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The Practicalities of Managing and Mapping Potentially Polluting Shipwrecks in the UK: Legal, Social and Ethical Considerations

Volume 1 of 1

by

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Abstract

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The issue of potentially polluting wrecks is relatively unstudied in the UK despite the potential threat presented by hundreds of shipwrecks in UK waters that contain oil, chemicals and other hazardous materials. As these wrecks degrade they will inevitably release their cargoes and fuel stores into the marine environment.

While there have been studies elsewhere that examine the risk from polluting shipwrecks, the limited work that has been undertaken on this topic in the UK is restricted to a number of government commissioned reports. These have attempted to quantify and risk assess the shipwrecks that pose a pollution threat in UK waters in order to inform ongoing management of these shipwrecks. However, there remain significant uncertainties about the nature of the threat from polluting shipwrecks in the UK. The existing studies also fail to take into account social and political influences that affect wreck management.

This research therefore critically examines the state of research and the current management of polluting shipwrecks in the UK. It does this through examination of the legal requirements to remediate wrecks and to determine who is responsible for managing these shipwrecks. It presents a critical analysis of the existing risk assessments, wreck databases and the data that underpins them to reveal the high level of uncertainty in existing studies. Finally it demonstrates that through spatial assessment of open source socio-economic datasets we can determine with more certainty the potential consequences of wreck pollution and its impacts on the UK.

The results of this research highlight issues relating to data availability and reliability which limits our ability to adequately risk assess and make decisions to pro-actively manage these wrecks. This research provides an alternative method for prioritising mitigation measures based on the spatial analysis of the socio-economic impact of wreck pollution rather than through traditional risk assessment. This allows us to examine these wrecks in a new manner and to make decisions despite high levels of uncertainty. It also allows for greater stakeholder engagement and integration into the management process. Ultimately this research presents the first holistic assessment of the management of potentially polluting wrecks in the UK.

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Research Thesis: Declaration of Authorship

Print name: Camilla Moore

Title of thesis: The Practicalities of Managing and Mapping Potentially Polluting Shipwrecks in the UK: Legal, Social and Ethical Considerations

I 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.

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. None of this work has been published before submission.

Signature: Date:

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Definitions and Abbreviations

AA..Annual Average (Concentration)

ABPmer ....ABP Marine Environmental Research Ltd.

AIS ....Automatic Identification System

AMAP2 ....Characterising the Potential for Wrecks Project

AMIO ....Atlantic, Mediterranean and Indian Ocean (shipwreck database)

AONB...................................Areas of Outstanding Natural Beauty

ArcGIS..................................ESRI's Geographical Information Software

Art. ....Article (legal)

BBC......................................British Broadcasting Corporation

BEIS ....Department for Business, Energy and Industrial Strategy

BODC ....British Oceanographic Data Centre

BSAC ....British Sub Aqua Club

CADW ....Welsh historic environment service

CBA......................................Cost Benefit Analysis

CCO......................................Channel Coastal Observatory

CEFAS ....Centre for Environment Fisheries and Aquaculture Science (UK)

CHP......................................Civil Hydrography Programme (UK)

CIFA ....Chartered Institute for Archaeologists

CLC.......................................International Convention on Civil Liability for Oil Pollution Damage 1992

CNI.......................................Critical National Infrastructure

CPNI.....................................Centre for the Protection of National Infrastructure

CPZ ....Counter Pollution Zone

DAERA ....Department of Agriculture, Environment and Rural Affairs (Northern Ireland)

DAIMON ....Decision Aid for Marine Munitions

DCMS .... Department for Culture, Media and Sport

DDT .... Dichloro ditheryl trichloroethane

DEEPP.................................. DEvelopment of European guidelines for Potentially Polluting shipwrecks.

DEFRA .... Department for Environment, Food and Rural Affairs (England)

DfT .... Department for Transport (England)

E-DBA .... Environmental Desk Based Assessment

EEZ .... Exclusive Economic Zone

EMODnet .... The European Marine Observation and Data Network

EMSA................................... European Maritime Safety Agency

ERW .... Explosive Remnants of War

EQS...................................... Environmental Quality Standards

EU.. European Union

FISH .... Forum on Information Standards in Heritage

GIS....................................... Geographic Information Systems

GT.. Gross Tonnes/Tonnage

GVA .... Gross Value Added

HER .... Historic Environment Record

Hg.. Mercury

HFO .... Heavy Fuel Oil

HMS .... Her Majesty's Ship

HNS .... Hazardous Noxious Substances

HQ....................................... Headquarters

IJNA .... International Journal of Maritime Archaeology

IMO .... International Maritime Organisation

ID... Identification

IOPC .... International Oil Pollution Compensation (funds)

ITOPF................................... International Tanker Owners Pollution Federation

JCCC.....................................Joint Casualty and Compassionate Centre

JNCC ....Joint Nature Conservation Committee

JSP ....Joint Service Publication

JoMA ....Journal of Maritime Archaeology

KMS ....Kriegsmarine Schiffe (Ship of the German Navy in WWII)

MA..Maximum allowable (concentration)

MA Ltd.................................Maritime Archaeology Ltd

MCA.....................................Maritime and Coastguard Agency (UK)

MCZ.....................................Marine Conservation Zone

MEDIN ....Marine Environmental Data and Information Network

MIDAS ....British cultural heritage standard

MMO ....Marine Management Organisation

MoD ....Ministry of Defence

MOOC..................................Massive Open Online Course

MS Access............................Microsoft Access (software)

MV.......................................Motor Vessel

MWD ....MoD's Master Wreck Database

NaPTAN ....National Public Transport Access Node

NCP......................................National Contingency Plan

NE..Natural England

NEQ ....Net Explosive Quantity

NISRA...................................Northern Ireland Statistics and Research Agency

NM ....Nautical Mile

NMR ....National Monuments Register (UK)

NOAA...................................National Oceanic and Atmospheric Administration (USA)

NRW ....Natural Resources Wales

NUTS....................................Nomenclature of Territorial Units for Statistics

