency-landing.html

Daily Mail (4th January 2012) The day it was so windy the waterfall ran uphill: Britain battered by 106mph gales which leave two dead - and there's more to come in the next 24 hours, http://www.dailymail.co.uk/news/article-2081141/UK-severe-weather-warning-Britain-battered-105mph-gales-leave-2-dead.html

Daily Mail (6th January 2012) Think this week's gales are bad? They're nothing compared to the storm that drowned Britain, www.dailymail.co.uk/news/article-2082939/uk-weather-this-weeks-gales-compared-storm-drowned-Britain.html

Daily Mail (23rd December 2013) The nightmare before Christmas: Getaway crippled by storms, thousands blacked out and flood-risk families told to flee homes, http://www.dailymail.co.uk/news/article-2528357/Storms-south-snow-north-Chaos-road-rail-millions-scramble-beat-weather-great-Christmas-getaway.html

Daily Mail (24th December 2013) Hundreds of passengers stranded at sea for 16 hours as storms batter ferries in ferocious seas and injured people are airlifted to safety, http://www.dailymail.co.uk/news/article-2528810/Ferries-forced-ride-storm-16-hours-battered-ferocious-seas-leaving-hundreds-people-stranded-dozens-injured.html

Daily Mail (7th January 2015) Did a loose JCB dig a HOLE in side of stricken Solent ship? Vessel may have been thrown off balance unsecured excavator on board, http://www.dailymail.co.uk/news/article-2899967/Loose-JCB-digs-hole-stricken-Solent-ship-Vessel-thrown-balance-unsecured-excavator-board.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490

Daily Mirror (29th October 2013) UK weather: St Jude repair bill will cost insurers a whopping £1 billion, http://www.mirror.co.uk/news/uk-news/uk-weather-st-jude-cost-2651167

Daily Post (27th April 2013) Moments that shocked North Wales: Towyn floods, http://www.dailypost.co.uk/news/nostalgia/moments-shocked-north-wales-towyn-3181218

Department for Transport, Rt Hon Patrick McLoughlin MP (2014) £1.7 million to repair small ports across England. in Transport Df (ed.).

Department of Energy and Climate Change (2014) Table of current UKCS installations.

Devon County Council (2008) MSC Napoli: The aftermath of the beaching off Branscome, East Devon, 20 January 2007. Devon County Council, p. 44.

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.

East Anglian Daily Times (23rd May 2011) Felixstowe: Port closed as winds strike coastal areas, http://www.eadt.co.uk/business/felixstowe_port_closed_as_winds_strike_coastal_areas_1_900971

East Anglian Daily Times (18th October 2012) Felixstowe 1987 Storm, http://www.eadt.co.uk/news/felistowe_1987_storm_1_1660646?id=2&storyId=1

eSurge (11th November 2012) Atlantic storm (2005), http://www.storm-surge.info/atlantic-storm-2005

eSurge (6th January 2014) Coastal Ireland storm surge event - 6th Jan. 2014, http://www.storm-surge.info/coastal-ireland-storm-surge-event-6th-jan-2014

European Commission (2002) Directive 2002/59/EC of the European Parliament and of the council of 27 June 2002 establishing a Community vessel traffic monitoring and information system and repealing Council Directive 93/75/EEC. in Commission E (ed.).

European Commission (2015) Report from the comission to the European Parliament and Council: European Union Solidarity Fund annual report 2013.

Felixstowe TV (4th May 2008) Cranes wreckage after crash & collapse at Port of Felixstowe, http://www.felixstowetv.co.uk/videos/cranes-wreckage-after-crash-collapse-at-port-of-felixstowe/

Fink AH, Brucher T, Ermert V, Kruger A, Pinto JG (2009) The European storm Kyrill in January 2007: synoptic evolution, meteorological impacts and some considerations with respect to climate change. Natural Hazards Earth System Science 9:405-423.

Flather RA (1984) A numerical model investigation of the storm surge of 31 January and 1 February 1953 in the North Sea. Quaternary Journal of the Royal Meterological Society 110:591-612.

Flather RA, Davies AM (1976) On the specification of meterological forcing in numerical models for the North Sea storm surge prediction with application to the surge of 2 to 4 January 1976. Hydrographische Zeitschrift, Erganzungsheft A 15:51.

Flather RA, R. P (1982) The west coast surge prediction experiment 1981-82. Institute of Oceanographic Sciences, Surrey, p. 83.

Fleetwood Weekly News (8th November 2007) Anniversary of Fleetwood floods marked, http://www.fleetwoodtoday.co.uk/news/local/anniversary-of-fleetwood-floods-marked-1-1559999

Gerritsen H (2005) What happened in 1953? The Big Flood in the Netherlands in retrospect. Philosophical transactions. Series A, Mathematical, physical, and engineering sciences 363:1271-1291.

Geschichteclub (2014) 1960 to 1960: Brief extract from the chronicle, http://www.geschichteclubstahl.at/en/The-Chronicle/1960-to-1969

Grimsby Telegraph (5th March 2014) Floods: Learning the lessons at Port of Immingham three months on, http://www.grimsbytelegraph.co.uk/learning-flooding-lessons-port-months/story-20791790-detail/story.html

Grumm RH (2012) Scottish Windstorm 3 January 2012. Pennsylvania State University, p. 25.

Heart (2010) Strong winds could cause Operation Stack, http://www.heart.co.uk/kent/news/local/strong-winds-could-cause-operation-stack/

Heart (3rd November 2013) Kent coast: Prepare for flooding, http://www.heart.co.uk/kent/news/local/coast-prepare-flooding/

Herald Scotland (9th November 1989) Crew rescued as rig sinks, http://www.heraldscotland.com/sport/spl/aberdeen/crew-rescued-as-rig-sinks-1.603993

HM Government (17th January 2014) Government announces nearly £7 million extra for flood recovery, https://www.gov.uk/government/news/government-announces-nearly-7million-extra-for-flood-recovery

ICIS (12th March 2008) Felixstowe port closes again due to high winds, http://www.icis.com/resources/news/2008/03/12/9108051/felixstowe-port-closes-again-due-to-high-winds/

ICIS (10th March 2008) Storm-hit port of Dover reopens, http://www.icis.com/resources/news/2008/03/10/9107271/storm-hit-port-of-dover-reopens/

ICIS (13th March 2008) UK ports resume normal operations after storms, http://www.icis.com/resources/news/2008/03/13/9108143/uk-ports-resume-normal-operations-after-storms/

International Marine & Dredging Consultants N. V. (2005) De storm van 1953: Literatuurstudie naar de devolgen van de overstromingen voor de Belgesche kust. in Infrastructuur Le (ed.), Antwerp, p. 18.

Ipswich Star (29th November 2011) Felixstowe: Strong winds bring work at port to a standstill, http://www.ipswichstar.co.uk/news/felixstowe-strong-winds-bring-work-at-port-to-a-standstill-1-1140570

Ipswich Star (7th December 2011) Felixstowe: Operation Stack in place as strong winds close port, http://www.ipswichstar.co.uk/news/felixstowe_operation_stack_in_place_as_strong_winds_close_port_1_1147902?usurv=skip

Ipswich Star (6th February 2012) Felixstowe: Port re-opens after workers clear snow, http://www.ipswichstar.co.uk/news/felixstowe_port_re_opens_after_workers_clear_snow_1_1199695

Irish Independent (6th January 2014) Downpours and gale force winds batter the country, http://www.independent.ie/irish-news/downpours-and-gale-force-winds-batter-the-country-29890730.html

Irish Independent (7th January 2014) The €300m cost of superstorm Christine, http://www.independent.ie/irish-news/the-300m-cost-of-superstorm-christine-29895077.html

Appendix B

Irish Independent (8th January 2014) Superstorm clean-up begins as State eyes aid from EU, http://www.independent.ie/irish-news/superstorm-cleanup-begins-as-state-eyes-aid-from-eu-29897013.html

ITV News (19th December 2013) Clean-up operation continues after severe storms, http://www.itv.com/news/wales/story/2013-12-19/heavy-rain-and-blustery-showers-causes-disruption/

ITV News (28th October 2013) Port of Dover, http://www.itv.com/news/topic/port-of-dover/

ITV News (5th December 2013) Thames Barrier to be closed 'to protect London', http://www.itv.com/news/update/2013-12-05/thames-barrier-being-closed-to-protect-london/

ITV News (12th February 2014) Region takes stock after Cumbria and southern Scotland battered by gales, http://www.itv.com/news/border/story/2014-02-12/storm-and-wind-warning-for-cumbria/

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.

Keane T (1976) The storm of January 2, 1976. Dublin, p. 11.

Kendon M The UK storms of winter 2013/2014. in Met Office NCIC, p. 11.

Law RJ, Kelly C, Matthiessen P, Aldridge J (2003) Note: The loss of the chemical tanker Ievoli Sun in the English Channel, October 2000. Marine Pollution Bulletin 46:254-257.

Lloyd's Loading List (13th February 2014) Port of Felixstowe closure affects freight due to weather, http://www.lloydsloadinglist.com/freight-directory/road/Port-of-Felixstowe-closure-affects-freight-due-to-weather/274.htm#VInPGEOfUI

Lord Cullen (1990) The public inquiry into the Piper Alpha disaster (command paper). Her Majesty's Stationary Office, p. 488.

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.

MAIB (1993) Report of the Chief Inspector of Marine Accidents into the engine failure and subsequent grounding of the Motor Tanker Braer at Garths Ness, Shetland. Southampton, p. 85.

MAIB (1996a) Report of the investigation into the grounding of the Passenger Ro-Ro Ferry Stena Challenger on 19 September 1995 Blériot-Plage, Calais. Southampton, p. 23.

MAIB (1996b) Report of the investigation into the grounding of the tanker Borga at Milford Haven. Southampton, p. 39.

MAIB (1997) Report of the Chief Inspector of Marine Accidents into the grounding and subsequent salvage of the tanker Sea Empress at Milford Haven between 15 and 21 February 1996. Southampton, p. 27.

MAIB (1999) A report on the investigation of the capsize and foundering of the workboat/tub Trijnie with the loss of one life in the approach channel to Milford Docks, Milford Haven, on 8 September 1998. Southampton, p. 43.

MAIB (2000) Report of an investigation of the flooding to the engine room of the cargo vessel MV Sonia off Sandown Bay, Isle of Wight on 1 September 1999. Southampton, p. 56.

MAIB (2001) Report on the investigation of the grounding of European Pioneer off Fleetwood 1 December 2000. Southampton, p. 28.

MAIB (2002a) Report on the investigation of the collision between the ro-ro ferry Stena Gothica and the eastern approach jetty at Immingham on 2 April 2002. Southampton, p. 44.

MAIB (2002b) Report on the investigation of the grounding of MV Lysfoss Sound of Mull, Scotland 7 May 2001. Southampton, p. 43.

MAIB (2003a) Report on the investigation of the collision between Pride of Portsmouth and HMS St. Albans Portsmouth Harbour 27 October 2002. Southampton, p. 33.

MAIB (2003b) Report on the investigation of the contact between Pride of Providence and The Southern Breakwater, Dover Harbour, eastern entrance on 18 April 2003. Southampton, p. 56.

MAIB (2007) Report on the investigation of the collision between Skagern and Samskip Courier in the Humber Estuary 7 June 2006. Southampton, p. 65.

MAIB (2008a) Report on the investigation of the loss of the tub Flying Phantom while towing Red Jasmine on the River Clyde on 19 December 2007 resulting in 3 fatalities and 1 injury. Southampton, p. 63.

MAIB (2008b) Report on the investigation of the structural failure of MSC Napoli English Channel on 18 January 2007. Southampton, p. 56.

MAIB (2009a) Report on the investigation into the flooding and foundering of the grab hopper dredger Abagail H in the Port of Heysham 2 November 2008. Southampton, p. 49.

MAIB (2009b) Report on the investigation into the grounding of Pride of Canturbury "The Downs" - off Deal, Kent 31 January 2008. Southampton, p. 28.

MAIB (2009c) Report on the investigation into the grounding, and subsequent loss, of the ro-ro cargo vessel Riverdance Shell Flats - Cleveleys Beach, Lancashire. Southampton, p. 74.

MAIB (2010) Report on the investigation into the loss of the tug Ijsselstroom in the port of Peterhead 14 June 2009. Southampton, p. 42.

MAIB (2012) Report on the investigation of the electrical blackout and subsequent grounding of the feeder container vessel Clonlee on the River Tyne, England 16 March 2011. Southampton, p. 68.

MAIB (2013) Report on the investigation of the grounding of the cargo ship Carrier at Raynes Jetty in Llanddulas, North Wales on 3 April 2012. Southampton, p. 69.

MAIB (2014) Collision between tug Christos XXII and its tow, EMSSTROM, Hope's Nose, Tor Bay, England 13 January 2013. Southampton, p. 8.

Margate Local History (2014) Margate Storms, http://www.margatelocalhistory.co.uk/Pictures/Pictures-Storms.html

Maritime and Coastguard Agency (2001) Crew abandoned sinking ship, http://www.gov-news.org/gov/uk/news/crew-abandoned-sinking-ship/7432.html

Maritime and Coastguard Agency (27th October 2002) 'Bothnia Stone' heads for Torbay, https://mcanet.mcga.gov.uk/public/news/release.asp?mcga_news_id=4&month=10&year=2002

Maritime Insight (21st July 2011) Worst maritime accidents: The Tricolor cargo ship accident, http://www.marineinsight.com/marine/life-at-sea/maritime-history/worst-maritime-accidents-the-tricolor-cargo-ship-accident/

Maritime Journal (2014) Lowestoft addresses the flood threat challenge, http://www.maritimejournal.com/news101/marine-civils/port,-harbour-and-marine-construction/lowestoft-addresses-the-flood-threat-challenge

McCallum E, Grahame NS (1993) The Braer storm - 10 January 1993. Weather 48:103-107.

McRobie A, Spencer T, Gerritsen H (2005) The Big Flood: North Sea storm surge. Philosophical transactions. Series A, Mathematical, physical, and engineering sciences 363:1263-1270.

Met Office (2014) Case Study - Floods, http://www.metoffice.gov.uk/education/teens/case-studies/floods

Met Office (1954) December 1954 - Mild; wet in Scotland, north-west England and Wales; frequent gales. Monthly Weather Report of the Meteorological Office, p. 1.

Met Office (2011a) Monday 26 February 1990 (Towyn Floods). National Meteorological Library and Archive.

Met Office (2011b) Severe weather, 30-31 March 2010, http://www.metoffice.gov.uk/news/releases/archive/2010/severe-weather-march

Met Office (2011c) Sunday 10 January 1993 (The Braer Storm). National Meteorological Library and Archive.

Met Office (2012a) Amber warning of wind, 11 and 12 November 2010, http://www.metoffice.gov.uk/guide/weather/warnings-case-studies/wind-warning-amber

Met Office (2012b) January 2005 - stormy spells, http://www.metoffice.gov.uk/climate/uk/interesting/jan2005wind

Met Office (2013) Stormy weather 13 and 14 November 2009, http://www.metoffice.gov.uk/news/releases/archive/2009/stormy-weather

Met Office (2014) The recent storms and floods in the UK. Exeter, p. 29.

Munich RE (2012) 50th Anniversary of the North Sea Flood of Hamburg. in Henghuber G (ed.), 13 February 2012 edn.

Namias J (1989) Anomalous climatological background of the storm of 15-16 October 1987. Weather 44:98-105.

Natural Resources Wales (2014) Flood and coastal erosion risk management in Wales, 2011-2014. Cardiff, p. 52.

Odell L, Knippertz P, Pickering S, Parkes B, Roberts A (2013) The Braer storm revisited. Weather 68:105-111.

Paté-Cornell ME (1993) Learning from the Piper Alpha accident: A portmortem analysis of technological and organisational factors. Risk Analysis, 13:215-232.

Appendix B

Port Strategy (2010) Snow forces UK port closures, http://www.portstrategy.com/news101/world/europe/snow-forces-uk-port-closures

Proctor R, Flather RA (1989) Storm surge prediction in the Bristol Channel - the floods of 13 December 1981. Continental Shelf Research 9:889-918.

Risk Management Solutions Inc. (2003) 1953 U.K. Floods: 50 year retrospective. p. 12.

Risk Management Solutions Inc. (2007) The great storm of 1987: 20-year retrospective. p. 18.

Royston Crow (2012) Felixstowe: Port closed as gales lash coast, http://www.royston-crow.co.uk/news/felixstowe_port_closed_as_gales_lash_coast_1_1359319?usurv=skip

Schneider T, Weber H, Franke J, Bronnimann S (2013) The storm surge event of the Netherlands in 1953. in Bronnimann S, Martius O (eds.) Weather Extremes during the past 140 Years. Gergraphica Bernensia, pp. 35-43.