PAH......................................Poly Aromatic Hydrocarbons

PhD .... Doctor of Philosophy

PLC .... Public Limited Company

PPW3 .... UK MoD's Potentially Polluting Wrecks 3

PPWD3 .... UK MoD's Potentially Polluting Wrecks 3 Database

PPW4 .... UK MoD's Potentially Polluting Wrecks 4

PPWD4 .... UK MoD's Potentially Polluting Wrecks 4 Database

PPWs .... Potentially Polluting Shipwrecks

RDX .... Cyclotrimethylenetrinitramine

RFA .... Royall Fleet Auxillary (ship)

ROV .... Remotely Operated Vehicle

RULET .... The Remediation of Underwater Legacy Environment Threats (database)

RUST .... Resources and Undersea Threats (database)

RYA .... Royal Yachting Association

SAC .... Special Areas of Conservation

SALMO .... Salvage and Marine Operations

SCUBA .... Self-Contained Underwater Breathing Apparatus

SeaZone .... SeaZone Ltd

SME .... Subject Matter Expert(s)

SMS .... Seiner Majestät Schiff (Austro-Hungarian Navy - His Majesty's Ship)

SNH .... Scottish Natural Heritage

SPREP .... South Pacific Regional Environment Programme

SPA .... Special Protection Areas

SS .... Steam Ship

SSI .... Sites of Scientific Interest

SQL .... Structured Query Language

SWERA .... Sunken Wreck Environmental Risk Assessment (Finland)

TBT .... Tributyltin

TNT .... Trinitrotoluene

TPH .... Total Petroleum Hydrocarbon (testing)

UB .... U-Boat (ship prefix)

UCH .... Underwater Cultural Heritage

UK .... United Kingdom

UKHO .... United Kingdom Hydrographic Office

UN .... United Nations

UNESCO .... The United Nations Educational, Scientific and Cultural Organisation

US/USA .... United States of America

USS .... United States Ship

UXO .... Unexploded Ordnance

VMS .... Vessel Monitoring Systems

VRAKA .... short for shipwreck risk assessment in Swedish.

WEEE .... Waste Electronic Equipment

WWI/WW1 .... First World War

WWII/WW2 .... Second World War

WWF .... World Wildlife Fund

Chapter 1 Introduction

The waters surrounding the UK contain thousands of shipwrecks (Figure 1). A significant number of these wrecks sank with cargos of potential pollutants in the form of oil, chemicals, heavy metals, ordnance and other hazardous substances. These shipwrecks are actively degraded by sea water and marine organisms, and therefore have a limited lifespan within the marine environment. As these wrecks degrade they will release their pollutants into the environment. It has been demonstrated that coastal zones within the United Kingdom (UK) are some of the highest risk locations from marine spills (Fernández-Macho, 2016) as a result it is vital that the risks posed by polluting vessels within UK waters are better understood.

There are a number of socially, economically and environmentally hazardous pollutants that might originate from shipwrecks. Oil pollution from shipwrecks has been the most studied of these pollutants but explosive remnants of war (ERW), chemicals and heavy metals also have the potential to create social, economic and environmental damage on a scale that is potentially equivalent if not greater than that of oil. Although their effects are perhaps not as visible to the media and the public more generally.

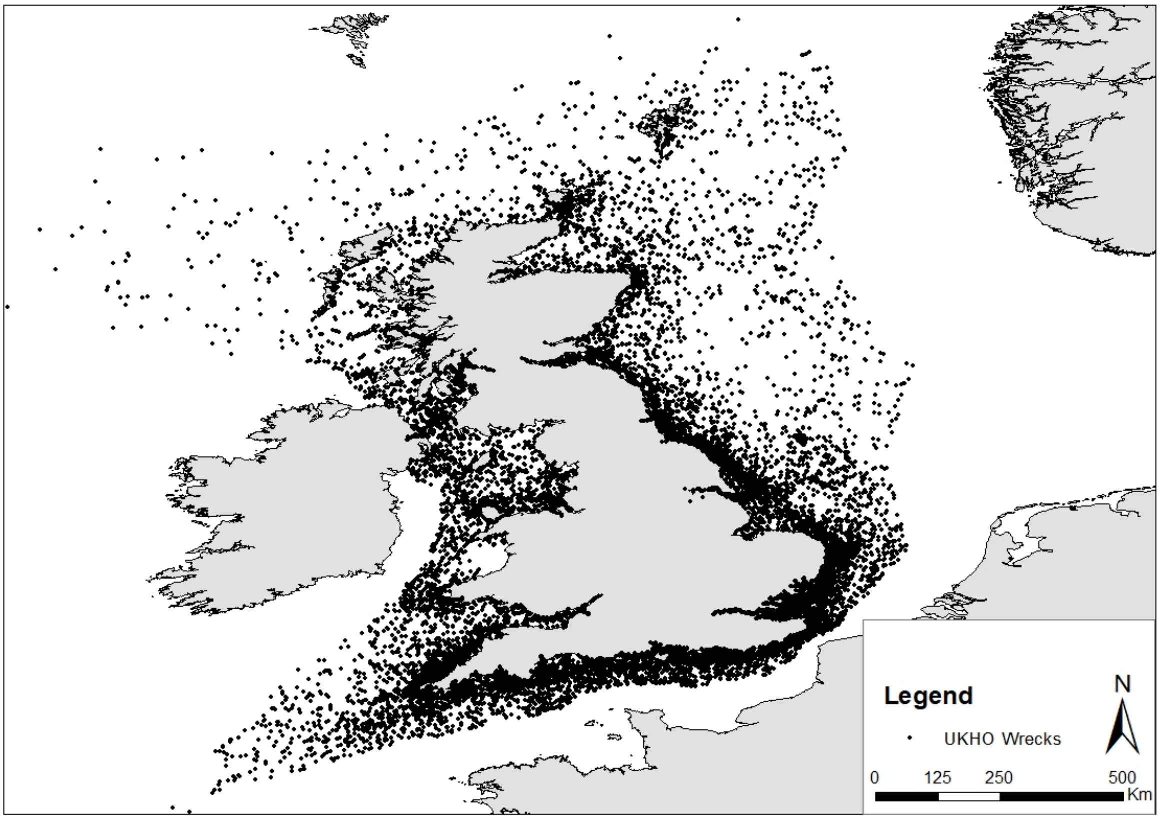

Figure 1 Shipwrecks in UK waters (author's own image).

The risk from polluting wrecks has been studied in the USA (Overfield & Symons 2009; Michel, et al. 2005), the Pacific (Gilbert and Nawadra, 2003; Monfils, Gilbert and Nawadra, 2006), the Baltic (Landquist et al., 2016; Ndungu et al. 2017; Rogowska et al. 2010; Rogowska et al. 2015) and Mediterranean (Alcaro *et al.*, 2007; Renzi et al. 2017), however, it remains relatively unstudied in the UK. There are only three published papers which examine the threat and risk from potentially polluting wrecks in UK waters, and these focus on specific shipwrecks (Wyse and Leary, 2016; Alexander, 2019; Goodsir *et al.*, 2019). In addition to these published papers, there have been government commissioned studies that aim to risk assess the wider wreck portfolio in the UK. The results of these assessments subject to considerable (and at times unquantified) uncertainties.

Many questions therefore remain on the subject of potentially polluting wrecks and their management in the UK. For example there is currently no understanding of whether there is in fact a legal requirement to remediate pollution from these wrecks. There is also uncertainty around the number of potentially polluting wrecks in UK waters, and their potential impact on the UK. There is also disparity between the ways in which these wrecks are currently managed. The majority of studies investigating shipwreck pollution also fail to take into account the social and economic factors that greatly influence the management of such shipwrecks.

The significant costs associated with remediating these wrecks means that there is a requirement to better understand if it is possible to assess the risk from these vessels and to develop suitable management strategies based on the available data. Remediation of these wrecks before a leak occurs is clearly preferable in order to prevent escalating costs and environmental damage. Therefore any management strategy should ideally be pro-active rather than reactive, however, given the various uncertainties that exist around shipwrecks it is not clear if the current available data and knowledge of potentially polluting shipwrecks in the UK even allows us to pursue a pro-active strategy. There is therefore a clear need for a better understanding of the threat that potentially polluting wrecks pose in the UK, what the existing management process for these wrecks is, whether it is suitable, and what else we can and/or should be doing to manage them.

The research presented in this thesis is a critical analysis of the state of research on potentially polluting wrecks in the UK. It contributes to our understanding of polluting wrecks by better quantifying the number of potentially polluting wrecks in UK waters, by identifying the legal requirements to remediate wrecks, by assessing the available data to determine what is feasible in relation to managing these wrecks, and finally, provides an assessment of the socio-economic impact of polluting wrecks in the UK. In filling these gaps in our knowledge of polluting wreck management this research establishes a foundation on which to move this subject forward, and delivers guidance to wreck managers regarding their responsibilities and their ability to risk manage these wrecks.

1.1 Research Questions

In light of the above, the research question this thesis addresses is:

What is the existing management and assessment process for potentially polluting wrecks in the UK, how can this be improved upon, taking into account practical, social, legal and ethical considerations?

Within this overarching question there are a number of sub-questions that need to be examined, namely:

- Is there a requirement to remediate potentially polluting wrecks in the UK?
- How many potentially polluting wrecks are there in the UK?
- What is the risk from potentially polluting wrecks in the UK?
- What are the consequences of potentially polluting wrecks in the UK?
- Is the current management strategy for potentially polluting wrecks suitable?
- What could be done moving forward?

1.2 Aims and Objectives

In accordance with the research questions discussed above there are a number of aims and objectives that this research hopes to achieve. These are namely to:

1. Determine the legal framework and management structure for potentially polluting wrecks in the UK and whether there is a legal requirement to remediate wreck.
2. Attempt to improve quantification of potentially polluting wrecks in UK waters through analysis of existing databases.
3. Critically analyse existing risk assessment methodologies for potentially polluting wrecks and determine where further development & improvement is necessary.
4. Attempt to understand the socio-economic impacts of pollution from wreck in the UK and the social and political influences on wreck management.

1.3 Methodology

This research takes an interdisciplinary approach to understanding the issue of potentially polluting shipwrecks. This is due to the complex nature of the problem as it sits at the intersection of social, biological, chemical and physical sciences. An assessment of polluting wreck management requires an understanding of the law, risk theory, marine social science, underwater cultural heritage, salvage, marine spatial planning, shipwreck research, and the environmental effects of pollution among many other factors. Archaeology is well placed to undertake research into such complex topics as in itself archaeology is interdisciplinary, borrowing knowledge and methods from philosophy, geography, social sciences, chemistry and a vast array of other disciplines. Within this thesis a number of methods have been used to approach the problem of potentially polluting shipwrecks, and to address the specific set of questions discussed above, these include literature and legislative reviews, statistical analysis, and spatial analysis. Each chapter details the methods used to undertake each part of this study separately.

1.4 Ethical Considerations of the Research

This research into polluting shipwrecks has been undertaken in conjunction with, and using data sets provided by, the Ministry of Defence (MoD). As a result of issues surrounding cultural heritage in the Iraq and Afghanistan wars, there has been increasing focus on examining the ethical and political implications of archaeologist's engagement with military institutions (La Piscopia 2013). Some have argued that the association of archaeologists with the military perpetuates ideas of colonialism within the discipline (Hamilakis 2012) and that professional associations are inherently damaging to archaeological interpretations, given that they are saturated with political influence, and preserve western capitalist and colonialist cultural associations.

More specifically to this project Flatman (2007) has also stressed, the requirement for maritime archaeology to consider its relationship with the military, particularly in understanding how maritime archaeology is responsible for maintaining and promoting British maritime power through examination of military wrecks, and utilisation of military derived technology. Flatman states that in undertaking archaeological assessments of military wrecks, maritime archaeology "makes a tacit statement of support for the military and the use of military force".

Others have argued against this stating in some cases that archaeology can be used in conjunction with the military to promote peace and open dialogues between conflicting parties in the present, as well as aiding in repairing relationships and damaged narratives as a result of historic wars (Rush 2015).