Sky News (2014) 'Red Alert' as storm brings 100mph winds, http://news.sky.com/story/1210213/red-alert-as-storm-brings-100mph-winds

South Wales Argus (2nd January 2014) Gwent escapes serious flooding from latest high tide, http://www.southwalesargus.co.uk/news/10911423.Gwent_escapes_serious_flooding_from_latest_high_tides/

Southern Daily Echo (2nd December 2010) Southampton container port shut by the snow, http://www.dailyecho.co.uk/news/briefing/snow_december_2010/8716511.container_port_shut_by_the_snow/

STV News (10th December 2014) Dangerous conditions as severe rain and gales batter much of Scotland, http://news.stv.tv/highlands-islands/302904-dangerous-conditions-as-scotstorm-weather-bomb-hits-west-coast/

The Argus (15th February 2014) Raging winds and rain cause chaos in Sussex - live updates, http://www.theargus.co.uk/news/11013755.Raging_winds_and_rain_cause_chaos_in_sussez_live_updates/?ref=var=0

The Guardian (8th December 2011) Scotland braces for hurricane force winds - Thursday 8 December, http://www.theguardian.com/news/blog/2011/dec/08/weather-scotland-uk

The Guardian (3rd January 2012) Travel chaos as storms lash Britain - Tuesday 3 January, http://www.theguardian.com/news/blog/2012/jan/03/travel-chaos-weather-live-updates

The Guardian (4th July 2013) Piper Alpha disaster: how 167 oil rig workers died, http://www.theguardian.com/business/2013/jul/04/piper-alpha-disaster-167-oil-rig

The Guardian (29th August 2013) Super Puma helicopter endured rapid dive before crash, says report, http://www.theguardian.com/uk-news/2013/aug/29/super-puma-rapid-dive-crash

The Guardian (24th December 2013) Transport disruption as storm hits UK before Christmas - live blog, http://www.theguardian.com/uk-news/2013/dec/24/storm-batters-uk-before-christmas-live-blog

The Guardian (21st October 2014) UK storms cause rush-hour disruption for road,rail and air travellers, http://www.theguardian.com/uk-news/2014/oct/21/uk-storms-rush-hour-disruption-road-rail-air-travellers-hurricane-gonzalo

The Guardian (21st October 2014) UK storms leave woman dead, homes without power and transport disrupted, http://www.theguardian.com/uk-news/2014/oct/21/uk-storms-woman-dead-trees-fall-london-hurricane-gonzalo

The Guardian (5th February 2014) UK storms: rail chaos and more homes evacuated, http://www.theguardian.com/environment/2014/feb/05/uk-storms-live-updates

The Guardian (3rd January 2014) UK weather live: high tides, rain and winds expected to bring severe flooding, http://www.theguardian.com/uk-news/2014/jan/03/floods-storms-and-high-winds-threaten-uk-live

The Highland Council (2013) Caithness and Sutherland Area Committee 18 February 2013: Storm Damage - 14/15 December 2012. in Transport EaCS (ed.), p. 7.

The Independent (9th July 1992) Submarine crew blamed for sinking of Antares, http://www.independent.co.uk/news/uk/submarine-crew-blamed-for-sinking-of-antares-1532324.html

The Independent (15th November 2009) Dover closed as winds hit 100mph, http://www.independent.co.uk/environment/nature/dover-closed-as-winds-hit-100mph-1820951.html

The Independent (15th February 2014) UK weather: Two dead and several injured as latest storm continues to batter Britain, http://www.independent.co.uk/news/uk/home-news/uk-weather-two-dead-and-several-injured-as-latest-storm-continues-to-batter-britain-9130531.html

Appendix B

The Lowestoft Journal (14th May 2010) Missing the boat saved his life!, http://www.lowestoftjournal.co.uk/news/missing_the_boat_saved_his_life_1_516825

The Scarborough Maritime Heritage Centre 1954 Scarborough Lifeboat Disaster, http://scarboroughsmaritimeheritage.org.uk/a1954scarboroughlifeboat.php

The Scotsman (2009) Forth Ports warned of climate change flood threat to docks, http://www.scotsmandep.com/news/forth-ports-warned-of-climate-change-flood-threat-to-docks-1-1203912

The Shetland Times (11th January 2010) North boat sailings disrupted after Aberdeen Harbour is closed, http://www.shetlandtimes.co.uk/2010/01/11/north-boat-sailings-disrupted-after-aberdeen-harbour-is-closed

The Telegraph (7th February 2001) Snow has Scotland in a stranglehold, http://www.telegraph.co.uk/news/uknews/1321506/Snow-has-Scotland-in-a-stranglehold.html

The Telegraph (7th November 2008) MSC Napoli second most expensive wreck in history, shows insurance report, http://www.telegraph.co.uk/news/uknews/3397327/MSC-Napoli-second-most-expensive-wreck-in-history-shows-insurance-report.html

The Telegraph (3rd December 2010) Snow UK: two pensioners feared to have died in freezing weather, http://www.telegraph.co.uk/news/weather/8178854/Snow-UK-two-pensioners-feared-to-have-died-in-freezing-weather.html

The Telegraph (3rd January 2012) Man killed in January storms as 100mph winds batter Britain bringing flooding and power cuts, http://www.telegraph.co.uk/news/weather/8989767/Man-killed-in-January-storms-as-100mph-winds-batter-Britain-bringing-flooding-and-power-cuts.html

The Telegraph (28th December 2012) Sick of all the rain? It's not as bad as the Big Freeze of 1963, http://www.telegraph.co.uk/news/weather/9769489/Sick-of-all-the-rain-Its-not-as-bad-as-the-Big-Freeze-of-1963.html

The Telegraph (5th December 2013) UK weather warning: live updates, http://www.telegraph.co.uk/news/weather/10497522/UK-weather-warning-live.html

The Telegraph (3rd January 2014) No respite from floods as wind and heavy rain are forecast for weekend, http://www.telegraph.co.uk/news/weather/10548343/No-respite-from-floods-as-wind-and-heavy-rain-are-forecast-for-weekend.html

The Whales & Dolphins of Clacton Pier (2009) The Storm Damage - January 1979, http://www.clactondolphins.co.uk/Pages/stormpage.html

Trade Winds News (2005) 'Tricolor' battle lines take shape, http://www.tradewindsnews.com/weekly/w2005-07-08/212297/tricolor-battle-lines-take-shape

Trade Winds News (2012) Clary ruling returns to court, http://www.tradewindsnews.com/casualties/665057/clary-ruling-returns-to-court

UK Haulier (6th February 2012) Snow forces closure of Felixstowe port, http://www.ukhaulier.co.uk/news/road-transport/weather/snow-forces-closure-of-felixstowe-port/

Vertikal (1st March 2008) Cranes damaged at Felixstowe, http://www.vertikal.net/en/news/story/5498/

Wadey MP, Haigh ID, Brown JM (2014) A century of sea level data and the UK's 2013/14 storm surges: an assessment of extremes and clustering using the Newlyn tide gauge record. Ocean Sci. 10:1031-1045.

Weather Forecast (14th February 2014) UK storm 14th February 2014 - 80mph + gales and heavy rain expected in the south, http://www.weatherforecast.co.uk/blog/uk-storm-14th-february-2014-80mph-gales-heavy-rain-expected-south/

Wells NC, Baldwin D, Wang J, Collins M (2001) Modelling of extreme storm surge events in the English Channel for the period 14-18 December 1989. The Global Atm and Ocean System 7:275-294.

West Coast News (2005) When a cruel sea took the heroes of Penlee, http://www.westcoast-news.org/story-penlee.htm

Western Morning News (2014) That was the west that was: Torcross storm damage, 1979, http://www.westernmorningnews.co.uk/West-Torcross-storm-damage-1979/story-20596395-detail/story.html

Williams J, Wilson C, Horsburgh KJ (2012) Re-analysis of the December 1981 storm surge event in the Bristol Channel using the current operational tide-surge model suite. National Oceanography Centre, Southampton, p. 17.

Willis Re (2007) Catastrophe Management - Windstorm Kyrill, 18 January 2007. p. 21.

Willis Re (2011) December 2011 Windstorm Friedhelm UK. London.

Yahoo! News (27th December 2014) Dover-Calais ferry services briefly suspended amid high winds, https://uk.news.yahoo.com/dover-calais-ferry-services-suspended-amid-160-km-100811386.html#vKl7bD7

Zong Y, Tooley MJ (2003) A historical record of coastal floods in Britain: frequencies and associated storm tracks. Natural Hazards 29:13-36.

Appendix C List of UK shipping forecast regions

Bailey

Cromarty

Dogger

Dover

Fair

Fareoes

Fastnet

Forth

Forties

Hebrides

Humber

Irish Sea

Lundy

Malin

Plymouth

Portland

Rockall

SE Iceland

Shannon

Sole

Thame

Tyne

Appendix C

Viking

Wight

Appendix D Summary table of the disruptive extreme events identified during the study.

CA – Coastal areas, EEZ – Exclusive Economic Zone, P – Ports, HE – Human error, MF – Mechanical fault, PV – Poor visibility, RS – Rough seas, S&I – Snow and ice, SS – Storm surge, WS – Wind storm, ✓✓ - Primary extreme event type, ✓ - Secondary extreme event type

Date(s) of event	Event severity	Zones affected			Key impacts	Primary and secondary event types						
		CA	EEZ	P		HE	MF	PV	RS	S&I	SS	WS
31/1/1953 – 1/2/1953	7	✓	✓	✓	Multiple vessels sank (including Princess Victoria car ferry); loss of, and damage to homes (24,000), businesses (200) and agricultural land/livestock (160,000 acres and 46,000 animals); multiple mortalities (475); Felixstowe docks destroyed				✓		✓✓	✓
17/11/1953	7		✓		Steamer Vittoria Claudia sank; mineral oil cargo lost; entire crew perished (20)	✓✓						
8/12/1954	7	✓			Scarborough lifeboat sank; crew perished (3)							✓✓
25/12/1962 – 6/3/1963	4	✓	✓	✓	Freezing conditions resulted in long term delays accessing ports					✓✓		✓
27/12/1965	7		✓		Sea Gem collapses; 13 died		✓✓					
20/1/1966	6		✓		MS Kremsertor sank; cargo of iron ore lost							✓✓

18/3/1967	6		✓		Torrey Canyon ran aground (eventually disposed via bombing); cargo of crude oil lost (>100,000 tonnes)	✓✓						
27/3/1967	3	✓		✓	Breaching of seawall; highly localised flooding; SW Scotland						✓✓	
15/1/1968	6		✓		SeaQuest broke anchors and was lost				✓✓			✓
6/3/1968	6		✓		Ocean Prince collapsed				✓✓			
2/1/1974	6		✓		Transocean capsized (in use for <6 months)		✓✓					
2-4/1/1976	4	✓			Over 400 houses flooded (Cleethorpes)						✓	✓✓
9-12/11/1977	4	✓			>500 properties flooded; 7900 acres agricultural land (including >7000 livestock); NW coast				✓		✓✓	✓
11/1/1978	4	✓		✓	>1000 houses flooded; localised sea wall breaches; Lincolnshire and East Anglia					✓	✓✓	✓
4-5/1/1979	4	✓			1500 houses flooded (Cleethorpes); localised sea defence breaching				✓		✓✓	✓
13/2/1979	7	✓			Houses destroyed in Portland				✓		✓✓	
13/8/1981	7		✓		Helicopter lost power and crashed into the sea; all 13 on board were killed		✓✓					
13/12/1981	3	✓			Flooding primarily affecting Somerset				✓		✓	✓✓
19/12/1981	7	✓			Union Star Coaster and Penlee lifeboat sank;				✓		✓✓	✓

					mortality of all aboard the vessels							
2/2/1983	3	✓			Localised flooding along the S-E England coast						✓✓	
6/11/1986	7		✓		Chinook crashed in North Sea; 45 died		✓✓					
15-16/10/1987	7	✓	✓	✓	Multiple vessels sank or were damaged (MV Hengist)							✓✓
6/7/1988	7		✓		Largest man-made catastrophe; Piper Alpha destroyed; 167 perished	✓✓						
22/9/1988	6		✓		Ocean Odyssey oil rig suffered a blowout; 1 crew member died (human error)		✓✓					
8/11/1989	6		✓		Interocean II broke free from tow lines and sank							✓✓
25/1/1990	5			✓	Multiple ports were closed for over 3 hours					✓		✓✓
26-28/2/1990	4	✓			2800 houses flooded; severe breaching of sea defences				✓		✓✓	✓
12/5/1990	6		✓		1100 tonnes of crude oil spilled	✓✓						
25/7/1990	7		✓		Helicopter crashed into North Sea, 6 on board died	✓✓						
5, 10/1/1993	7		✓		MV Braer broke up and lost cargo; 84700 metric tons of light crude oil spilled				✓			✓✓
19/9/1995	3			✓	Minor damage to ferry Stena Challenger; 24 hour delay	✓✓						✓
29/10/1995	1			✓	Tanker Borga ran aground, short term delays	✓✓						

15-21/2/1996	6	✓		✓	71,800 tonnes of crude oil cargo spilt; Sea Empress was salvaged	✓✓						
8/9/1998	4			✓	Single mortality; Trijnie capsized but was re-floated	✓✓						
24/8/1999	4		✓		Damage to vessels Norwegian Dream and Ever Decent; latter partially lost cargo	✓✓						
1/9/1999	2		✓	✓	MV Sonia required assistance after taking on water		✓✓					
30/10/2000	6		✓		Ievoli Sun sank; 6000 tonnes (styrene and ethyl ketone) cargo lost				✓✓			✓
4/2/2001	5			✓	Aberdeen Harbour closed; >100 ferry passengers stranded for 41 hours in North Sea				✓	✓✓		✓
7/5/2001	4	✓			MV Lysfoss grounded and sustained substantial damage; ~80 litres diesel oil spilt	✓✓	✓					
1/12/2001	2			✓	European Pioneer grounded; delayed for one tidal cycle	✓✓						
12/12/2001	2			✓	Collision between grounded Celtic Forester and Rolf Buck	✓✓						
16/12/2001	7		✓		Dina sank; 2430 tonnes of fluorspar lost; 35 tonnes marine gas bunker oil spilt		✓✓					
2/4/2002	4			✓	Collision between Stena Gothica and eastern approach jetty at Immingham; some cargo	✓✓						

					damage; vessel required urgent assistance							
5/7/2002	7		✓		Helicopter crashed into the North Sea; 11 killed		✓✓					
26-27/10/2002	4	✓		✓	Bothnia Stone required assistance; lost part of timber cargo overboard (some retrieved); collision between Pride of Portsmouth and HMS St. Albans	✓						✓✓
14/12/2002	7		✓		Tricolor lost after collisions with Kariba, Vicky and Nicola; partial cargo loss; 1990 tonnes heavy fuel oil spilt	✓✓		✓				
18/4/2003	2			✓	Contact between Pride of Providence and southern breakwater at Dover Harbour; 30 injuries sustained	✓✓						
11-12/1/2005	2	✓	✓		Crew rescued from a Spanish fishing boat; flooding in Outer Hebrides				✓		✓	✓✓
3/11/2005	3	✓			Regions of Hayling Island were flooded						✓✓	
7/6/2006	4			✓	Collision between Samskip Courier and Skagern; Skagern partially sank	✓✓		✓				
27/12/2006	7		✓		Aerospatiale helicopter crashed off the North Morecambe gas platform; all 7 on board perished	✓✓						
17-19/1/2007	6	✓	✓	✓	MSC Napoli deliberately beached and broke up; 302 tonnes light fuel oil spilt; Dover, Dublin and Felixstowe ports closed		✓		✓			✓✓

8/5/2007	5			✓	Extended closure of Felixstowe Port							✓✓
19/12/2007	7			✓	Tug Flying Phantom lost; three crew members perished			✓✓				
31/1/2008	6		✓	✓	Ferry Riverdance sank; Pride of Canterbury grounded sustaining major damage; Port of Dover closed				✓			✓✓
1/3/2008	4			✓	Zhen Hua 23 broke free of mooring in Felixstowe Port destroying cranes				✓			✓✓
10-12/3/2008	5	✓		✓	Dover, Felixstowe and Southampton Ports closed; widespread flooding in English Channel				✓		✓	✓✓
2/11/2008	6			✓	Grab hopper dredger Abigail H sank; ~100 litres lubricating and diesel oil spilt		✓✓					
14/6/2009	6			✓	Tug Ijsselstroom sank	✓✓						
14/11/2009	5			✓	Dover Port closed; coastal flooding in Dorset; multiple ferry service delays and cancellations							✓✓
6/1/2010	5			✓	Felixstowe Port closed							✓✓
10/1/2010	5			✓	Aberdeen Harbour closed; vessels unable to exit harbour (including Hjaltland)				✓✓			
30-31/3/2010	3			✓	Multiple ferry service delays and cancellations					✓✓		✓
11-12/11/2010	3			✓	Multiple ferry service delays and cancellations							✓✓

2/12/2010	5			✓	Felixstowe, Southampton, Immingham, Thamesport, Tilbury and Grangemouth Ports were closed					✓✓		
16/3/2011	1			✓	Clonlee grounded in Port of Tyne entrance		✓✓					
23/5/2011	4			✓	Felixstowe Port closed							✓✓
29/11/2011	4			✓	Felixstowe Port closed							✓✓
8/12/2011	5			✓	Felixstowe Port closed; multiple ferry service delays and cancellations				✓			✓✓
3/1/2012	5	✓	✓	✓	Felixstowe and Dover Ports closed; rescues from multiple vessels; multiple ferry service delays and cancellations				✓			✓✓
6/2/2012	5			✓	Felixstowe Port closed					✓✓		
3/4/2012	4	✓			Cargo ship Carrier grounded on shore (Conwy); ~33,000 litres of gas and lubricating oils spilt				✓			✓✓
25/4/2012	4			✓	Felixstowe Port closed							✓✓
14-15/12/2012	3	✓		✓	Ferry service delays and cancellations; localised damage to sea defences and harbour walls						✓✓	✓
13/1/2013	2	✓		✓	Collision between Tug Christos XXII and Emsstrom (nb. Not classed as severity level 6 as Emsstrom was deliberately sunk)	✓✓						

28-19/1/2013	5			✓	Felixstowe Port closed							✓✓
23/8/2013	7		✓		Super Puma helicopter lost power and crashed off Shetland; 4 passengers were killed		✓✓					
28/10/2013	5			✓	Felixstowe and Dover Ports closed; Ferry service delays and cancellations				✓			✓✓
3/11/2013	4	✓		✓	Evacuation of homes in Newport; multiple sea defences breached and flooding				✓		✓	✓✓
5-6/12/2013	7	✓		✓	7 homes washed into the sea and >10,000 people evacuated; Immingham and Dover Ports closed; Immingham port severely damaged						✓✓	
23/12/2013	3			✓	Dover Port closed; ferry service delays and cancellations				✓	✓		✓✓
24/12/2013	5		✓	✓	Dover Port closed; ferry service delays and cancellations; injured ferry passengers required hospitalization				✓			✓✓
26/12/2013	3			✓	Ferry service cancellations				✓✓			
27/12/2013	3			✓	Delays at Dover Port due to closure of Calais Port				✓			✓✓
6/1/2014	4	✓		✓	1400 homes flooded; 18,000 people evacuated; ferry service delays and cancellations				✓		✓	✓✓
12-15/2/2014	4	✓	✓	✓	Felixstowe and Dover Ports closed; 1 passenger				✓			✓✓

					died aboard Marco Polo cruise liner, 14 required medical assistance							
21/10/2014	3			✓	Ferry service delays and cancelations							✓✓
9-10/12/2014	3	✓		✓	Non-standard assistance given to damaged trawler; ferry service delays and cancellations				✓			✓✓

Appendix E List of ports included within reports of extreme events

Major ports are marked with an asterisk.

Aberdeen*

Belfast*

Chatham*

Cairnryan*

Clydeport*

Dover*

Felixstowe*

Fishguard*

Glasgow

Grangemouth*

Heysham*

Holyhead*

Hull*

Immingham*

Larne*

Liverpool*

Lowestoft

Milford Haven*

Newhaven*

Peterhead*

Plymouth*

Poole*

Portsmouth*

Roscoff

Rosslare

Southampton*

Thamesport*

Tilbury*

Torbay

Wells

Yarmouth

Appendix F Extreme event case studies

Case study 1: The 1953 storm surge

January 31st-February 1st 1953

A temperate cyclone interacted with spring tides to form a 1 in 250 year storm surge event (Baxter, 2005; Lumbroso and Vinet, 2011), resulting in the UK's most severe post-war extreme event (Trade Winds News, 2005; Wadey, 2013). Sea levels peaked at a height of 4.5m above mean sea level (Jonkman and Kelman, 2005). The combined high winds, storm surge and rough seas had major impacts for the UK's ports, coastal areas and EEZ. A total of 475 people and in excess of 46,000 livestock are known to have perished as a direct consequence of the event, with fatalities occurring both on land and at sea. Other recorded damaged include the destruction of the docks at Felixstowe Port (Levinson, 2008), and flooding of an estimated 24,000 properties and 160,000 acres of agricultural land (Lumbroso and Vinet, 2011). Vessels that were sunk during the storm surge included the *MV Princess Victoria* in the North Sea, with 133 of the 177 people on board lost. Those on board that perished included the Norther Ireland Deputy Prime Minister and Finance Minister (BBC, 2008a). Damages resulting from the event reached £50 million (£1.26 billion in 2017) (Risk Management Solutions Inc., 2003). Following this devastating event a number of government level responses were made, including the installation of a tidal gauge early warning system, improved sea defences, and the construction of the Thames Barrier (Jonkman and Kelman, 2005).

Case study 2: Piper Alpha oil rig fire

July 6th 1988

Piper Alpha was the largest oil platform located in the North Sea, supplying 10% of the UK's oil and gas. Following a sequence of explosions the oil rig ignited, and it took three weeks for the fire to be brought under control. Workers aboard both the rig and standby vessels were killed, with a total of 167 of the total 228 workforce lost (The Guardian, 2013; Trade Winds News, 2005). Losses suffered by Lloyds Insurance Marketplace, in the region of £1 billion, made piper Alpha the most common non-weather insured disaster, and the worst offshore catastrophe globally (BBC, 2008b; Department for Transport, 2012). Studies by Paté-Cornell (1993) and the Lord Cullen (1990) report conclude that the event arose from a myriad of errors and poor decision-making. This lead to 106 recommendations being made regarding health and safety recommendations being made for operations on offshore platforms.

Case study 3: Sinking of the Tricolor

December 14th 2002

The carrier ship *Tricolor* sank in the Dover Strait following a collision with the container vessel *Kariba* in heavy fog (BBC, 2002a; Trade Winds News, 2005). The *Tricolor's* 24 crew were rescued by the *Kariba*. The stricken vessel posed a navigational hazard as it had sunk in a busy shipping lane (BBC, 2002b; Department for Transport, 2012). Further damage occurred to the T*ricolor* as two vessels – *Nicola* and *Vicky* ignored isolation zones and struck the vessel on the 16th December and 1st January respectively (Maritime Insight, 2011). These events were followed by a collision by a salvage tug, causing environmental pollution. Loss of cargo was valued at £30 million, comprising approximately 3000 luxury cars, making the disaster one of the most expensive automobile cargo losses (BBC, 2002a; Maritime Insight, 2011). The entire cost was determined as £130 million, with the distribution of fault split between Kariba, Clary and Tricolor. Following this event, in 2003 a tracking system was implemented for all vessels passing through the Dover Strait.

Appendix G All UK commercial ports

All UK commercial ports according to Department for Transport (2016a) data. Major ports are in bold, minor ports in italics, and ports that are not presently in operation are marked by an asterisk.

Port group	Ports
Scotland East Coast	**Aberdeen, Forth, Cromarty Firth, Dundee, Orkney, Peterhead, Sullom Voe** *Buckie, Burghead, Fraserburgh, Gill's Bay Scotland, Inverkeithing, Inverness, Lerwick, Lossiemouth, Macduff, Montrose, Perth, Scalloway, Scrabster, Tayport, Wick*
Northern Ireland	**Belfast, Kilroot Power Station Jetty*, Larne, Londonderry, Warrenpoint** *Bangor, Carrickfergus, Coleraine, Killyleagh, Kilroot, Larne Bank Quays*, Magheramorne*, Portrush, Red Bay*
Wash and Northern East Anglia	**Boston, Great Yarmouth** *Fosdyke, King's Lynn, Lowestoft, Sutton Bridge, Wells, Wisbech*
Bristol Channel	**Bristol, Cardiff, Newport, Port Talbot, Swansea** *Appledore, Barnstaple*, Barry, Bideford, Bridgwater, Burry Port, Llanelli*, Neath, Penarth*, Sharpness, Watchet**
Scotland West Coast	**Cairnryan, Clyde, Gensanda, Loch Ryan, Stranraer*** *Ardrishaig, Ayr, Barra Castlebay, Corpach, Craignure, Garlieston, Girvan, Irvine, Kirkcudbright, Kyle of Lochalsh, Loch Carnan, Lochaline, Port Askaig, Stornoway, Troon*
Thames and Kent	**Dover, London, Medway** *Brightlingsea, Colchester*, Folkestone, Maldon, Rye, Sandwich, Wallasey*, Whitstable*
Haven	**Felixstowe, Harwich, Ipswich** Mistley

West and North Wales	**Fishguard, Holyhead, Milford Haven** *Anglesea Marine Terminal*, Caernarfon, Llandulas, Mostyn, Port Penrhyn, Shotton*
Lancs and Cumbria	**Fleetwood, Heysham, Liverpool, Manchester** *Barrow, Garston, Lancaster, Preston*, Silloth, Whitehaven, Workington*
West Country	**Fowey, Plymouth, Poole** *Bridport, Charleston, Dartmouth, Dean Point Quarry*, Exmouth*, Falmouth, Gweek, Hughtown (St. Mary's), Newlyn, Padstow, Par, Penryn, Penzance, Porthoustock, Teignmouth, Torquay, Truro, Weymouth and Portland*
Humber	**Goole, Hull, Grimsby and Immingham, Rivers Hull and Humber*, River Trent*** *Dutch River Quarry*, River Ouse*
Sussex and Hampshire	**Newhaven, Portsmouth, Shoreham, Southampton** *Chichester, Cowes, Fareham, Littlehampton, Newport*
North East	**Sunderland, Tees and Hartlepool, Tyne** *Berwick, Blyth, Seaham, Warkworth, Whitby and Scarborough*

Appendix H Complete range of extreme range of weather event types and risks identified in the Adaptation Reports

The complete range of extreme weather types of concern for ports, and specific risks associated with those types recorded within the Adaptation Reports

	Risks	**ABP**	**Dover**	**Felixstowe**	**Harwich Haven**	**Liverpool**	**Milford Haven**	**Teesport/Hartlepool**	**Port of London Authority**	**Sheerness**
High winds	Wind delaying vessel operations	✓	✓					✓	✓	✓
	Tugs required more often		✓					✓		
	Higher insurance costs		✓	✓			✓	✓		
	Vessel parts from the ship/shore interface		✓	✓				✓		
	Port temporarily closed		✓	✓	✓			✓		✓
	Winds affecting maintenance operations	✓	✓	✓	✓		✓	✓		✓
	Winds affecting dockside operations		✓	✓	✓	✓	✓	✓		✓
	Power outages			✓			✓			

	Containers blown over			✓		✓		✓		✓
	Buildings and infrastructure damaged			✓		✓		✓		✓
	Water supplies cut off			✓						
	Standard operating procedures have to change							✓		
	Increased grounding risks							✓		✓
	Damaged cargoes							✓		✓
	Air draft issues								✓	
High temperatures	Water shortages		✓							
	Sunburn/UV exposure		✓				✓			
	Reduced thermal efficiency		✓	✓			✓			✓
	Uncomfortably warm working conditions	✓	✓	✓	✓		✓	✓	✓	
	Tarmac melting	✓	✓	✓		✓		✓		✓
	Increased incidents arising from leisure activities	✓			✓		✓			
	Reduced engine efficiency	✓			✓		✓			
	More alien species				✓	✓	✓		✓	✓

	Power outage					✓				
	Increased demand for animal feedstuffs						✓			
	Increased illnesses						✓			
	Degradation of cargoes							✓		✓
	New traffic study needed								✓	
	Increased up-river abstraction								✓	
Flooding and rainfall	Flooding of port land	✓	✓		✓	✓	✓	✓	✓	
	Inadequate drainage		✓	✓		✓	✓	✓		✓
	Contamination of potable water		✓					✓		
	Cargo damage		✓			✓	✓	✓		✓
	Tugs required more often		✓	✓					✓	
	Buildings flooded/damaged			✓		✓		✓		✓
	Road/rail flooded			✓		✓		✓		
	Substation flooded	✓		✓	✓	✓		✓		✓
	Reduced freshwater flow					✓	✓			

	Uncontrolled lock gate opening					✓				
	Subsidence					✓				
	VTS/IT systems flooded	✓				✓				
	Heavy rain affecting radar							✓		
	Flooding causing delays									✓
	Historical buildings flooded									✓
Sea-level rise	Low/high tide affecting vessel clearance	✓			✓				✓	
	More or less dredging	✓			✓	✓	✓	✓		
	Corrosion					✓				✓
	Flooding of IT systems					✓				
	Increased risk of responsibility	✓					✓			
	Inaccuracy of height beacons						✓			
	New developments to consider SLR							✓		
	Impacts on internationally designated sites							✓		
	Infrastructure damage								✓	✓

Snow and ice	Snow affecting other transport modes		✓				✓	✓		
	Stock shortages		✓							
	Costs for labour, plant, grit		✓							
	Slips/trips		✓							
	Diesel freezing						✓			
	Vehicles lose grip/traction							✓		
	Delayed cargo movement							✓		
	Damage to hard standings									✓
Storm surge	Staff absence or more passengers	✓	✓		✓					
	Damage to navigational equipment		✓							✓
	Corrosion	✓	✓							
	Beach erosion and scouring		✓		✓					
	Increased debris brought downstream		✓	✓						
	Damage to sea defences	✓	✓			✓	✓		✓	✓
	Increased suspended sediments							✓		

	Unable to store cargo							✓		
	Beach erosion and scouring								✓	
	Increased need for towpath management							✓		
Poor visibility	Delayed vessel movements		✓					✓		✓
	Reduced navigational safety									✓

Appendix I Adaptation measures proposed in the Adaptation Reports

Event type	Adaptation type	Completed/ underway	Adaptation measure
Flooding and increased rainfall	Hard		Improved, maintained or repaired flood defences, lock or flood gates
			Maintained or increased drainage capacity
		✓	Flood-proof, relocate equipment or build underground cabling
		✓	Move electrical installations
			Upgraded water supply hoses
	Soft	✓	Inundation maps, flood plan or risk monitoring
			New parking arrangements or alternative access routes
		✓	Place containers on concrete plinths
			Shelter conveyor system or plan movement of water-sensitive items
High temperatures	Hard	~	Increase building and refrigeration thermal efficiency or review server room sizes
			Install heat resistant cranes

			Develop renewable on-site energy generation
			Increase number of moorings
	Soft		Grey water and back-up reservoir access
			Pest control measures
			Continuous reviews of temperature controlling practices and client liaison
			Lorry turning only at night or at specific locations, and tarmac protection or replacement
			Use knowledge from ports in hotter environments
			Risk assessments and traffic surveys for leisure users
			Change supplied clothing
High winds/storm surge	Hard	✓	Upgrade, maintain or monitor condition of infrastructure
			More or bigger tugs
			Change positions of moorings
			Move VTS to resilient locations
	Soft		More flexible working hours to accommodate storms and temperature
			Modify or review dredging requirements

		✓	Pre and port storm inspection regime improved
			Wave modelling for improved berths
			Cranes automatically power down
			Use Environment Agency surge forecasts
			Ongoing reviews of storage and stack management for containers
Sea-level rise	Hard	✓	Asset improvements, such as installing articulated walkways or berth floating fingers
			New terminal
		✓	Raise quay or seawall height
			Crane sizes matched to vessels
	Soft		Design specifications to accommodate SLR and climate change
Snow and ice	Hard	✓	Enlarged grit store
	Soft	✓	Contractors used to remove snow
Extreme weather (in general)	Hard	✓	Radar adjustment or enhancement
		✓	Increase robustness of vessels, buildings or infrastructure
		✓	High visibility lighting

		✓	Maintenance programme to reduce insurance
	Soft		Improved plans or recommendations (e.g. Business Continuity or Health and Safety Plans)
			Modify charging mechanisms in pressurised times
		✓	Overflow space made available for foot passengers and additional freight vehicles
		✓	Fuel suppliers store a reserve offsite or use backup generators
		✓	Increased staffing levels
		✓	Warning signs or flags to increase risk awareness
			Raise awareness of, or implement, contingency plans
		✓	Incorporate climate change into work licenses
		✓	Monitoring (meteorological station, lightning strikes etc.)
			Monitor condition of protected areas
		✓	Develop emergency forums or engage with on-site organisations
			Regular sweeping to prevent dust damage
		✓	Increased tree and driftwood collection activities

Appendix J Sample questionnaire disseminated to all UK commercial ports

Port decision-makers questionnaire

Introduction

Thank you for taking part in this survey, which should only take a few minutes.

Rationale: Disruptive weather events can have costly negative impacts for UK businesses, including ports. The period of severe weather during the winter of 2013/14 is an important example.

This survey has been designed to assess how prepared UK ports are for present and future challenges that may occur; and whether port legislation and policy guidance is beneficial for making adaptation decisions. The outcomes of this survey will assist the development of new guidelines and advice to help UK ports to increase their resilience to the present and future challenges expected to arise from climate change.

Esmé Flegg (PhD Researcher, University of Southampton)

Dr. Sally Brown (Senior Research Fellow, University of Southampton)

Prof. Robert Nicholls (Professor of Coastal Engineering, University of Southampton)

Prof. Mikis Tsimplis (Director of the Institute of Maritime Law and Professor of Law and Ocean Sciences, University of Southampton)

Context/background information

1. What port do you work for?

   ……

2. If your port has multiple terminals, which terminal are you based at?

   ……

3. How many years have you worked in the port industry; and in your present position?

   ………

4. How many ports have you worked at during your career?

   ………

5. What is your current job role?

   ………

Adapting against the challenges of extreme events

6. Adaptation refers to actions taken to reduce the risks, and impacts, of extreme weather events. Adaptations can be either “hard” options, such as making infrastructure or equipment more resistant to extreme conditions, or “soft” such as improving planning regulations and health and safety rules. If your port has made any adaptations to protect against the challenges of extreme weather events – which of the below options motivated those decisions. Tick all that apply.

Adaptation type	
To protect infrastructure and equipment from damage	
To meet health and safety requirements	
To prevent or reduce damage to goods and vessels	
To reduce downtime and stoppages	
To reduce insurance premiums	
To spread the financial costs of port upgrades	
To maintain or improve the port’s reputation with current and future clients	
Other (please specify)	
Don’t know	

7. Is a specific person, or persons, responsible for decisions regarding preparing your port against extreme events and climate change?