Clearly it is necessary for maritime archaeologists to consider the associations and impact of our work in order to produce ethically responsible research. However, in considering polluting shipwrecks it is worth noting that the majority relate to the two World Wars, and a significant proportion of these are military vessels. There needs to be a balance between whether conducting archaeological research into these wrecks is unethical based on their military connection, against the ethical implications of allowing polluting material to continue its escape from the wrecks, and the potential loss of heritage associated with these wrecks.

Many of the polluting shipwrecks studied are military vessels, which are culturally and socially significant; to ignore these on the basis that they are military vessels is also unethical and as La Piscopa (2013) notes, to reduce the argument for concern of destruction or loss of cultural heritage to the often problematic concept of “stewardship” and thus fetishisation of the record is backward and unhelpful. It is possible to study these vessels without tacitly supporting the military and the use of military force, particularly when the wrecks are considered in the context of loss of life and tragedy, rather than as a display of military strength and prowess. In truth potentially polluting wrecks are environmentally, socially, politically, legally and ethically problematic, in studying all facets of these wrecks in a more holistic fashion one hopes to engender an ethically suitable method for studying and managing them. A method that goes beyond propagating nationalist and militaristic ideologies, beyond a technological focus and beyond the traditional maritime archaeological narratives associated with shipwrecks.

While this research does not directly include research that engages with human subjects or involve physical remains, the topic does touch on sensitive subjects such as loss of human life and management of human remains, therefore ethical approval for the work has been obtained through the University’s Ergo approval process. Where there are ethical aspects of the research to be considered these form separate sections in the relevant chapters.

1.5 Conflicts of Interest

It is necessary to state that in addition to working closely with the MoD, during the write up of this thesis I entered into employment with the Maritime and Coastguard Agency (MCA), which is an executive agency of the Department for Transport (DfT), as the Receiver of Wreck (RoW). There is some overlap between the work undertaken during the PhD and the work conducted by the RoW, however, the main body of research was undertaken prior to my employment at the MCA and any conclusions draw regarding the responsibilities of the DfT, MCA and the RoW in relation to wrecks discussed in this thesis were made independently of that role. Additionally, any opinions expressed in this thesis regarding management of shipwrecks by the MoD, DfT and other agencies remain my personal opinions and not linked to any official agencies or departments. Nor have the MoD attempted to influence any of the work presented. I have endeavoured to prevent my involvement with any of these agencies from affecting my research and any subsequent recommendations and observations made in this thesis.

1.6 Thesis Outline

This chapter thus far has provided a brief introduction to the content of the thesis, and introduced the research question and the aims and objectives. It also sets out ethical considerations of the research and any prospective conflicts of interest.

The next chapter gives a detailed background regarding the area of study and the motivation for the project, as well as the history of scholarship surrounding potentially polluting wrecks. Chapter 2 also examines the theory of risk as it relates to management of polluting wrecks and highlights some of the key considerations behind the research undertaken in this thesis.

Chapter 3 examines whether there is a legal requirement to remediate legacy potentially polluting wrecks, and presents the applicable legislative framework for the UK. It examines international, EU, UK and case law to draw conclusions regarding who may be liable for remediating wrecks, as well as what that responsibility is likely to entail. It also examines the existing management structure for shipwrecks in the UK and whether the current management of polluting wrecks meets the legal requirements.

A critical analysis of the various shipwreck databases utilised to determine quantification of potentially polluting wrecks in UK waters is undertaken in Chapter 4, including those datasets held (and kindly provided) by the UK MoD. This research provides a new calculation for the number of polluting wrecks in the UK. It also examines whether there is sufficient data to successfully undertake risk assessments in the UK, what uncertainties exist in the risk assessment process, and what data might be available to reduce these uncertainties. This is critical for understanding whether existing risk assessments provide a suitable basis for subsequent decision making with respect to polluting wreck management.

In Chapter 5 we address the lack of socio-economic assessment for potentially polluting wrecks through a spatial analysis of various socio-economic datasets against the wrecks identified as being polluting in the previous chapter. The consequences of pollutant release from wreck in UK waters is demonstrated through this spatial assessment. It also provides an alternative means of assessing where further work should be focused based on the areas highlighted as having the greatest density of wrecks and areas which are most vulnerable to pollution. An overview of ethical and non-tangible social and cultural beliefs and perceptions of wreck is also discussed in this chapter. This allows us to examine how stakeholder engagement, perspectives and risk tolerance impact polluting wreck management.

In Chapter 6 the evidence and results from the preceding chapters are discussed in order to conclusively answer the overarching research question and the sub-questions posed above. This chapter draws together the various strands of evidence to assess the suitability of the UK's management of polluting wrecks taking into account the legal requirements determined in Chapter 3, the availability of data and level of uncertainty identified in Chapter 4, and the socio-economic consequences and stakeholder perspectives discussed in Chapter 5. This chapter also discusses what can be done to improve the management of, and to mitigate or minimise the risk from polluting wrecks.

Finally, Chapter 7 concludes this work with a discussion of the research journey that led to the above conclusions. It defines the research contribution, and also highlights limitations to the work presented herein. This chapter also discusses opportunities and areas for further research moving forward.

Chapter 2 Polluting Wreck Threat

In order to determine if the UK's management of potentially polluting wrecks is sufficient, it is necessary first to understand the background and motivation behind polluting wreck management. This chapter sets out the types of pollutant that might be encountered in potentially polluting wrecks and gives a background to the history and effects of wreck pollution. This chapter also discusses previous approaches to identifying, assessing and managing the threat from polluting wrecks both internationally and in the UK to date.

2.1 Threat Assessment

2.1.1 Oil Pollution

The vast majority of studies undertaken on potentially polluting wrecks consider oil pollution to be the primary and most pressing threat posed by these wrecks. Oil pollution causes environmental damage in the short term through physical smothering, where oil coats organisms and interferes with their physiological processes resulting in mortality (Farrington, 2014). This is often the most visible effect of oil pollution and images of oiled seabirds that die from a result of smothering are often shown by the media in the event of an oil spill. Chemical toxicity is another effect of oil pollution which results in poisoning of susceptible organisms resulting in their death (Farrington, 2014). In the long term, oil pollution also causes ecological changes and has indirect effects such as loss of habitat (ITOPF, 2011c).