Yes	
No	
Don’t know	
Other (please specify)	

If "yes", please can you detail their name and contact details below.

………

Preparedness for climate change

Climate change is defined as a long-term shift in the Earth's climate, and involves changes such as sea-level rise, rising temperatures, increased coastal erosion and changes to weather patterns. With climate change, the risk to ports from extreme weather events (such as storm surges, high speed wind events and temperature extremes) will potentially increase.

8. Does your port have a definition of climate change adaptation? If yes, please detail it below.

Yes	
No	
Don't know	
Other (please specify)	

What document is this included in (e.g. environmental statement?

………

If "no", what are the reasons behind this?

………

………

9. On a scale of 1 to 10 how prepared or unprepared do you feel your port is for the impacts of climate change?

Unprepared									**Prepared**
1	2	3	4	5	6	7	8	9	10

10. As an organisation, is your port concerned about extreme weather events and/or climate change? If so, which of the following are of the most concern now, and in 20 years time?

Extreme event or climate change feature	**Today**			**2030s**		
	Concerned	Aware	Unconcerned	Concerned	Aware	Unconcerned
Sea-level rise						
Storm surge						
High winds gusts						
Temperature extremes (heat and cold)						
Changing rainfall						
Visibility issues (fog, mist etc.)						
Other… (please detail)						

……

……

Guidance for adaptation

11. When adaptation decisions are being made in your port, what sources of guidance and information are used?

Using national legislation	
Guidance from local councils	
Advice from government organisations, such as the Environment Agency or DEFRA	
Using guidance from external consultancies	
Independent – "in-house" knowledge	

12. Would your port welcome clearer, more specific, guidance adaptation on extreme events and climate change?

Yes	
No	
Don't know	
Maybe	
Other (please specify)	

………

13. What forms of information would be most beneficial to help your port to adapt to extreme events and climate change?

Risk information documentation summarising the threats of extreme weather events and climate change impacts for ports	
Decision-aiding tools to guide pathways of choices for adaptation	
Provision of assessment templates to aid ports in determining their specific adaptation needs	
Improved national or regional legislation or policy guidelines	
A policy brief that explains adaptation actions available against extreme events and climate change, and its benefits, to the wider port community	
Other (please specify)	
Don't know	

If you are unable to provide an answer to this question, could you please supply the details of a contact who may be able to.

………

………

If your organisation submitted an adaptation report(s) to the Secretary of State in response to the Climate Change Act 2008 please may you kindly attach a copy or provide a web link to your submission.

Appendix K Key locations detailed in the thesis

Bramble Bank A sandbank located in the centre of The Solent, to the side of the narrow shipping lane leading to Southampton Port.

Channel Tunnel Opened in 1994 to connect England (Folkestone, Kent) and France (Coquelles, Pas-de-Calais) by running a passenger and vehicle train under the English Channel. The primary types of transport are: the movement of passengers, postal/courier freight, computers and electronics and vehicle parts (Ernst and Young LLP, 2016).

Dover Strait The narrowest part of the English Channel, between England and France (located approximately between Dover and Calais). The strait connects the English Channel to the North Sea.

English Channel The body of water separating England and France.

Humber estuary A large tidal estuary located on the North-East English coast.

Irish Sea Sea located between Great Britain and Ireland.

Isle of Wight An island located in the English Channel approximately ten kilometres off the south coast.

Mersey estuary An estuary located on the north-west English coast, which has a maximum width of five kilometers.

North Sea A sea located in Northern Europe that is bordered by UK, Belgium, Denmark, France, Germany, the Netherlands and Norway.

River Thames	The second longest river in the UK, passing through London and connects to the North Sea.
Southampton Water	A tidal estuary connecting the rivers Test, Itchen and Hamble to the Solent and the English Channel.
Swansea Bay	A bay located within the Bristol Channel on the Welsh coast.
The Solent	A 20 mile area of water separating the Isle of Wight and Southern England.

Appendix L Climate change adaptation: proposals for the third round of adaptation reporting

Introduction

The Climate Change Act 2008 gives the Secretary of State the power to direct reporting organisations (those with functions of a public nature or statutory undertakers) to produce reports detailing:

- **the current and future projected impacts of climate change on their organisation;**
- **proposals for adapting to climate change;**
- **an assessment of progress towards implementing the policies and proposals set out in previous reports.**

This is known as the Adaptation Reporting Power (ARP).

The ARP was introduced to help ensure reporting organisations are taking appropriate action to adapt to the future impacts of climate change. It helps do this both directly, through engaging organisations in reporting, and indirectly, through raising awareness, building capacity in organisations, and making examples of good practice publicly available.

Under the Climate Change Act 2008, the government's proposed approach or strategy for exercising the ARP should be subject to consultation with relevant parties.

1. What is your name?

Esmé Frances Flegg

2. What is your email address?

If you enter your email address then you will automatically receive an acknowledgement email when you submit your response.

eff1g08@soton.ac.uk

3. What is your organisation?

University of Southampton

4. Would you like your response to be confidential?

No

Proposal for reporting

In the third round of reporting the government is seeking to build on the previous cycles of reporting. We propose to develop a hybrid between the top-down directed approach of the first round and the bottom-up flexible approach in the second round by agreeing with reporting organisations sector- or organisation-specific reporting proposals.

Government does not intend to issue directions under the third round of the ARP, but proposes that reporting is done in line with the reporting power on a voluntary basis.

We propose to build on the work of reporting organisations from the second round of reporting by focussing on the following principles, to:

- **be proportionate, risk-based and streamlined to minimise burdens or duplications;**
- **build on previous rounds of reporting to improve report quality and participation; and**
- **be clear that the primary objective of reporting is to support the integration of climate change risk management into the work of reporting organisations, with a secondary objective of understanding the level of preparedness of key sectors to climate change, from critical infrastructure operators and public bodies at a sectoral and national level to feed into the ASC's reports to Parliament.**

By seeking to agree sectoral or organisational proposals on reporting, we will address much of the feedback from our evaluation and achieve the following benefits:

- **greater consistency and detail of reporting;**
- **freedom for reporters to set out their perspectives and approaches to climate risks in accordance with the needs and priorities of their organisation;**

- **an increase in participation within sectors, driven by greater clarity on content and expectations in reporting proposals;**
- **greater coherence between the work of reporting organisations and the work of the ASC in reporting to Parliament on progress addressing climate change risks and implementing the NAP;**
- **acknowledgement of the differences between organisations across and within sectors and of the unique sector characteristics including their specific regulatory processes;**
- **appreciation of the diversity of approaches and experiences across all reporting organisations and history of previous work undertaken on climate change adaptation.**

5. Do you agree that reporting in the third round should continue to be voluntary?

No

Please give your justification here. If you are a reporting organisation please include information on how effective a voluntary or mandatory approach to reporting would be for your sector.

A mandatory approach to reporting will encourage reporting organisations to continue assessing their adaptation needs in light of new developments in operations or climate change projections.

I am currently a PhD student whose research focus is on UK port sector adaptation (for further reference all answers refer purely to ports).

<u>**6. Do you agree with the principles for reporting in the third round? (These principles are: proportionate, risk-based and streamlined to minimise burdens or duplications; build on previous reporting rounds to improve report quality and participation; and that reporting will primarily support integration of climate change risk management into organisations' work, with a secondary objective to understand levels of preparedness to feed into the ASC's reports to Parliament).**</u>

Yes

Please set out your justification here

The proposed principles are well designed to reduce burdens on reporting organisations. It is important that climate change risk management is effectively integrated into the work of reporting organisations as this will reduce the impacts of climate change on their operations and functionality.

In 2017 I carried out a detailed analysis of the previous two round of Adaptation Reports produced by UK ports and carried out detailed interviews with all UK commercial ports on how prepared they currently feel for climate change. In conversations with ports it became clear that climate change adaptation would be more likely to be integrated into port planning decisions if they were provided with more accessible scientific information on likely future changes they will experience, and given additional Government guidance on when adaptation measures should begin to be implemented.

7. Do you agree that reporting in the third round should build on the second round by agreeing sector or organisational reporting proposals?

Yes

Please set out your justification here. If you are a reporting organisation, please include information on how effective or otherwise a reporting proposal would be for your sector.

Additional guidance in the form of a reporting proposal will potentially be very effective in aiding reporting organisations in their adaptation needs. This would encourage consistency in reporting between adaptation reports within the same sector.

Few UK ports are currently putting in place, or considering, a need for adaptation. The main justification for this inaction is that many ports (whether classed by the Department for Transport as major or minor) are extremely unsure of the types or severities of risks they may face from climate change.

Timescales for report submission

We propose that reports should be submitted to a timescale that best suits reporting organisations in order to minimise burdens and streamline the process against any other business or regulatory pressures. We propose that organisations report within the period 2019 – 2021 with a final deadline of 31 December 2021

8. Do you agree that the reporting date should be determined by sector, reflecting regulatory or business pressures, within the reporting window of 2019-2021, with a final deadline of 31 December 2021?

Yes

Please set out your justification here. If you are a reporting organisation please indicate when it would be suitable for your organisation to report

The reporting window for the third round of reports is suitable. The publication of UKCP18 will be beneficial in aiding reporting organisations in identifying the challenges they is likely to face due to climate change, and what risks in particular they need to adapt against.

Criteria for identifying reporting organisations

In the government's first reporting strategy, we defined criteria to designate reporting organisations within scope. For the third round we propose that reporting is proportionate, risk based and streamlined to minimise burdens and duplications. We will therefore build on the previous criteria and use the following methodology:

- **identifying those organisations which are eligible for reporting;**
- **identifying those organisations that are vulnerable to the projected impacts of climate change as according to the UK's Climate Change Risk Assessment (CCRA) published in January 2017 ;**
- **preventing duplication by identifying organisations which are not already subject to other adaptation reporting requirements, or are not already covered by an existing voluntary agreement;**
- **targeting reporting organisations proportionately.**

Organisations under consideration for reporting

Please see section D of the consultation document for the details on the organisations/sectors referenced below.

1) the following which reported in the last cycle of adaptation reporting:

- **transport organisations covering: road, rail, airports, ports and lighthouses**

- **water companies**

- **energy companies covering: electricity transmission and distribution, gas transportation and energy generators**

- **public bodies covering environment, marine, fisheries, health and heritage**

- **data centres**

- **water, energy, communications and insurance regulators**

The scope of reporting will be expanded to include participation from the following:

- **financial regulators**

- **new rail infrastructure**

- **environmental heritage organisations**

- **telecommunications**

9. Are there any other sectors which you believe should be included on the list?

No

10. Are there any organisations that the Government proposes to invite to report which you believe should not be included?

No

11. Are there any organisations that have not been included which you believe should be?

No

Additional circumstances in which reports may be required

We propose that there are additional circumstances which may result in a direction to report being given to organisations. These circumstances are:

- **where a future event exposes vulnerability;**
- **where evidence is obtained of bodies' poor performance to reduce vulnerability to climate change;**
- **where a new body is created that fulfils the criteria outlined in the previous section; or**
- **where an existing body's role changes so that it fits these criteria.**

12. Do you agree with the additional situations in which organisations may be asked to report?

Yes

Additional information

13. Please include any other information you would like us to consider as part of this consultation

Please include any additional information here

It would be of benefit to provide reporting authorities with additional support to aid identification of their adaptation needs. Although the UKCP projections are very detailed and represent a useful resource their scientific format is not always fully accessible to the non-scientific background of many of those working in reporting authorities. Many reporting authorities would appreciate the provision of summary documentation that highlights the likely risks they will face in future decades due to climate change.

Consultee feedback on the online survey

Dear Consultee

Thank you for taking your time to participate in this online survey. It would be appreciated, if you can provide us with an insight into how you view the online tool and the area(s) you feel are in need of improvement, by completing our feedback questionnaire.

<u>14. Overall, how satisfied are you with our online consultation tool?</u>

Satisfied

Please give us any comments you have on the tool, including suggestions on how we could improve it. (Required)

An answer is required

An opportunity to give feedback on the guidance given for previous rounds of adaptation reporting would be useful.

Your response has been submitted

Thank you for completing the consultation.

When this consultation ends, we will summarise the responses and place this summary on our website at: https://www.gov.uk/defra. This summary will include a list of organisations that responded but not personal names, addresses or other contact details.

Copies of responses will be made available to the public on request. If you do not want your response (including your name, contact details and any other personal information) to be publicly available, please say so clearly in writing when you send your response to the consultation. Please explain why you need to keep details confidential. We will take your reasons into account if someone asks for this information under Freedom of Information legislation. But, because of the law, we cannot promise that we will always be able to keep those details confidential. Please note, if your computer automatically includes a confidentiality disclaimer, this will not count as a confidentiality request.

Your response ID is ANON-KAN1-CE7B-C. Please have this ID available if you need to contact us about your response.

Glossary of Terms

Adaptation Actions or decisions taken to reduce potential risk, such as those associated with climate change (e.g. sea-level rise) or extreme weather events through both hard (e.g. building defences) and soft (e.g. policies or ecosystem manipulation) measures.

Autonomous adaptation A form of adaptation, that arises spontaneously due to other pressures, such as economic or social, rather than a planned response to issues associated with extremes (such as extreme weather) or climate change.

Automatic Identification System (AIS) A shipping tracking system that is legally required to be installed on all passenger vessels, and all cargo vessels of 300 giga-tonnes or over (International Maritime Organisation, 2005). AIS is used by both vessels and ports to monitor the speed, identity and course of vessels in their area, and is designed to help reduce the occurrence of collisions between vessels.

Business as usual Where day-to-day operations are able to continue within standard operational limits.

Cargo Goods carried by sea, road, rail or air (such as foods, electricals and fuel). Includes goods carried by TEU, RoRo, LoLo and liquids.

Climate The long-term, or average (usually 30 years), weather conditions present in a certain area.

Climate change A long-term change in climate, such as changing temperatures, or rising sea-levels. Anthropogenically induced climate change is arising from emissions of greenhouse gases, including carbon dioxide and methane.

Climate variability Variations from the average climate for a specific location. For example, ranges in variables away from the mean (such as temperature or wind speeds) over scales including months and years.

Clustered minor disruptions When multiple extreme events, caused by the same event type (e.g. storm surge or human error) occur before port operations have fully recovered to "normal" following an initial disruption. The occurrence of repeated disruptions act to reduce the ability of a port to continue with business as usual operations (see disruption).

Coastal areas The region of interface between land and coast, such as areas protected by sea defences.

Coastal flooding Flooding arising from high sea levels and/or waves.

Coastwise routes A domestic service where vessels transfer freight between ports within a country and its waters. The most commonly moved vessel types transferring goods in 2015 were dry cargo, tankers, oil tankers, and passenger craft. In 2015 almost 42,000 domestic passengers travelled between UK ports (Department for Transport, 2015).

Compound events Where a single disruptive event is caused by multiple event types.

Consequences Changes that occur following a disruptive extreme event, such as the altering of local policies or national legislation.

Containerisation The transport of cargo within shipping containers (usually TEUs) on sea-going vessels and lorries.

Coping mechanism Knee-jerk responses, where actions are taken to directly counter a specific negative circumstance, or circumstances arising from extreme events.

Creeping change Incremental changes in climate, such as sea-level rise or changes in mean temperatures, which occur gradually over years or decades.

Damage	Tangible negative impacts on physical, business, financial or societal outcomes of a commodity (such as port infrastructure). Damage impairs the usual functionality, or value, of a commodity by causing harm.
Decision-makers	Those within a port, or port group, responsible for making business and operational decisions, such as deciding if a port is able to continue functioning during an extreme weather event. Responsible parties range from harbour-masters, to business managers who operate multiple ports.
Deep-sea	International transport of goods on an intercontinental scale, involving vessels crossing oceans, rather than due to the depth of the water over which they pass.
Deep-water port	Deep-water ports have water depths of over nine meters to the sea bed, compared with six meters at mean sea level for traditional ports. The UK currently has 15 deep-water ports.
Defence	Hard management, or adaptation, strategies that are designed to prevent damage or disruption from occurring, or reduce the impacts of a damage or disruptive causing circumstance (e.g. a sea wall).
Delay	Where poor weather or non-weather conditions affect operations so that vessels, trains or lorries are unable to operate at scheduled times, or within agreed turnaround periods. Delays are of particular importance in terms of "just-in-time" deliveries, and can affect vessels at sea, operations within a port, and those operating beyond port limits on road or rail networks. Examples of delay include vessels or goods, being unable to move in, out, or within a port for extended periods of time.
Direct impacts	Occur as a direct consequence of an extreme event occurring (e.g. a wind

storm knocks over high-level cranes).

Displacement Where passengers, vessels or cargo end up in the wrong place and/or at the wrong time due to extreme weather or non-weather events.

Disruption An interruption, or deviation, from normal operations and/or business functionality as a whole.

Dissipation The passing of an extreme event after it has reached a peak. As an extreme event dissipates it still has the potential to cause disruptions.

Dock-side Land in a port or harbour located adjacent to the water.

Domestic traffic Vessels or goods travelling within a single country by road, rail, air or sea.

Downtime A period of time at which operations or equipment are out of action. Downtime can be either unexpected or expected, such as when pre-emptive stoppages occur in response to weather forecast warnings.

Driver A global-scale factor (e.g. climate change) that puts pressure on a resource or asset (e.g. a port)

Duration The period of time over which an extreme event (e.g. a storm surge) occurs from its initiation to complete dissipation.

Effect Consequence of an extreme event driver.

Estuary The area of water where a river connects to the sea. Estuarine water is a combination of waters from a river and the sea, its salinity increases with proximity to the estuary mouth.

European Economic Area	European Single Market including EU member states, Iceland, Liechtenstein and Norway.
European Union (EU)	An economic union of 28, as of 2017, member countries with policies including the free movement of people and trade.
Exclusive Economic Zone (EEZ)	An area of water surrounding the UK that extends from 12 nautical miles to a maximum of 200 nautical miles (370km) out to sea.
Extreme event	Weather or non-weather events that are unusually severe, not predicted, or unseasonal.
Extreme weather	Severe or unseasonal weather conditions which deviate from mean weather (e.g. storm surge).
Fire	Combustion following the ignition of chemicals, and sustained by oxygen. Both landward (e.g. fires affecting port buildings or power substations) or seaward (e.g. fire aboard a vessel docked at a port).
Flood risk	The likelihood of a flood affecting a particular area.
Flooding	An area becoming temporarily submerged with water. Can have multiple sources: coastal, fluvial and pluvial.
Fluvial flooding	Arising from rivers bursting their banks caused by rainfall events occurring locally or far upstream, or snow melt.
Fog	Visibility of less than 1000m
Freight	See cargo.

Frequency	How often an extreme event occurs.
Fuel shortages	Where demand exceeds its current level of supply.
Guidance	Non-statutory advice designed to give assistance in regard to a specific problem or challenge.
Hard adaptation	Technological or infrastructural adaptations, such as seawalls.
Health and safety regulations	Regulations in place designed to reduce the chances of injury or accidents from occurring. Regulations are either legally enforced, whether nationally or internationally, or locally advisory (e.g. port internal regulations).
High-level cranes	Dockside gantry cranes used to move containers entering and exiting the port by vessel or truck.
Historical vulnerability	The past frequencies of damage, disruption or delay that affected a particular area.
Human error	Poorly chosen or timed decisions or actions that result in damage, disruption or delay (e.g. misjudging vessel movements resulting in a collision between a vessel and the dockside).
Impacts	The effects and consequences of a pressure (e.g. flooding of a port's substation.
Indirect impacts	Secondary or tertiary impacts. Indirect impacts do not occur as a direct result of an extreme event, but are part of a sequence of impacts (e.g. a power substation is flooded causing a power cut at a port, which prevents refrigerated goods from being stored safely).

Industrial action Where staff take protest action such as strikes or working to rule. Industrial action is often motivated by pay or working condition disputes.

Inland transport breakdown Disruptions to other transport routes, such as road, rail or air can have multiple implications for ports. Such circumstances can either act to isolate the port, preventing the movement of goods both landwards and seawards, or to choke the port with additional trade.

Intercontinental The movement of goods between continents by sea, air, rail or road. The UK trades the most with the EU, United States and China.

International traffic The movement of goods between countries by sea, air, rail or road, such as goods travelling between the UK and France.

Isostatic rebound The rising of an area of land following the removal of ice sheets that were present during the last ice age.

Just-in-time deliveries Where deliveries of goods are timed to arrive precisely when required, rather than keeping goods in stock by predicting changes in demand. The use of just-in-time deliveries reduces costs associated both with stock and the storage of goods.

Knock on/supply chain effects The global interconnectivity of ports can lead to knock-on disruptions if delays occur at other ports, particularly in terms of just-in-time products or by disruptions to power supplies. Port for whom most vessel traffic only services a small number of ports tend to be more severely impacted by knock-on effects.

Land levels The elevation of land compared to mean sea level. The level of land relative to the sea has been changing in the UK since the last ice age. Scotland, for example is rising upwards due to isostatic rebound in response to ice no

	longer pressing down the land, whereas in contrast the south of England is sinking.
Landward	Towards the land rather than the sea.
Legacy of impacts	Where the outcomes of an extreme event are felt for extended periods of time.
Legislation	A group of laws that are in force, and are enforced by relevant organisations, such as the Health and Safety Executive.
Liquid fuels	Power or heat generating sources including petroleum and natural gas.
Local authority port	Ports managed by a local council authority.
Location scale	Whether affecting coastal areas, EEZ or ports, and the extent of the area over which impacts are experienced.
LoLo	Lift-on/lift-off cargo that is moved by a crane
Long-term	In the context of this research defined as in excess of 100 years.
Maladaptation	Poor adaptive decisions that inadvertently have harmful or negative effects that increase risks associated with climate change or extreme weather events. Maladaptation can be identified after a decision or action is made, often when new information, or data, becomes available.
Maintenance	Actions taken to support the current standard and functionality of an item, such as repairing a vessel so it is able to continue its usual operations during its physical lifespan.

Major event	Powerful events (classed as Levels 3 to 5) with the potential to cause damage, disruption and displacement to both dock-side and landward operations. Other impacts potentially include port closures, environmental pollution and injury or death.
Major ports	53 of the UK's 162 commercial ports are classed as "major" by the Department for Transport. Major ports are classed as those that move in excess of 1 million tonnes of cargo per annum.
Maritime sector	Ports (see port sector), shipping, coastal areas, offshore energy services, local employment, contributes to local and national economy, and tourism.
Mechanical or structural fault	Weakness or fault in infrastructure, vessels, equipment, facilities or buildings.
Mechanisation	The increased use of and complexity of machinery.
Minor events	Nuisance events (classed as Level 1 or 2 on the severity scale) which causes isolated delays or disruption to services and operations (e.g. passenger vessels unable to dock for up to three hours).
Minor ports	109 of the UK's 162 commercial ports are classed as "minor" by the Department for Transport. Minor ports are classed as those that move less than 1 million tonnes of cargo per annum.
Mist	Obscured visibility of 1000m or more. Mist has a lower density than fog.
Mitigation	Actions to reduce or prevent the emissions of greenhouse gases, such as carbon dioxide and methane into the atmosphere.

Non-commercial ports	The UK has around 200 non-commercial ports that are classed as active by Lloyd’s List, providing services such as fishing boat moorings and marinas for leisure facilities (Lloyd's List, 2015b).
Non-weather events	Human caused extreme events, such as industrial action, or human error.
Offshore platform	An oil rig located at sea that extracts oil or natural gas from beneath the sea bed.
One port	Where goods are moved around within a single port by high-level cranes, trains and lorries, stored or processed to gain value-added benefits, rather than transferred to other ports.
Operating guidelines	Rules or procedures detailing how a particular system, or equipment should be used. General guidelines tend to be defined by national and local government, and port specific guidelines by port authorities.
Operations	Business functions that take place within a port, such as the movement of goods or passengers within and out of the port boundary.
Packaged goods	A cargo type, includes dry goods and items such as clothing and electricals.
Peaking time	The period of time when the intensity of an extreme event is at its greatest.
Pluvial flooding	Flooding arising from rainfall occurring directly on land. The extent of flooding depends on the intensity, duration and quantity of rainfall, and the efficiency of drainage.
Policy brief	A guidance and information document which summarises a particular research challenge (such as the likely impacts associated with storm

surges), and provides options and recommendations aimed at those who develop policies within government.

Poor visibility Where visibility is reduced during periods of fog or mist.

Port A harbour where vessels can dock and load/unload cargo or passengers.

Port calls A port at which a vessel stops during an itinerary.

Port closure A period of time during which a port is closed to cargo, and passenger operations. Vessels are also not permitted to enter or exit the port.

Port cluster Independent ports, and on-site businesses, working on activities in the same port region, which act in a jointly competitive manner.

Port infrastructure The physical structure (e.g. quays), buildings and equipment located in port environments.

Port operators A company or local authority that manages a port.

Port orientation The compass angle that a port faces (e.g. north-west).

Port sector A part of the economy including ports, specialist companies, professional services, tourism and port management, a wide range of products and services and transport by sea, road and rail. See maritime sector.

Power disruption A loss of electrical power, for either a short or long-term period. Power disruptions occur in ports either from a losses of power from transformers within the port boundary (such as due to flooding or wind damage to electrical cables), or a knock-on effect of power losses from a nearby power station.

Preparedness	The level of readiness for particular challenges, such as extreme weather events, oil spills, industrial action or climate change.
Present day	The current period of time, defined as within the past 10 years.
Prevailing wind	The direction that winds usually come from at a particular time or location.
Privately managed port	A port operated by a private company.
Proactive adaptation	Where long-term adaptation decisions are made in advance with the intention of reducing future vulnerability to climate change or risk of disruption. In ports infrastructure decisions are usually made to apply on the scale of 5-30 years.
Protection	Infrastructure, actions or behaviours that act to shield a port and its operations from potential damage or disruption.
Recovery	The period of time required to return to "normal" operations or functions.
Regulation	A specific aspect, law, or requirement, included within statutory legislation.
Resilience	The ability to prepare for extreme events, and to recover swiftly from damage, disruption and displacement.
Response	Decisions or actions implemented to reduce or avoid impacts (e.g. development of storm surge warning systems).
Reactive adaptation	Adaptation actions or decisions that are designed and implemented

following an extreme event. For example, following the partial flooding of Immingham port during winter 2013/14 a new dock gate has been designed and installed.

Rough seas Where wave heights are high enough to cause damage to vessels, depending on vessel size, (typically either at sea, or near port) or port structures.

RoRo Roll-on/roll-off wheeled cargo (e.g. vehicles)

Sea trade Cargo that travels by vessel.

Sea-level rise An increase in the global sea level due to a greater volume of water being present in the oceans. Current sea-level rise is occurring due to climate change, resulting from the melting of land-based ice, and thermal expansion of sea-water, with additional contributions of water from land (such as from reservoirs and increased groundwater abstraction).

Seasonal trends The occurrence of particular weather conditions regularly occurring at a certain interval during the calendar year.

Severity The strength and extent of impacts arising from extreme events. Severity is classed from a scale of 1 -7, where Level 7 is the most severe (See Section 3.2).

Shipping The movement of cargo and passengers by boat.

Shipping zones Areas of sea surrounding the UK. The UK has 22 shipping regions: Bailey, Cromarty, Dogger, Dover Fair Isle, Fastnet, Forth, Forties, Hebrides, Humber, Irish Sea, Lundy, Malin, Plymouth, Portland, Rockall, Shannon, Sole, Thame, Tyne, Viking and Wight.

Short-sea routes	Defined by the UK Department for Transport as the transport of goods between the UK and countries within the European Economic Area, EU candidate countries, and the Mediterranean and Black Seas.
Short-term	A scale of months to a few years.
Soft adaptation	Adaptation measures in the form of knowledge, new policies and management strategies. Soft adaptations can also act as an enabler for the implementation of hard adaptation strategies.
Strength of event	How powerful an event is (e.g. wind gust speed recorded during a wind storm).
Strike	A form of employee protest where staff refuse to work until specified requests (e.g. salary) are made.
Storm surge	The combination of a predicted astronomical high tide and high water produced by pressure and wind set-up during storms.
Surface flooding	Where flooding occurs from rainfall, coastal flooding or rising groundwater levels.
Temperature extremes	High and low extremes of temperature beyond the average range of temperatures for the time of year.
Terminal	An area where cargo can be loaded or offloaded from vessels.
Territorial seas	An area of water extending up to 12 nautical miles out to sea.
Twenty-foot equivalent unit (TEU)	A standard shipping container.

Trade nodes Ports that are critical hubs for transport and trade.

Trust port Ports managed by an independent statutory body, and is regulated by an internal board which has formed operating rules and regulations.

Twitter A global internet social media service that enables companies, businesses and individuals to communicate information publically via individual accounts in 140 characters (known as tweets), which can be accompanied with photos or videos (Twitter, 2017). Original Tweets can be reposted or forwarded by other accounts, known as Retweets.

Unpackaged goods Fuels, liquids and loose food products.

Vessel Ships and boats including those used for cargo, passenger, tugs and piloting.

Vessel shifts The movement of shipping contracts from one port to another.

Vulnerability The extent of susceptibility to, and ability to contend with, extreme events and/or climate change.

Warning systems A means of providing warning of a future threat or danger with the intent of providing ample time for preparedness

Weakness Aspects of operations, or infrastructure which are not robust during extreme events.

Weather Conditions in an area, at a particular time or place in terms of wind speed and direction, temperature, rainfall, sunshine etc.

White papers Documents produced by the UK Government, or Government authorities detailing information on a particular topic or issue.

Wind storm A storm characterised with strong wind gust speeds. Wind storms are classified as where wind speeds exceed 55 kilometers per hour.

References

ABP (2010) Port of Southampton Master Plan 2009-2030, ABP Print Solutions, p. 136, http://www.southamptonvts.co.uk/admin/content/files/PDF_Downloads/Master%20Plan/SMP.pdf [Accessed 06/05/2016]

ABP (2014) The Humber Estuary Flood Risk Management Strategy: Summary Strategy and Business Case, Capita Property and Infrastructure, p.54, http://www2.eastriding.gov.uk/EasySiteWeb/GatewayLink.aspx?alId=592095 [Accessed 04/03/2016]

ABP (2016) Climate change adaptation report 2016 update, ABP Print Solutions, p.25, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/573573/climate-adrep-associated-british-ports.pdf [30/10/2017]

ABP (2017) UK's largest port to improve its resilience to tidal flooding, http://www.abports.co.uk/newsarticle/395/ [Accessed 23/03/2017]

Adam EF, Brown S, Nicholls R, Tsimplis MN (2016) A systematic assessment of maritime disruptions affecting UK ports, coastal areas and surrounding seas from 1950 to 2014. Nat Hazards 83:691-713.

Adger WN, Barnett J (2009) Four reasons for concern about adaptation to climate change. Environment and Planning 41:2800-2805.

Adger WN, Dessai S, Goulden M, Hulme M, Lorenzoni I, Nelson D, Naess L, Wolf J, Wreford A (2009) Are there social limits to adaptation to climate change? Climatic Change 93:335-354.

Adger WN, Hughes TP, Folke C, Carpenter SR, Rockström J (2005) Social-Ecological Resilience to Coastal Disasters. Science 309:1036-1039.

Aerts JCJH, Botzen WJW, Emanuel K, Lin N, de Moel H, Michel-Kerjan EO (2014) Evaluating Flood Resilience Strategies for Coastal Megacities. Science 344:473-475.

Amundsen H, Berglund F, Westskog H (2010) Overcoming barriers to climate change adaptation - a question of multilevel governance? Environment and Planning C: Government and Policy 28:276-289.

Anon (1826) Eddystone Lighthouse. Mechanics' Magazine. Knight and Lacey.

Bailey R, Wellesley L (2017) Chokepoints and vulnerabilities in global food trade, Chatham House, The Royal Institute of International Affairs, p. 124, https://www.chathamhouse.org/sites/default/files/publications/research/2017-06-27-chokepoints-vulnerabilities-global-food-trade-bailey-wellesley-final.pdf [Accessed 14/12/2017]

Baker CC, Seah AK (2004) Maritime accidents and human performance: The statistical trail. ABS Technical Papers:16.

Barnett J, O'Neill S, Waller S, Rogers S (2013) Reducing the risk of maladaptation in response to sea-level rise and urban water security. in Moser SC, Boykoff MT (eds.) Successful adaptation to climate change: Linking science and policy in a rapidly changing world, Routledge, p. 360

Baxter PJ (2005) The east coast Big Flood, 31 January-1 February 1953: a summary of the human disaster. Philosophical transactions. Series A, Mathematical, physical, and engineering sciences 363:1293-1312.

Bibliography

BBC (2002a) £30m cargo 'lost' as ship sinks, http://news.bbc.co.uk/1/hi/world/europe/2576179.stm [Accessed 07/01/2015]

BBC (2002b) Ship sinks after Channel collision, http://news.bbc.co.uk/1/hi/world/europe/2575009.stm [Accessed 07/01/2015]

BBC (2008a) 1953: 130 die in ferry disaster, http://news.bbc.co.uk/onthisday/hi/dates/stories/january/31/newsid_2505000/2505913.stm [Accessed 07/01/2015]

BBC (2008b) 1988: Piper Alpha Oil Rig Ablaze, http://news.bbc.co.uk/onthisday/hi/dates/stories/july/6/newsid_3017000/3017294.stm [Accessed 27/02/2015]

BBC (2015) Dawlish rail line: Closure 'costs economy up to £1.2bn', http://www.bbc.co.uk/news/uk-england-devon-31140192 [Accessed 05/02/2015]

BBC (2018) Shipping forecast, https://www.bbc.co.uk/weather/coast_and_sea/shipping_forecast [Accessed 03/03/2018]

Becker A, Englander J (2014) Superstorms and rising sea levels: the new challenge for seaports. Port Technology International 64:25-26.

Becker A, Inoue S, Fischer M, Schwegler B (2011a) Climate change impacts on international seaports: knowledge, perceptions, and planning efforts among port administrators. Climatic Change 110:5-29.

Becker A, Inoue S, Fischer M, Schwegler B (2011b) Considering climate change: A survey of global seaport administrators. Centre for Integrated Facility Engineering, p. 69.

Becker A, Matson P, Fischer M, Mastrandrea MD (2014) Towards seaport resilience for climate change adaptation: Stakeholder perceptions of hurricane impacts on Gulfport (MS) and Providence (RI). Progress in Planning 99:1-50.