The impact of oil spills in the marine environment depends on a number of factors. The type of oil spilled and it's persistence within the environment is one factor (Anderson, 2001). Light oils (such as gasoline or marine diesel oil) tend to have a high toxicity but lower persistence, whereas heavy oils (such as heavy fuel oil (HFO)) have a high persistence and are more likely to have a smothering effect but a lower toxicity (ITOPF, 2011c). Thus, it tends to be heavy oils which cause the greatest concern as they continue to affect the environment for a time after the initial spill, whereas light oils are more readily dispersed, degraded or evaporated naturally (Anderson, 2001). Clean up response to heavy oils is often greater than that of light oils for this reason.

The impact of oil pollution also depends on the type of environment, weather conditions and time of year within which the incident occurs. Oil pollution tends to have a more damaging effect in the nearshore environment where the oil is subject to mixing through the water column due to wave action, and in the inter-tidal zone where it settles onto sediments (ITOPF, 2011c). In comparison in offshore environments a typical oil spill is generally less harmful as it tends to remain on the surface. The exception to this is oil from sunken shipwrecks which has the potential even in the offshore environment to be detrimental to benthic fauna (particularly for heavy fuel oils) (ITOPF, 2011c; Faksness *et al.*, 2015). Similarly, sensitive environments such as salt-marshes are likely to be more affected in the long term by oil pollution than a rocky coastline that is subject to tidal flushing and wave action. Birds and benthic fauna are susceptible to oil pollution through smothering (Henkel *et al.*, 2014) and the effects of oil pollution can have long term impacts on populations, for example, current populations of seabirds have been shown to demonstrate the detrimental effects of oiling events from WWII (Birkhead, 2016). The severity of the impacts of an oil spill are linked to seasonality, impacts on seabirds for example are greater during nesting seasons where there is an accumulation of specific bird populations, and this is similar for most flora and fauna in the marine environment (ITOPF, 2011c; Henkel *et al.*, 2014).

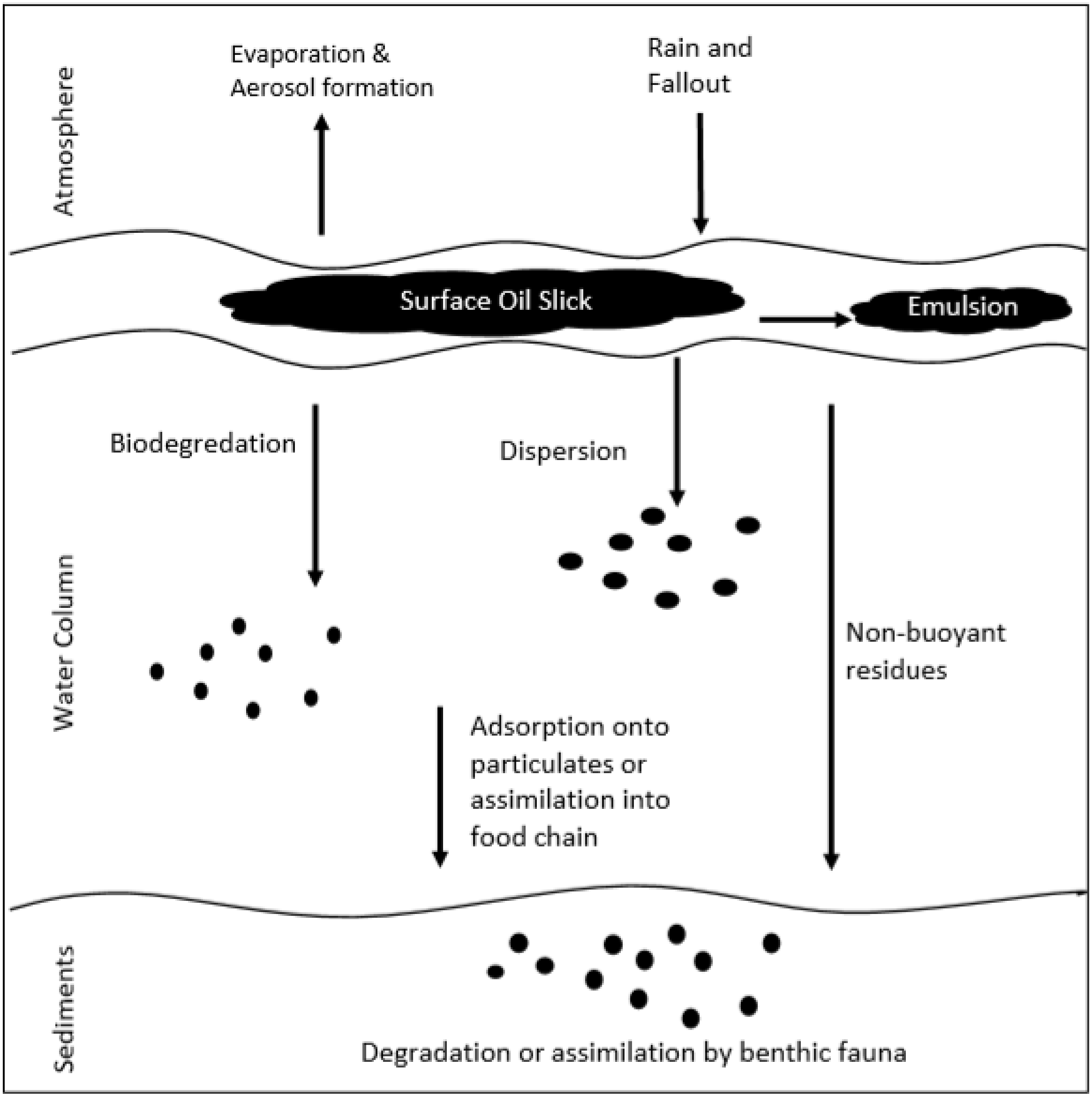

Figure 2 Diagram of oil mixing and settlement (author's own image).

In addition to the environmental impacts of oil pollution it also has effects on the economy and society more generally, fisheries and aquaculture can be severely affected (Ritchie, 1995; Goodlad, 1996; ITOPF, 2011a, p. 27) as well as tourism related industries (Bonnieux and Rainelli, 2004; Garza *et al.*, 2009; ITOPF, 2011b; Cheong, 2012) and local communities that rely on the sea or coastal zone for subsistence (The International Tanker Owners Pollution Federation 2011a, p2). There are also significant public health concerns associated with oil pollution for those living in affected coastal zones and for those engaged in clean-up operations (Antizar-Ladislao, 2008; Aguilera *et al.*, 2010; Farrington, 2014; Laffon *et al.*, 2016).

Several high profile oil polluting incidents between the late 1960's and early 2000's raised awareness surrounding the environmental, economic and social costs of oil pollution occurring as a result of vessel related accidents. One of the first significant oil polluting events resulting from a shipwreck involved the Liberian oil tanker SS *Torrey Canyon*, which ran aground off Land's End in the UK on the 18th March 1967, releasing 119,000 tonnes of crude oil into the sea (Jacobsson, 2017; Wells, 2017).

Efforts were made to contain the oil spill through use of detergents and attempts were made to re-float the ship. During one such attempt on the 23rd March the ship broke into three pieces (Kamm, 2014). The British Government ordered the aerial bombardment of the wreck in the hope that the majority of the remaining oil contained in the ship would burn off, and while this strategy was partially successful it did not prevent significant portions of the southwest of the UK, the Channel Islands and Brittany in France from suffering pollution from the incident (Wells, 2017). Indeed oil recovered from the *Torrey Canyon* spill was still undergoing bio-remediation in a quarry in Guernsey up until late 2010 (BBC News, 2010).

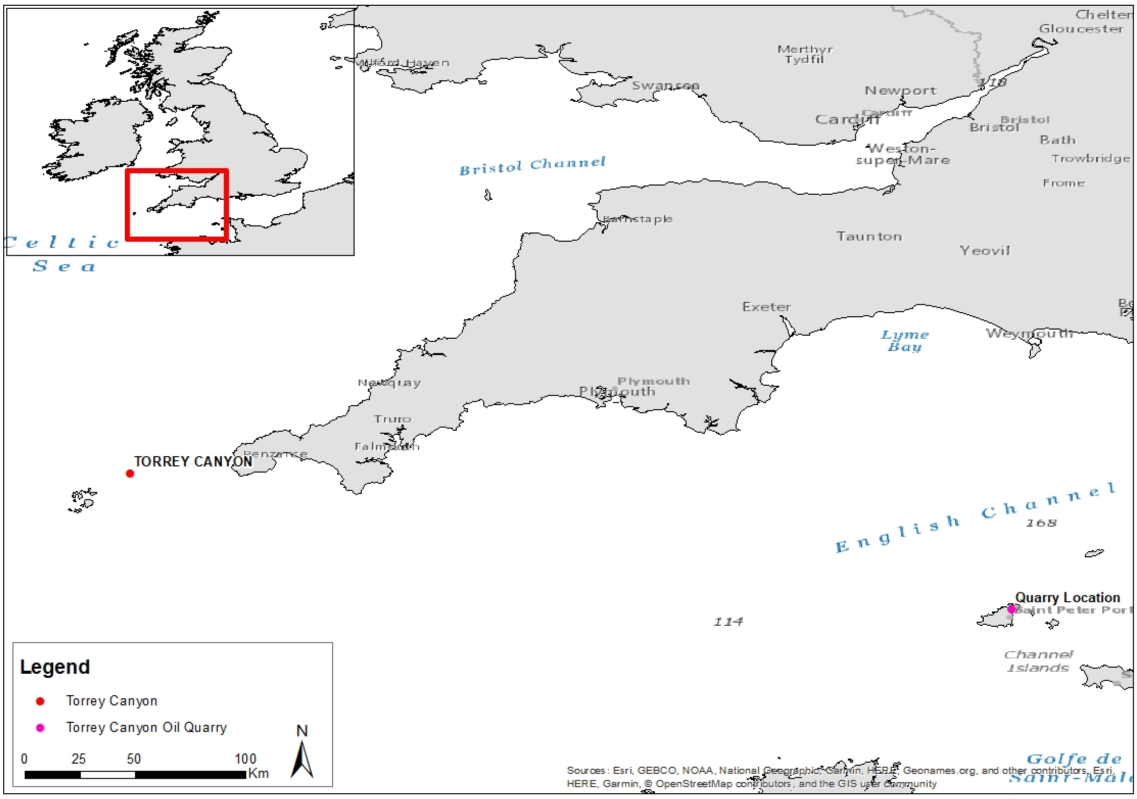

Figure 3 The *Torrey Canyon* location and quarry of oil location. (author's own image).

Figure 4 Quarry containing oil from *Torrey Canyon* (image bbcworldservice, licensed under CC BY-NC 2.0)

The use of chemical dispersants to treat the oil from the spill caused significant long term environmental damage that could have been avoided had the oil been left to degrade naturally, and which while also considered to be a pollutant would have caused less damage than the specific dispersants and aggressive clean up strategy utilised (Cooper and Green, 2017). Unfortunately, lessons regarding the use of dispersants during the *Torrey Canyon* spill were not learned and similar long-term environmental damage was caused by the use of dispersants during clean-up of the spill of the *Sea Empress* in 1996 (Edwards and White, 1999; Law and Kelly, 2004). Key environmental findings that arose from experiences during the *Torrey Canyon* remediation process included an understanding of the high sensitivity of marine mammals and birds to oiling, the ecological impact of chemical dispersants and the persistence of oil within sediments and ecological systems (Wells, 2017).

The economic impact of the oil pollution on beaches in these regions during the summer tourist season was felt heavily and the clean-up costs were estimated at around three million pounds (at 1976 value) (De La Rue and Anderson, 2009). The incident highlighted legal issues relating to the right of states to intervene in response to polluting incidents that might affect their coasts, and relating to rights for compensation in light of such an incident (Kamm, 2014). More recently there have been efforts to understand the lasting social impact that the wrecking of the *Torrey Canyon* has left with the communities affected both by the pollution itself and also by the decisions made during the remediation process (Green and Cooper, 2015; Cooper and Green, 2017).