Becker A, Ng AKY, McEvoy D, Mullett J (2018) Implications of climate change for shipping: Ports and supply chains. Wiley Interdisciplinary Reviews: Climate Change 9:2 18pp

Becker AH, Acciaro M, Asariotis R, Cabrera E, Cretegny L, Crist P, Esteban M, Mather A, Messner S, Naruse S, Ng AKY, Rahmstorf S, Savonis M, Song D-W, Stenek V, Velegrakis AF (2013) A note on climate change adaptation for seaports: a challenge for global ports, a challenge for global society. Climatic Change 120:683-695.

Belfast Harbour Authority (2013a) Environmental Report 2013, Belfast Harbour Office, p15, https://www.belfast-harbour.co.uk/documents/download/260 [Accessed 08/02/2016]

Belfast Harbour Authority (2013b) Port Master Plan: 20-30 year period, Belfast Harbour Office, p15, https://www.belfast-harbour.co.uk/documents/download/997 [Accessed 08/02/2016]

Belliveau S, Smit B, Bradshaw B (2006) Multiple exposures and dynamic vulnerability: evidence from the grape industry in the Okanagan Valley, Canada. Global Environmental Change 16: 364-78

Beniston M, Stephenson DB (2004) Extreme climatic events and their evolution under changing climatic conditions. Global and Planetary Change 44:1-9.

Berrang-Ford L, Ford JD, Paterson J (2011) Are we adapting to climate change? Global Environmental Change 21:25-33.

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.

Biesbrock GR, Klostermann JEM, Termeer CJAM, Kabat P (2013) On the nature of barriers to climate change adaptation. Regional Environmental Change 13:1119-1129.

Boulter SL, Palutikof J, Karoly DJ, Guitart D (eds.) (2013) Natural disasters and adaptation to climate change. Cambridge University Press, Cambridge, 288pp.

Bours D, McGinn C, Pringle P (2013) Monitoring & evaluation for climate change adaptation: A synthesis of tools, frameworks and approaches. SEA Change CoP, Phnom Penh and UKCIP, Oxford p. 67.

Brayne M (2003) The Greatest Storm: Britain's night of destruction November 1703. The History Press, Stroud, 288pp.

Brown S, Hanson S, Nicholls RJ (2014a) Implications of sea-level rise and extreme events around Europe: a review of coastal energy infrastructure. Climatic Change 122:81-95.

Brown S, Nicholls RJ, Hanson S, Brundrit G, Dearing JA, Dickson ME, Gallop SL, Gao S, Haigh ID, Hinkel J, Jiménez JA, Klein RJT, Kron W, Lázár AN, Neves CF, Newton A, Pattiaratachi C, Payo A, Pye K, Sánchez-Arcilla A, Siddall M, Shareef A, Tompkins EL, Vafeidis AT, van Maanen B, Ward PJ, Woodroffe CD (2014b) Shifting perspectives on coastal impacts and adaptation. Nature Climate Change 4:752-755.

BSI (2013) Code of practice for the safe use of cranes. Inspection, maintenance and thorough examination. Cargo handling and container cranes. p. 40.

Bureau of Maritime Affairs Monrovia (1967) Liberian casulty report: report to the board of investigation in the matter of the stranding of the S. S. Torrey Canyon, March 18, 1967. p. 8.

Burke L (2013) The Sea Gem: A story of material failure. Journal of Undergraduate Engineering Research and Scholarship, PT-13-Burke, 7pp

Burton I, Huq S, Lim B, Pilifosova O, Schipper EL (2002) From impacts assessment to adaptation priorities: the shaping of adaptation policy. Climate Policy 2:145-159.

Butler JRA, Wise RM, Skewes TD, Bohensky EL, Peterson N, Suadnya W, Yanuartati Y, Handayani T, Habibi P, Puspadi K, Bou N, Vaghelo D, Rochester W (2015) Integrating Top-Down and Bottom-Up Adaptation Planning to Build Adaptive Capacity: A Structured Learning Approach. Coastal Management 43:346-364.

Capstick S, Demski C (2016) Personal experiences of extreme weather and climate change preparedness. Tyndall Centre - Not for Experts, WebEx Audio Visual Presentation, 13/07/2016

CDP (2015) Supply chain sustainability revealed: A country comparison. Supply chain report 2014-15, Accenture Strategy, p. 21, https://www.cdp.net/en/research/global-reports/global-supply-chain-report-2015 [Accessed 21/05/2016]

Centeno MA, Nag M, Patterson TS, Shaver A, Windawi AJ (2015) The emergence of global systemic risk. Annual Review of Sociology 41:65-85.

Chang SE (2000) Disasters and transport systems: loss, recovery and competition at the Port of Kobe after the 1995 earthquake. Journal of Transport Geography 8:53-65.

Chatterton J, Clarke C, Daly E, Dawks S, Elding C, Fenn T, Hick E, Miller J, Morris J, Ogunyoye. F., Salado R (2016) The costs and impacts of the winter 2013 to 2014 floods, SC140025/R2, Environment Agency, p. 36.

Chhetri P, Cocoran J, Gekara V, Corbitt B, Wickramsinghe N, Jayatilleke G, Basic F, Scott H, Manzoni A, Maddox C (2013) Functional resilience of port environs in a changing climate - assets and operations. Work Package 2 of Enhancing the resilience of seaports to a changing climate report series. National Climate Change Adaptation Research Facility, Gold Coast, p. 118.

Chhetri P, Corcoran J, Gekara V, Maddox C, McEvoy D (2015) Seaport resilience to climate change: mapping vulnerability to sea-level rise. Journal of Spatial Science 60:65-78.

Chhetri P, Jayatilleke G, Gekara V, Manzoni A, Corbitt B (2016) Container terminal operations simulations (CTOS) - Simulating the impact of extreme weather events on port operation. European Journal of Transport and Infrastructure Research:195-213.

Church JA, Aarup T, Woodworth PL, Wilson WS, Nicholls R. J., Rayner R, Lambeck H, Mitchum GT, Steffen K, Cazenave A, Blewitt G, Mitrovica JX, Lowe J (2010) Sea-level rise and variability: Synthesis and outlook for the future. in Church JA, Woodworth PL, Aarup T, Wilson WS (eds.) Understanding sea-level rise and vulnerability. Wiley-Blackwell, p. 428.

CMA CGM Australia (2012) USEC Port/Terminal Update Hurricane Sandy NYC Omission (Letter), 2 pp, http://www.blueprint-global.com.au/bp/images/stories/CC/USEC%20Port%20Update%20-%20Hurrican%20Sandy%20-%20NYC%20Omission%20-%202012.pdf [Accessed 03/06/2015]

Committee on Climate Change (2015) Progress in preparing for climate change: 2015 report to parliament, Committee on Climate Change, p. 244, https://www.theccc.org.uk/wp-content/uploads/2015/06/6.736_CCC_ASC_Adaptation-Progress-Report_2015_FINAL_WEB_250615_RFS.pdf [Accessed 30/06/2015]

Corfee-Morlot J, Agrawala S (2004) The benefits of climate policy. Global Environmental Change 14:197-199.

Cusano MI, Ferrari C, Tei A (2015) Port planning and climate change: Evidence from Italy. in Ng AKY, Becker A, Cahoon S, Chen S-L, Earl P, Yang Z (eds.) Climate change and adaptation planning for ports. Routledge, pp. 103-116.

Dalesio EP (2005) Smaller ports pick up shipping traffic from New Orleans. Star Banner Newspaper, 09/09/2005, p. 42.

Dawson RJ, Thompson D, Johns D, Gosling S, Chapman L, Darch G, Watson G, Powrie W, Bell S, Paulson K, Hughes P, Wood R (2016) UK Climate Change Risk Assessment Evidence Report: Chapter 4, Infrastructure. Adaptation Sub-Committee of the Committee on Climate Change, London.

de la Vega-Leinert AC, Nicholls RJ (2008) Potential Implications of Sea-Level Rise for Great Britain. Journal of Coastal Research 242:342-357.

DEFRA (2007) A Sea Change: A marine bill white paper. in Environment FaRA (ed.). The Stationary Office, London, p. 176.

DEFRA (2009a) Adapting to climate change: helping key sectors to adapt to climate change. Statutory guidance to reporting authorities 2009, The Stationary Office, London, p. 38.

DEFRA (2009b) Adapting to climate change: UK Climate Projections. in DEFRA (ed.), London, p. 52.

DEFRA (2010a) Climate change adaptation report direction. in DEFRA (ed.), London, p. 2.

DEFRA (2010b) Frequently asked questions and answers on the adaptation reporting power. March 2011 edn, The Stationary Office, London, p. 21.

DEFRA (2012) UK Climate Change Risk Assessment: Government Report. in Environment FaRA (ed.). The Stationary Office, London, p. 48.

DEFRA (2013) Adapting to climate change: ensuring progress in key sectors. 2013 strategy for exercising the adaptation reporting power and list of priority for reporting authorities, The Stationary Office, London, p. 30.

DEFRA (2014a) Second round of reporting under the Adaptation Reporting Power. List of organisations which were invited to participate in the second round, The Stationary Office, London, p. 8.

DEFRA (2014b) Second round of reporting under the Adaptation Reporting Power: List of organisations which were invited to participate in the second round, The Stationary Office, London, p. 8.

DEFRA (2017) Central Government funding for flood and coastal erosion risk management in England, The Stationary Office, London, p. 12.

DEFRA (2018) A consultation on the government's proposed strategy for the third round of the climate change Adaptation Reporting Power, The Stationary Office, London, p. 51.

Department for Transport (2007) Ports Policy Review Interim Report. in Transport Df (ed.) , The Stationary Office, London.

Department for Transport (2012) National Policy Statement for Ports. in Transport (ed.). The Stationary Office, London, p. 76.

Department for Transport (2014a) Government response to the transport resilience review, The Stationary Office, London, p. 58.

Department for Transport (2014b) Transport resilience review. A review of the resilience of the transport network to extreme weather events, The Stationary Office, London, p. 168.

Department for Transport (2015) UK Port Freight Statistics: 2015. in Transport (ed.). The Stationary Office, London, p. 21.

Department for Transport (2016a) Port freight statistics - Table PORT0208: UK major ports, container traffic and TEU, annually: 2000-2015, https://www.gov.uk/government/statistical-data-sets/port-and-domestic-waterborne-freight-statistics-port [Accessed 08/01/2017]

Department for Transport (2016b) Shipping Fleet Statistics 2015, 5 pp., https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/563285/shipping-fleet-statistics-2015.pdf [Accessed 25/01/2017]

Department for Transport, Rt Hon Patrick McLoughlin MP (2014) £1.7 million to repair small ports across England. in Transport Df (ed.).

Department of Energy and Climate Change (2014) Table of current UKCS installations, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/482440/Installations_December_v1.xls [Accessed 18/09/2015]

Dilling L, Daly M. E., Travis W. R., Wilhelmi O. V., A KR (2015) The dynamics of vulnerability: why adapting to climate variability will not always prepare us for climate change. WIREs Climate Change 6:413-425.

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.

Dover Harbour Board (2015) Climate Change Adaptation Report, Dover Harbour Board, p. 53, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/488087/climate-adrep-dover-port.pdf [Accessed 27/07/2016]

Dover Harbour Board (2017) Environmental Policy, Dover Harbour Board, p. 2, https://www.doverport.co.uk/csr/environmental-policy/ [Accessed 27/07/2016]

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 28/07/2015]

DP World LG (2014) DP World London Gateway proves reliability during bad weather, http://www.londongateway.com/news/press-releases/dp-world-london-gateway-proves-reliability-during-bad-weather/ [Accessed 24/01/2017]

Drew GH, Pollard SJT, Rocks SA, Jude SR (2010) Evaluating the risk assessments of Reporting Authorities under the Climate Change Act, 2008. The Collaborative Centre of Excellence for Understanding and Managing Natural and Environmental Risks (Risk Centre), Sustainable Systems Department, School of Applied Sciences, Cranfield University, p. 35.

Dronkers J, Gilbert JTE, Butler LW, Carey JJ, Campbell J, James E, McKenzie C, Misdorp R, Quin N, Ries KL, Schroder PC, Spradley JR, Titus JG, Vallianos L, von Dadelszen J (1990) Strategies for adaptation to sea level rise. Report of the IPCC Coastal Zone Management Subgroup: Intergovernmental Panel on Climate Change, Geneva, pp. 148

Eisenack K, Moser SC, Hoffman E, Klein RJT, Oberlack C, Pechan A, Rotter M, Termeer CJAM (2014) Explaining and overcoming barriers to climate change adaptation. Nature Clim. Change 4:867-872.

Eisenack K, Stecker R (2012) A framework for analysing climare change adaptations as actions. Mitigation and Adaptation Strategies for Global Change 17:243-260.

Ekstrom JA, Moser SC (2013) Institutions as key element to successful climate adaptation processes: results from the San Fransisco Bay Area. in Moser SC, Boykoff MT (eds.) Successful adaptation to climate change: Linking science and policy in a rapidly changing world. Routledge, Abingdon, pp. 360

Environment Agency (2012) Thames Estuary 2100: Managing flood risk through London and the Thames estuary, Thames Estuary 2100 (Environment Agency), p. 230.

Environment Agency (2016) Flood Map for Planning, http://apps.environment-agency.gov.uk/wiyby/37837.aspx [Accessed 29/09/2016]

Ernst and Young LLP (2016) Economic footprint of the Channel Tunnel fixed link: An analysis of the economic value of trade and passenger traffic travelling through the Channel Tunnel, Ernst and Young LLP, London, p. 40.

ESRC (2012) Global food systems and UK food imports: Resilence, safety and security, Discussions from the ESRC Puplic Policy Seminar 30 March 2012, p. 19, https://esrc.ukri.org/files/news-events-and-publications/news/2013/global-food-systems-and-uk-food-imports-resilience-safety-and-security/

Felixstowe Dock and Railway Company (2011) Climate Change Adaptation Report, Felixstowe Dock and Railway Company, Felixstowe p. 26, https://www.ukcip.org.uk/wp-content/PDFs/ARP-felixstowe-dock-railway.pdf

Felixstowe Dock and Railway Company (2015) Climate Change Adaptation Report, Felixstowe Dock and Ralway Company, Felixstowe, p. 37, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/530910/climate-adrep-port-felixstowe.pdf

Fenn T (2017) Impacts of 2013/14 floods on ports (private communication).

Flather RA (1984) A numerical model investigation of the storm surge of 31 January and 1 February 1953 in the North Sea. Quaternary Journal of the Royal Meterological Society 110:591-612.

Fleetmon (2015) AIS Live Vessel Tracking Community, https://www.fleetmon.com.

French J, Mawdsley R, Fujiyama T, Achuthan K (2017) Artificial Neural Network forecasting of storm surge water levels at major estuarine ports to supplement national tide-surge models and improve port resilience planning. in EGU General Assembly Conference Abstracts, p. 15018.

French J, Mawdsley R, Fujiyama T, Achuthan K (2017b) Combining machine learning with computational hydrodynamics for prediction of tidal surge inundation at estuarine ports. Procedia IUTAM 25:28-35.

FSA (2007) Working together on imported food, Food Standards Agency Ltd., p. 5, https://acss.food.gov.uk/sites/default/files/multimedia/pdfs/publication/importedfood1005.pdf

Fussel HM (2007) Adaptation planning for climate change: concepts, assessment approaches, and key lessons. Sustainability Science 2:265-275.

Gerrard S (2016) Communication between ports (private communication).

Gerritsen H (2005) What happened in 1953? The Big Flood in the Netherlands in retrospect. Philosophical transactions. Series A, Mathematical, physical, and engineering sciences 363:1271-1291.

Gilbert S, Horner R (1984) The Thames Barrier. Thomas Telford Ltd., London.

Google (2017) Google Maps, https://www.google.com/maps

Government Office for Science (2004) Foresight Report: Future Flooding. Executive Summary, Foresight Directorate, London, 59 pp, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/300332/04-947-flooding-summary.pdf

Haasnoot M, Kwakkel JH, Walker WE, ter Maat J (2013) Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global Environmental Change 23:485-498.

Haigh ID, Wadey MP, Gallop SL, Loehr H, Nicholls RJ, Horsburgh K, Brown JM, Bradshaw E (2015) A user-friendly database of coastal flooding in the United Kingdom from 1915–2014. Scientific Data 2:150021.

Hall JW, Brown S, Nicholls RJ, Pidgeon NF, Watson RT (2012) Proportionate adaptation. Nature Clim. Change 2:833-834.

Hallegatte S, Ranger N, Mestre O, Dumas P, Corfee-Morlot J, Herweijer C, Wood RM (2011) Assessing climate change impacts, sea level rise and storm surge risk in port cities: a case study on Copenhagen. Climatic Change 104:113-137.

Handmer J, Honda Y, Kundzewicz ZW, Arnell N, Benito G, Hatfield J, Mohamed IF, Peduzzi P, Wu S, Sherstyukov B, Takahashi K, Yan Z (2012) Changes in impacts of climate extremes: human systems and ecosystems. in Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds.) Managing the risks of extreme events and disasters to advance climate change adaptation, pp. 231-290.

Hanson S, Nicholls R (2012) Extreme Flood Events and Port Cities through the Twenty-First Century: Implications of Climate Change and Other Drivers. in Asariotis R, Benamara H (eds.) Maritime Transport and the Climate Change Challenge, pp. 243-265.