As demonstrated by the *Torrey Canyon* and the *Sea Empress* incidents, the short-term effects of oil pollution are significant, however, in the long term it is often found that the recovery of environments is quicker than anticipated, and economies do not suffer as greatly as expected (Edwards and White, 1999; ITOPF, 2011b) although this is likely linked to the speed of clean-up response, time of year and type of habitat. While habitats might not return to their exact pre-spill state, they prove to be resilient and return to normal functioning in terms of bio-diversity and productivity relatively rapidly which is the point at which they are considered to have recovered from an oil spill (Kingston, 2002; Peterson *et al.*, 2003; ITOPF, 2011c).

Table 1 Typical habitat recovery periods (reproduced from ITOPF 2011)

Habitat	**Recovery Period**
Plankton	Weeks/months
Sand beaches	1-2 years
Exposed rocky shores	1-3 years

Habitat	**Recovery Period**
Sheltered rocky shores	1-5 years
Saltmarsh	3-5 years
Mangroves	10 years +

Three recent studies investigating oil pollution from legacy shipwrecks identified hydrocarbon residues in the sediments and local fish stocks Rogowska et al (2010 & 2015) examined surface sediment pollution at the wreck of the SS *Stuttgart* in the Gulf of Gdansk (Southern Baltic). Their study looked at a series of pollutants at the wreck site including heavy metals and oil. Their results identified that there were higher polycyclic aromatic hydrocarbon (PAH) concentrations within the centre of the shipwreck owing to fuel contamination from the wreck, however, they stated that it was not possible to unequivocally determine the type of fuel polluting the area around the shipwreck, as the PAH's identified in sea bed sediments were not derived from crude oil but from coal transformation and therefore could have many sources.

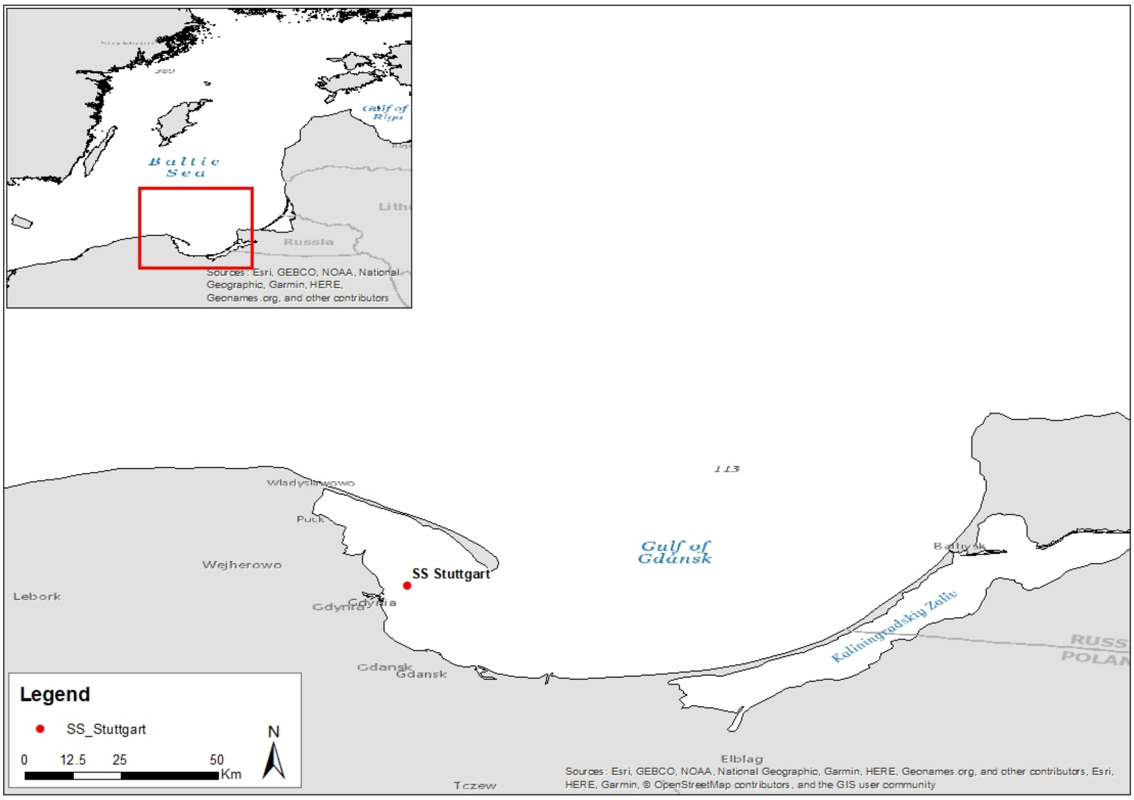

Figure 5 Location of the *SS Stuttgart* (author's own image).

In the Norwegian Skaggerak, Ndungu et al (2017) investigated oil pollution in the sediments surrounding the wreck of the Nordvard, located in Mossesundet (near the harbour of Moss). They undertook total petroleum hydrocarbon (TPH) and PAH analysis of sediments at the wreck site and from the wider Mosseundet region. Whilst the highest values of PAH and TPH were found in the vicinity of the wreck, high TPH concentrations were also found at 7Km from the wreck. Leading the authors to conclude that it was not possible to ascertain whether it was the wreck or other PAH sources (such as aerosol deposition and marine traffic emissions) that contributed significantly to the sediment pollution at the site of the wreck.