Hanson S, Nicholls R, Hallegatte S, Corfee-Morlot J (2010) The effects of climate mitigation on the exposure of world's large port cities to extreme coastal water levels. Work stream 2, Report 7 of the AVOID programme (AV/WS2/D1/R07), p. 48.

Hinkel J Adaptation problem types. in Amsterdam Conference on the Human Dimensions of Global Environmental Change.

Hinkel J (2011) “Indicators of vulnerability and adaptive capacity”: Towards a clarification of the science–policy interface. Global Environmental Change 21:198-208.

Hinkel J, Lincke D, Vafeidis AT, Perrette M, Nicholls RJ, Tol RSJ, Marzeion B, Fettweis X, Ionescu C, Levermann A (2014) Coastal flood damage and adaptation costs under 21st century sea-level rise. PNAS 111:3292-3297.

HM Government (2008) Climate Change Act 2008 (c.27), The Stationary Office Limited, London, p. 108, http://www.legislation.gov.uk/ukpga/2008/27/pdfs/ukpga_20080027_en.pdf [Accessed 08/02/2016]

Hooven C, Hirsch J, White M, Daugherty D, Messner S, Moran L, Kim D (2011) Port of San Diego climate mitigation and adaptation plan. Ad hoc expert meeting on climate change impacts and adaptation: A challenge for global ports. Air and waste management association, p. 7.

House of Commons (2014) Transport Committee: Forging ahead? The Stationary Office, p. 89.

HR Wallingford (2012) Climate change risk assessment for the transport sector, Department for Environment, Food and Rural Affairs, London, p. 166.

Huang C, Vaneckova P, Wang X, Fitzgerald G, Guo Y, Tong S (2011) Constraints and barriers to public health adaptation to climate change: a review of the literature. American Journal of Preventative Medicine 40:183-190.

Inoue S (2012) Climate initiatives of the world's ports. in Asariotis R, benamara H (eds.) Maritime transport and the climate change challenge. Routledge, Abingdon, pp. 225-240.

International Association of Ports and Harbors (2008) IAPH tool box for port clean air programs. Improving air quality while promoting business development, International Association of Ports and Harbors. p. 91, http://wpci.iaphworldports.org/iaphtoolbox/DRAFT%20IAPH%20TOOL%20BOX%20%20dea.pdf

International Maritime Organisation (2005) International Convention for the Safety of Life at Sea - Articles of the International Convention for the Safety of Life at Sea, 1974 in International Maritime Organisation (ed.) Version 9.4, International Maritime Organisation, London, p. 910.

International Maritime Organisation (2017) Recent actions and decisions taken by IMO in relation to emissions from international maritime transport. in COP 23 Special Side Event, Bonn, p. 13, https://unfccc.int/sites/default/files/cop_23_special_side_event_imo_final_short.pdf

IPCC (2000) IPCC Special Report: Emissions Scenarios - Summary for Policymakers, Intergovernmental Panel on Climate Change, Geneva, Swtitzerland, p. 27.

IPCC (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. in Pachauri RK, Reisinger A (eds.), Geneva, Switzerland, p. 104.

IPCC (2012) Managing the risks of extreme events and disasters to advance climate change adaptation. in Field CB, Barros V, Stocker TF, Dahe Q, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds.), p. 594.

IPCC (2014a) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Summaries, Frequently Asked Questions, and Cross-Chapter Boxes. A Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. in Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds.). World Meterological Organisation, Geneva, Switzerland, p. 190.

IPCC (2014b) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. in Pachauri RK, Meyer LA (eds.), Geneva, Switzerland, p. 151.

Jan Brooke Environmental Consultant Ltd. (2015) A climate change report card for infrastructure. Working technical Paper. Transport: Inland waterways, ports and marine infrastructure. Natural Environment Research Council, Swindon, p. 44.

Jenkins G, Murphy JM, Sexton DMH, Lowe J, Jones P, Kilsby CG (2009) UK Climate Projections: Briefing report, Met Office, Exeter, p. 59.

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.

Juhola S, Keskitalo ECH, Westerhoff L (2011) Understanding the framings of climate change adaptation across multiple scales of governance in Europe. Environmental Politics 20:445-463.

Kalra N, Hallegatte S, Lempert R, Brown C, Fozzard A, Gill S, Shah A (2014) Agreeing on robust decisions: New processes for decision-making under deep uncertainty. The World Bank, Office of the Chief Economist, Washington D. C., 37 pp.

Kates RW, Travis WR, Wilbanks TJ (2012) Transformational adaptation when incremental adaptations to climate change are insufficient. Proceedings of the National Academy of Sciences 109:7156-7161.

Kendon M (2014) Presentation on: The UK storms of winter 2013/2014. in Met Office NCIC, p. 11, http://www.hydrology.org.uk/assets/bhssw_files/m.kendon_20140620.pdf

Kendon M, McCarthy M (2015) The UK's wet and stormy winter of 2013/2014. Weather 70:40-47.

Khan M, R., Roberts JT (2013) Towards a binding adaptation regime: three levers and two instruments. in Moser SC, Boykoff MT (eds.) Successful adaptation to climate change: Linking science and policy in a rapidly changing world. Routledge, Abingdon, p 360.

Kidson R, Rutherford T, Malarz A, O'Mahony S (2015) Impact of increasing container ship size on container handling productivity at Australian ports. Australasian Transport Research Forum (ATRF), 37th, Sydney, New South Wales, Australia, p. 15.

Knatz G (2015) Foreword. in Ng AKY, Becker A, Cahoon S, Chen SL, Earl P, Yang Z (eds.) Climate Change and Adaptation Planning for Ports. Routledge, Abingdon, pp. xxvii-xxviii.

Kong D, Setunge S, Molyneaux T, Zhang G, Law D (2013) Structural resilience of core port infrastructure in a changing climate. Work package 3 of Enhancing the resilience of seaports to a changing climate report series. National Climate Change Adaptation Research Facility, Gold Coast, p. 172.

Kopp A (2012a) Transport costs, trade and climate change. in Asariotis R, benamara H (eds.) Maritime transport and the climate change challenge. Routledge, Abingdon, pp. 42-47.

Kousky C, Cooke RM (2009) Climate change and risk management: challenges for insurance, adaptation, and loss estimation, RFF Discussion Paper No. 09-03-REV.

Kron W (2012) Coasts: the high-risk areas of the world. Natural Hazards 66:1363-1382.

Lamb HH (2012) Weather, Climate and Human Affairs: A Book of Essays and Other Papers. Routledge Revivals, Abingdon, 384 pp.

Lee RD, Schofield RS (1981) The economic history of Britain since 1700: Volume 1: 1700-1860. Cambridge University Press, p. 12

Lennart Bengtsson, Kevin I. Hodges, Noel Keenlyside (2009) Will Extratropical Storms Intensify in a Warmer Climate? Journal of Climate 22:2276-2301.

Levinson M (2008) The Box: How the shipping container made the world smaller and the world economy bigger. Princeton University Press, United States, p. 544.

Liverpool Echo (2014) Peel Ports picks up pace on £300m Liverpool2 development, http://www.liverpoolecho.co.uk/news/business/peel-ports-picks-up-pace-7863804 [Accessed 23/10/2017]

Lloyd's List (2015a) Outlook 2016: Tianjin casts long shadow over quiet marine insurance year, http://www.lloydslist.com/ll/sector/finance/article476399.ece [Accessed 05/02/2016]

Lloyd's List (2015b) Ports, Lloyd's List, http://directories.lloydslist.com/index.html?p=1615&SESSID=63f1qpoad4cjtpmkji7ngdo3u7 [Accessed 05/10/2015]

Lo Bianco D, Giddings B (2010) Strategic asset management at the port of Melbourne. PIANC MMX Congress Liverpool 2010, Liverpool, UK, p. 11, http://aapa.files.cms-plus.com/PDFs/Strategic%20Asset%20Management%20at%20the%20Port%20of%20Melbourne.pdf

Loh HS, Van Thai V (2014) Managing Port-Related Supply Chain Disruptions: A Conceptual Paper. The Asian Journal of Shipping and Logistics 30:97-116.

Lord Cullen (1990) The public inquiry into the Piper Alpha disaster (command paper). Her Majesty's Stationary Office, London p. 488.

Lowe J, Howard T, Pardaens A, Tinker J, Holt J, Wakelin S, Milne G, Leake J, Wolf J, Horsburgh K (2009) UK Climate Projections science report: Marine and coastal projections, Met Office Hadley Centre, Exeter, p. 12.

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.

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.

Mann ME, Rutherford S, Wahl E, Ammann C (2007) Robustness of proxy-based climate field reconstruction methods. Journal of Geophysical Research: Atmospheres 112:n/a-n/a.

Maritime Insight (2011) Worst maritime accidents: The Tricolor cargo ship accident, http://www.marineinsight.com/marine/life-at-sea/maritime-history/worst-maritime-accidents-the-tricolor-cargo-ship-accident/ [Accessed 18/04/2016]

Matthews T, Murphy C, Wilby RL, Harrigan S (2014) Stormiest winter on record for Ireland and UK. Nature Clim. Change 4:738-740.

McCarthy JJ, Canziani OF, Learty NA, Dokken DJ, White KS (2001) Climate change 2001: Impacts, adaptation and vulnerability.

McDonald J (2011) The role of law in adapting to climate change. Wiley Interdisciplinary Reviews: Climate Change 2:283-295.

Mcdonald J (2013) Creating legislative frameworks for adaptation in Palutikof J, Boulter SL, Ash AJ, Stafford Smith M, Guitart D (eds.) Climate adaptation futures. John Wiley & Sons, New Jersey, United States, pp. 126-132.

McEvoy D, Mullett J (2013) Enhancing the resilience of seaports to a changing climate: Research synthesis and implications for policy and practice. Enhancing the resilience of seaports to a changing climate. National Climate Change Adaptation Research Facility, Gold Coast, p. 118.

McEvoy D, Mullett J, Millin S, Scott H, Trundle A (2013) Understanding future risks to ports in Australia. Work package 1 of enhancing the resilience of seaports to a changing climate report series. National Climate Change Adaptation research Facility, Gold Coast, p. 77.

McEvoy D, Mullett J, Trundle A, Hunting A, Kong D, Setunge S (2016) A decision support toolkit for climate resilient seaports in the Pacific region. in Ng AKY, Becker A, Cahoon S, Chen AS, Earl P, Yang Z (eds.) Climate change and adaptation planning for ports. Routledge, Abingdon, pp. 215-231.

McFadden L, Penning-Rowsell E, Tapsell S (2009) Strategic coastal flood-risk management in practice: Actors' perspectives on flood risk management in London and the Thames Estuary. Ocean and Coastal Management 52:636-645.

Mendelsohn R, Emanuel K, Chonabayashi S, Bakkensen L (2012) The impact of climate change on global tropical cyclone damage. Nature Clim. Change 2:205-209.

Messner S, Moran L, Reub G, Campbell J (2013) Climate change and sea level rise impacts at ports and a consistent methodology to evaluate vulnerability and risk. WIT Transactions on Ecology and the Environment 169:141-153.

Met Office (2014) The recent storms and floods in the UK. Met Office, Exeter, p. 29.

Met Office (2015) Winter 2014/15, https://www.metoffice.gov.uk/climate/uk/summaries/2015/winter [Accessed 20/03/2017]

Meyer MD (2008) Design standards for U.S. transportation infrastructure: The implications of climate change. Georgia Institute of Technology, Transportation Research Board Special Report 290, USA.

Mileti D (1999) Disasters by Design: A Reassessment of Natural Hazards in the United States. Joseph Henry Press, Washington D.C., pp. 376.

Milford Haven Port Authority (2015) Adapting to Climate Change II., Milford Haven Port Authority, p. 18.

Mimura N (2013) Wise adaptation to climate change: the view from Japan. in Palutikof J, Boulter SL, Ash AJ, Stafford Smith M, Guitart D (eds.) Climate Adaptation Futures. John Wiley & Sons New Jersey, United States, pp. 111-118.

Moftakhari HR, AghaKouchak A, Sanders BF, Matthew RA (2017) Cumulative hazard: The case of nuisance flooding. Earth's Future 5:214-223.

Mojafi TA (2014) Development of policy for climate change adaptation for South African ports. Master of Science in Maritime Affairs, World Maritime University, Malmo, Sweden.

Morss RE, Wilhelmi O. V., Meehl G. A., Dilling L. (2011) Improving societal outcomes of extreme weather in a changing climate: An integrated perspective. Annual Review of Environment and Resources 36:1-25.

Moser D, Stakhiv E, Vallianos L (1990) Risk-cost aspects of sea level rise and climate change in the evaluation of coastal protection projects. in Titus JG (ed.) Changing climate and the coast. Environmental Protection Agency, Washington D. C., p. 10.

Moser SC, Boykoff MT (2013) Successful Adaptation to Climate Change: Linking Science and Policy in a Rapidly Changing World. Taylor & Francis, Abingdon, pp. 360

Mullett J, McEvoy D (2011) Climate resilient seaports. Diverse and developing: Proceedings of the 20th Australasian coastal and ocean engineering conference and the 13th Australasian port and harbour conference. Conference paper, Barton A.C.T. Engineers Australia, pp. 523-528.

NACS (2013) How hurricane Sandy affected the fuels industry, http://www.nacsonline.com/YourBusiness/FuelsReports/GasPrices_2013/Pages/How-Hurricane-Sandy-Affected-the-Fuels-Industry.aspx [Accessed 03/06/2015]

Ng AKY, Becker A, Cahoon S, Chen S-L, Earl P, Yang Z (2015) Climate change and adaptation planning for ports. Routledge, Abingdon, p. 318

Ng AKY, Chen S-L, Cahoon S, Brooks B, Yang Z (2013) Climate change and the adaptation strategies of ports: The Australian experiences. Research in Transportation Business & Management 8:186-194.

Ng AKY, Wang T, Yang Z, Li KX, Jiang C (2016) How is Business Adapting to Climate Change Impacts Appropriately? Insight from the Commercial Port Sector. Journal of Business Ethics:1-19.

Ng AKY, Zhang H, Afenyo M, Becker A, Cahoon S, Chen SL, Esteban M, Ferrari C, Lau YY, Lee PT-W, Monios J., Tei A, Yang Z, Acciaro M (2018) Port decision-maker perceptions on the effectiveness of climate adaptation actions. Coastal Management 46:3 148-175

Nicholls R, Corfee-Morlot J, Château J, Patmore N, Herweijer C, Muir-Wood R, Hanson S, Hallegatte S (2008) Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates. OECD Environment Working Papers, No 1, OECD Publishing, 63 pp.

Nicholls RJ, Brown S, Hanson S, Hinkel J (2010) Economics of coastal zone adaptation to climate change. The International Bank for Reconstruction and Development/The World Bank, Washington D.C., Discussion Paper 10, p. 62.

Nicholls RJ, Hanson SE, Lowe JA, Warrick RA, Lu X, Long AJ (2014) Sea-level scenarios for evaluating coastal impacts. Wiley Interdisciplinary Reviews: Climate Change 5:129-150.

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.

Nursey-Bray M, Blackwell B, Brooks B, Campbell ML, Goldsworthy L, Pateman H, Rodrigues I, Roome M, Wright JT, Francis J, Hewitt CL (2013) Vulnerabilities and adaptation of ports to climate change. Journal of Environmental Planning and Management 56:1021-1045.

O'Keeffe JM, Cummins V, Devoy RJN, Lyons D, Gault J (2016) Stakeholder awareness of climate adaptation in the commercial seaport sector: A case study from Ireland. Marine Policy. Corrected proof, p. 10.

OECD (2014) The Competitiveness of Global Port-Cities: Synthesis report., OECD, Paris, p. 272.

Ornitz B, Champ MA (2002) Oil spills first principles: Prevention and best response. Elsevier, New York, p. 678

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.

Oxford Economics (2015) The economic impact of the UK Maritime Services Sector: Ports. p. 22.

P&O Ferries (2015) Dover to Calais Timetable, http://www.poferries.com/en/dover-calais/travelling-with-us/timetable [Available 22/03/2018]

Pallis AA, Vitsounis TK, De Langen PW (2010) Port Economics, Policy and Management: Review of an Emerging Research Field. Transport Reviews 30:115-161.

Palmer T (2011) Energetic swell waves in the English Channel, School of Civil Engineering and the Environment, University of Southampton, pp. 248.

Palutikof J, Boulter SL, Ash AJ, Stafford Smith M, Parry M, Waschka M, Guitart D (2013a) Climate Adaptation Futures. John Wiley & Sons, Somerset, NJ, USA.

Palutikof J, Parry M, Stafford Smith M, Ash AJ, Boulter SL, Waschka M (2013b) The past, present and future of adaptation: setting the context and naming the challenges. in Palutikof J, Boulter SL, Ash AJ, Stafford Smith M, Guitart D (eds.) Climate adaptation futures. John Wiley & Sons, New Jersey, United States, p. 44.

Park SE, Marshall NA, Jakku E, Dowd AM, Howden SM, Mendham E, Fleming A (2012) Informing adaptation responses to climate change through theories of transformation. Global Environmental Change 22:115-126.

Parker D, Kirkpatrick C (2012) The economic impact of regulatory policy: A literature review of quantitative evidence. Measuring Regulatory Performance. Expert paper No. 3, OECD, Paris, p. 47.

Parris A, Bromirksi P, Burkett VR, Cayan D, Culver M, Hall J. W., Horton R, Knuuti K, Moss R, Obeysekera J, Sallenger A, Weiss J (2012) Global sea level rise scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1, 37 pp.

Paté-Cornell ME (1993) Learning from the Piper Alpha accident: A portmortem analysis of technological and organisational factors. Risk Analysis, 13:215-232.

Peel Ports (2011) Mersey Ports Master Plan: A 20 year strategy for growth, Peel Ports, Liverpool, p. 132.

Pelling M, Maskrey A, Ruiz P, Hall P, Peduzzi P, Dao Q-H, Mouton F, Herold C, Kluser S (2004) Reducing disaster risk: a challenge for development, United Nations Development Programme, Bureau for Crisis Prevention and Recovery, New York, 191 pp.

Pielke RAJ (2007) Future economic damage from tropical cyclones: sensitivities to societal and climate changes. Philosophical transactions. Series A, Mathematical, physical, and engineering sciences 365:12.

Pigna FJ (2014) The city-port relationship: its evolution, changing dynamics and challenges for port authorities. in Lecomte JP (ed.) Port-city governance, pp. 77-92.

Popovic R, Kulovic M, Stanivuk T (2014) Meteorological Safety of Entering Eastern Adriatic Ports. Transactions on Maritime Science 1:53-60.

Port of Dover (2011) Climate change adaptation report, Dover Harbour Board p. 41.

Port of Dover (2015) Operating Limitations, http://www.doverport.co.uk/operations/operating-limitations/ [Accessed 28/01/2015]

Port of London Authority (2011) Adapting to climate change. Report to the Secretary of State. Port of London Authority, London, p. 55.

Port of London Authority (2015) Adapting to climate change. Update report to the Secretary of State. Port of London Authority, London, p. 48.

Port of San Diego (2013) Climate Action Plan 2013, Environ, MIG and Chambers Group Inc., p. 44.

Preston BL, Westaway RM, Yuen EJ (2011) Climate adaptation planning in practice: an evaluation of adaptation plans from three developed nations. Mitigation and Adaptation Strategies for Global Change 16:407-438.

Pricewaterhouse Coopers LLP (2010) Adapting to climate change in the infrastructure sections: Maintaining robust and resilient infrastructure systems in the energy, transport, water and ICT sectors. Pricewaterhouse Coopers LLP, London, p. 102.

Pugh D (2004) Changing sea levels: Effects of tides, weather and climate. Cambridge University Press, 280 pp.

Risk Management Solutions Inc. (2003) 1953 U.K. Floods: 50 year retrospective, Risk Management Solutions, London, p. 12.

Roh S, Thai VV, Wong YD (2016) Towards Sustainable ASEAN Port Development: Challenges and Opportunities for Vietnamese Ports. The Asian Journal of Shipping and Logistics 32:107-118.

Rose A, Wei D (2012) Estimating the economic consequences of a port shutdown: the special role of resilience. Economic Systems Research 25:212-232.

Royal Haskoning (2011a) PD Teesport (Ports of Teesport and Hartlepool) Climate Adaptation Assessment. Report to Defra under the Adaptation Reporting Powers, Royal Haskoning, Peterborough, p. 56.

Royal Haskoning (2011b) Port of Sheerness Ltd. Adaptation Assessment. Report to Defra under the Adaptation Reporting Powers, Royal Haskoning, Peterborough, p. 62.

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.

Sanchez RJ, Hoffmann J, Micco A, Pizzolitto GV, Sgut M, Wilmsmeier G (2003) Port Efficiency and International Trade: Port Efficiency as a Determinant of Maritime Transport Costs. Maritime Econ Logistics 5:199-218.

Savonis M, Meyers A, Potter JR (2012) Climate change and ports in America's Gulf Coast: Planning for change. in Asariotis R, Benamara H (eds.) Maritime transport and the climate change challenge. Routledge, Abingdon, pp. 266-285.

Sayers PB, Hall JW, Meadowcroft IC (2002) Towards risk-based flood hazard management in the UK. Proceedings of the Institution of Civil Engineers - Civil Engineering 150:36-42.

Schneider T, Weber H, Franke J, Bronnimann S (2013) The storm surge event of the Netherlands in 1953. in Bronnimann S, Martius O (eds.) Weather Extremes during the past 140 Years. Gergraphica Bernensia, G89, Institute of Geography, Univerity of Bern, Switzerland, pp. 35-43.

Schuster S (2013) Natural hazards and insurance. in Palutikof J, Boulter SL, Ash AJ, Stafford Smith M, Guitart D (eds.) Climate adaptation futures. John Wiley & Son, pp. 133-140.

Schwierz C, Köllner-Heck P, Zenklusen Mutter E, Bresch DN, Vidale P-L, Wild M, Schär C (2010) Modelling European winter wind storm losses in current and future climate. Climatic Change 101:485-514.

Scott H, McEvoy D, Chhetri P, Basic F, Mullett J (2013a) Climate change adaptation guidelines for ports. Enhancing the resilience of seaports to a changing climate report series, National Climate Change Adaptation Research Facility, Gold Coast,. p. 28.

Scott H, McEvoy D, Chhetri P, Basic F, Mullett J (2013b) Climate change adaptation guidelines for ports. Enhancing the resilience of seaports to a changing climate report series. Enhancing the resilience of seaports to a changing climate. National Climate Change Adaptation Research Facility, Gold Coast, p. 30.

Sekovski I, Newton A, Dennison WC (2012) Megacities in the coastal zone: Using a driver-pressure-state-impact-response framework to address complex environmental problems. Estuarine, Coastal and Shelf Science 96:48-59.

Sexton DMH, Murphy J (2010) Probabilistic projections of wind speed. UK Climate Projections,, Department of Environment, Food and Rural Affairs, London, p. 18.

Shafieezadeh A, Ivey Burden L (2014) Scenario-based resilience assessment framework for critical infrastructure systems: Case study for seismic resilience of seaports. Reliability Engineering & System Safety 132:207-219.

Smith RW (2015) The good, the bad, and the robust: Climate change adaptation choices for the port of Rotterdam, Port of San Diego, and Naval Base Kitsap - Bremerton, University of Washington.

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.

State of New Jersey (2013) Rule Revisions Cut Red Tape and Streamline DEP Permits for Vital Rebuilding Projects. in Protection DoE (ed.), http://www.nj.gov/dep/newsrel/2013/13_0065.htm [Accessed 27/02/2018]

Stenek V, Amado J-C, Connell R, Palin O, Wright S, Pope B, Hunter J, McGregor J, Morgan W, Stanley B, Washington R, Liverman D, Sherwin H, Kapelus P, Andrade C, Pabon JD (2011) Climate risks and business: Ports. Terminal Maritimo Muelles el Bosque Cartegena, Colombia. p. 190.

Stott PA, Christidis N, Otto FEL, Sun Y, Vanderlinden J-P, van Oldenborgh GJ, Vautard R, von Storch H, Walton P, Yiou P, Zwiers FW (2016) Attribution of extreme weather and climate-related events. Wiley Interdisciplinary Reviews: Climate Change 7:23-41.

Swart ROB, Raes F (2007) Making integration of adaptation and mitigation work: mainstreaming into sustainable development policies? Climate Policy 7:288-303.

The Guardian (2013) Piper Alpha disaster: how 167 oil rig workers died, http://www.theguardian.com/business/2013/jul/04/piper-alpha-disaster-167-oil-rig [Accessed 18/04/2016]

The National Archives (2018) Currency Converter, https://www.nationalarchives.gov.uk/currency/default0.asp [Accessed 24/01/2018]

The Port Authority of New York and New Jersey (2012) Superstorm Sandy. The experience of The Port Authority of New York and New Jersey, Seminar, http://aapa.files.cms-plus.com/SeminarPresentations/2012Seminars/12HurricaneWorkshop/Saporito.pdf

The Royal Society (2014) Resilience to Extreme Weather. The Royal Society, London, p. 124.

The Scotsman (2009) Forth Ports warned of climate change flood threat to docks, http://www.scotsmandep.com/news/forth-ports-warned-of-climate-change-flood-threat-to-docks-1-1203912 [Accessed 13/02/2018]

Thorsen CA (2014a) Berthing Requirements. in Squires J (ed.) Port Designer's Handbook, Third Edition edn. ICE Publishing, London, pp. 99-142.

Thorsen CA (2014b) Design Considerations. in Squires J (ed.) Port Designer's Handbook, Third Edition edn. ICE Publishing, London, pp. 157-174.

Thorsen CA (2014c) Environmental Forces. in Squires J (ed.) Port Designer's Handbook, Third Edition edn. ICE Publishing, London, pp. 37-78.

Thurrock Council (2013) Section 19 Flood and Water Management Act. Flood Investigation Report. Quebec Road, Tilbury, Thurrock Council, Thurrock, p. 11.

Tobey J, Rubinoff P, Robadue Jr. D, Ricci G, Volk R, Furlow J, Anderson G (2010) Practicing coastal adaptation to climate change: Lessons from integrated coastal management. Coastal Management 38:314-335.

Tol RSJ, Klein RJT, Nicholls RJ (2008) Towards Successful Adaptation to Sea-Level Rise along Europe's Coasts. Journal of Coastal Research 242:432-442.

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.

Tompkins EL, Few R, Brown K (2008) Scenario-based stakeholder engagement: Incorporating stakeholders preferences into coastal planning for climate change. Journal of Environmental Management 88:1580-1592.

Townend IH, Burgess KA (2001) Methodology for assessing the impact of climate change upon coastal defence structures. ASCE, 29th International Conference on Coastal Engineering:3953-3966.

Trade Winds News (2005) 'Tricolor' battle lines take shape, http://www.tradewindsnews.com/weekly/w2005-07-08/212297/tricolor-battle-lines-take-shape [Accessed 18/04/2016]

Tsatsou A (2014) Port cities and climate change: actions for resilience, Erasmus University Rotterdam, P. 99.

TT Club, ICHCA International, Port Equipment Manufacturers Association (2011) Recommended minimum safety specifications for quay container cranes, TT Club, ICHCA International and Port Equipment Manufacturers Association, London, p. 15.

Twitter (2017) Using Twitter, https://support.twitter.com/articles/166337 [Accessed 23/03/2017]

Uitto JI (1998) The geography of disaster vulnerability in megacities: A theoretical framework. Applied Geography 18:7-16.

UK Government (2017) Climate change adaptation reporting: second round reports, https://www.gov.uk/government/collections/climate-change-adaptation-reporting-second-round-reports [Accessed 14/11/2017]

UK Government (2018) The Thames Barrier, https://www.gov.uk/guidance/the-thames-barrier [Accessed 26/01/2018]

UKCIP (2007) Identifying adaptation options, UKCIP, Oxford, p. 35.

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.

UNCTAD (2013) Review of Maritime Transport 2013. United Nations Publication, Geneva, Switzerland, p. 204.

United Nations (1982) United Nations Convention on the Law of the Sea (Artcle 57), Montego Bay Jamaica, p.208, http://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf [Accessed 14/07/2015]

United States Environmental Protection Agency (2008) Planning of climate change impacts at U.S. ports. p. 17.

United States Global Change Research Program (2014) 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. in Melillo JM, Richmond TC, Yohe GW (eds.), United States Government Printing Office, p. 841.

Urwin K, Jordan A (2008) Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance. Global Environmental Change 18:180-191.

van Barneveld N (2013) Rotterdamse adaptatiestrategie – Themarapport Waterveilighied. Rotterdam Climate Initiative, Rotterdam, p. 48.

Varley A (1994) Disaster, development and environment. Wiley, New Jersey, 182 pp.

Vellinga T, De Jong M (2012) Approach to climate change adaptation in the Port of Rotterdam. in Asariotis R, Benamara H (eds.) Maritime transport and the climate change challenge. Routledge, Abingdon, pp. 305-319.

Vogel C, Moser SC, Kasperson RE, Dabelko GD (2007) Linking vulnerability, adaptation, and resilience science to practice: Pathways, players, and partnerships. Global Environmental Change 17:349-364.

Wade SD, Rance J, Reynard N (2013) The UK Climate Change Risk Assessment 2012: Assessing the Impacts on Water Resources to Inform Policy Makers. Water Resources Management 27:1085-1109.

Wadey MP (2013) Understanding defence failures and coastal flood events: a case study approach, University of Southampton, Southampton.

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, Haigh ID, Nicholls RJ, Brown JM, Horsburgh K, Carroll B, Gallop S, Mason T, Bradshaw E (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, article 84, 27 pp.

Wahl T, Haigh ID, Woodworth PL, Albrecht F, Dillingh D, Jensen J, Nicholls RJ, Weisse R, Wöppelmann G (2013) Observed mean sea level changes around the North Sea coastline from 1800 to present. Earth-Science Reviews 124:51-67.

Wahl T, Jain S, Bender J, Meyers SP, Luther ME (2015) Increasing risk of compound flooding from storm surge and rainfall for major US cities. Nature Clim. Change 5:1093-1097.

Wang J, Olivier D, Notteboom T, Slack B (2007) Ports, cities and global supply chains. Ashgate Publishing Limited, Farnham, 296 pp.

Ware C, Berge J, Sundet JH, Kirkpatrick JB, Coutts ADM, Jelmert A, Olsen SM, Floerl O, Wisz MS, Alsos IG (2014) Climate change, non-indigenous species and shipping: assessing the risk of species introduction to a high-Arctic archipelago. Diversity and Distributions 20:10-19.

WASA Group (1998) Changing Waves and Storms in the Northeast Atlantic? Bulletin of the American Meteorological Society 79:741-760.

Watson D (2017) Port of Immingham flood defence improvement project, p. 9, https://www.nelincs.gov.uk/wp-content/uploads/2017/02/Urgent-Business-Port-of-Immingham-Flood-Defence.pdf

Welsh Government (2011) National Strategy for Flood and Coastal Erosion Risk Management in Wales, Crown Copyright Welsh Government, p. 90.

Wheaton EE, Maciver DC (1999) A framework and key questions for adapting to climate variability and change. Mitigation and Adaptation Strategies for Global Change 4:215-225.

Wilbanks T, Fernandez S, Backus G, Garcia P, Jonietz K, Kirshen P, Savonis M, Solecki B, Toole L (2012) Climate change and infrastructure, urban systems, and vulnerability. Technical report to the U.S. Department of Energy in support of the National Climate Assessment. Oak Ridge National Laboratory. U.S. Department of Energy, Island Press, 109 pp.

Wiltshire A (2014) Victorian Centre for Climate Change Adaptation Research. Governance and legislative issues for critical infrastructure adaptation to climate change. Case study - ports., Victorian Centre for Climate Change Adaptation Research, p. 26.

Wise RM, Fazey I, Stafford Smith M, Park SE, Eakin HC, Archer Van Garderen ERM, Campbell B (2014) Reconceptualising adaptation to climate change as part of pathways of change and response. Global Environmental Change 28:325-336.

Wisner B, Blaikie P, Cannon T, Davis I (2004) At Risk: Natural hazards, people's vulnerability and disasters. Routledge, Abingdon, 496 pp.

Wood NJ, Good JW (2004) Vulnerability of Port and Harbor Communities to Earthquake and Tsunami Hazards: The Use of GIS in Community Hazard Planning. Coastal Management 32:243-269.

Woodworth PL, Teferle FN, Bingley RM, Shennan I, Williams SDP (2009) Trends in UK mean sea level revisited. Geophysical Journal International 176:19-30.

Woodworth PL, Tsimplis MN, Flather RA, Shennan I (1999) A review of the trends observed in British Isles mean sea level data measured by tide gauges. Geophysical Journal International 136:651-670.

World Maritime News (2015a) DFDS takes over damaged MyFerryLink Duo, https://worldmaritimenews.com/archives/171801/dfds-takes-over-damaged-myferrylink-duo/ [Accessed 22/02/2018]

World Maritime News (2015b) Severe weather closes Australian ports, http://worldmaritimenews.com/archives/158481/severe-weather-closes-australian-ports/ [Accessed 03/02/2016]

Wright P (2013) Impacts of climate change on ports and shipping. Marine Climate Change Impacts Partnership: Science Review:263-270.

Xiao Y-b, Fu X, Ng AK, Zhang A (2015) Port investments on coastal and marine disasters prevention: Economic modeling and implications. Transportation Research Part B: Methodological 78:202-221.

Yeo G-T, Ng AKY, Lee PT-W, Yang Z (2014) Modelling port choice in an uncertain environment. Maritime Policy & Management: The flagship journal of international shipping and port research 41:251-367.

Zanuttigh B (2011) Coastal flood protection: What perspective in a changing climate? The THESEUS approach. Environmental Science & Policy 14:845-863.

Zhang H, Ng AKY, Becker A (2017) A critical discussion on the roles of institutions on ports' adaptation to the impacts posed by climate change. in Leal Filho W, Keenan JM (eds.) Climate Change Adaptation in North America: Fostering Resilience and the Regional Capacity to Adapt. Springer, New York City, pp. 105-117.

Zhao B (2016) Facts and lessons related to the explosion accident in Tianjin Port, China. Natural Hazards 84:707-713.

Zhong H, van Overloop P-J, van Gelder P, Rijcken T (2012) Influence of a storm surge barrier's operation on the flood frequency in the Rhine Delta area. Water 4:474-493.