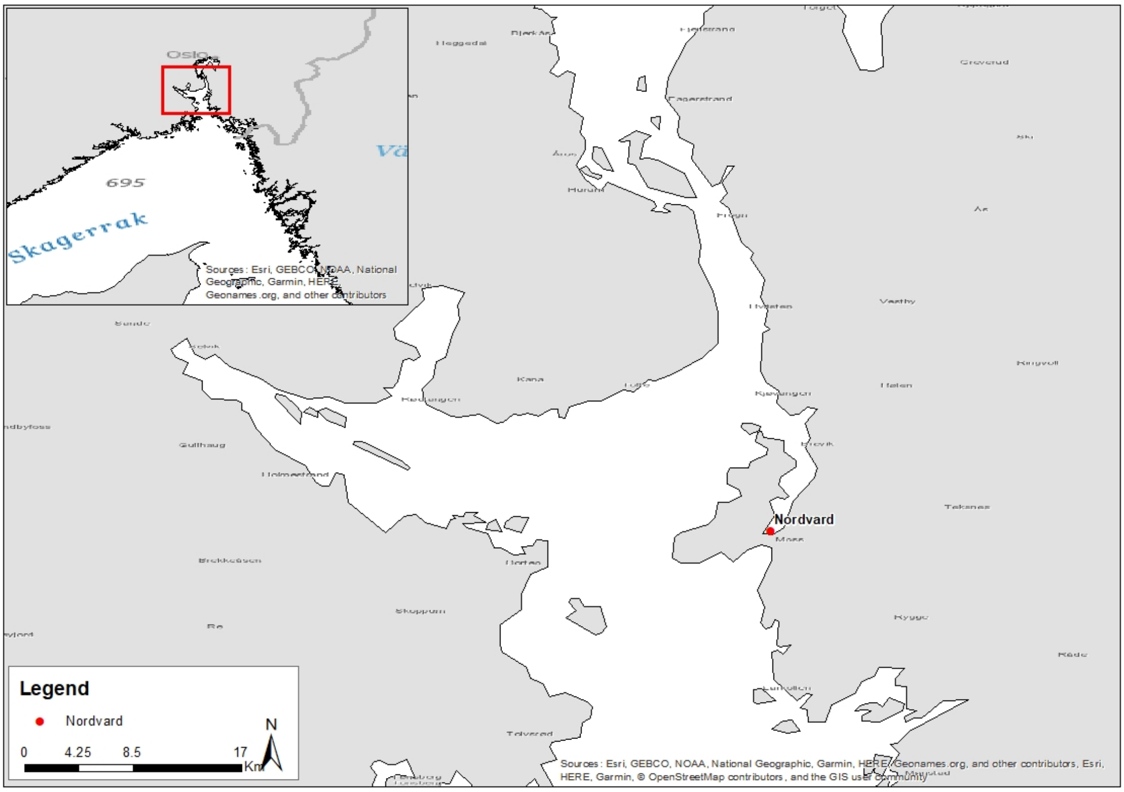

Figure 6 Location of the *Nordvard* (author's own image).

Renzi et al. (2017) examined the polluting impact of three shipwrecks, within the straits of Sicily in the Mediterranean, on the biodiversity fish and benthic assemblages, and determining correlation with sediment pollution levels and trophic web pollution. This study also involved a control site also located within the straits of Sicily. The study found that organic pollutants were often higher at the control sites than within the vicinity of the shipwrecks and were likely to have had a terrestrial origin. In addition the shipwrecks were found to promote biodiversity in fish and that oil pollution from the shipwrecks could not be detected in fish assemblages.

All three studies found that while it was probable that wrecks had contributed to the pollutant levels both at the time of sinking and in subsequent years, it was the background pollution input of hydrocarbons from urban and shipping inputs that contributed the majority of the pollution in the vicinity of the wrecks (Ndungu et al. 2017; Rogowska et al. 2010; Rogowska et al. 2015; Renzi et al. 2017).

The studies by Renzi et al. and Rogowska et al. suggest that while shipwrecks may be polluting, the wider environment is contaminated by other sources of pollutants that may in fact be of greater concern than those related to shipwrecks. It is therefore likely that, in the cases where there is not likely to be a catastrophic release of oil from a wreck, remediating polluting wrecks will have negligible impact on the reduction of marine pollution, and that governmental resources should instead be directed towards reducing pollutants from other sources. It is however, worth noting that the studies conducted by Renzi et al. and Rogowska et al. took place in the specific and relatively enclosed marine environment of the Baltic which is likely to retain higher levels of pollution from other sources as it is not subject to the same "flushing" mechanisms that UK waters experience. As similar studies have not been undertaken in the UK it is unknown if the same high levels of general pollution are likely to be found and caution should be exercised in transposing findings from the Baltic to UK waters which are hydrologically significantly different.

Approximately 46% of global oil pollution results from natural oil seeps (Farrington, 2013). The contribution to global oil pollution from sunken shipwrecks is difficult to estimate, however, it is unlikely that shipwreck pollution amounts to anywhere near the amount stemming from natural sources, even though we expect the amount of oil from shipwrecks increase over time as these wrecks degrade, until such time as they have all broken down. Some have questioned the requirement to remediate polluting legacy shipwrecks at all (Renzi *et al.*, 2017), given the long term environmental recovery and the relatively minor part that polluting shipwrecks have to play towards overall global pollution levels. It is necessary to determine whether the benefits of remediating the short term effects of oil pollution outweigh the costs of remediation. The evidence demonstrates that the long term effects of oil pollution may not as severe as thought, and the marine environment is subject to greater pollution from other sources. The money spent remediating polluting wrecks may well be better spent tackling these other sources of pollution.

The argument for remediating potentially polluting wrecks is therefore based not on concerns for the environment, but around concerns relating to the social, economic and political effects from oil pollution in the short term. The reputational and presentational damages that result in the event of a pollutant release from wrecks is of significant concern to governments. In the *Torrey Canyon* incident it was public health concerns, combined with perceived economic loss that drove the requirement to remediate polluting shipwrecks at a social and political level, and environmental legislation is the vehicle by which this was achieved (Cooper and Green, 2017) and it is these same factors that force the requirement to remediate legacy polluting shipwrecks.

Further discussion regarding the impact of stakeholders on oil pollution management from shipwrecks is presented in Chapter 5.

The increased awareness of the environmental, economic and social impact of oil pollution generated from the wrecking of the *Torrey Canyon*, and from similar wrecking events resulting in chronic oiling, including the *Amoco Cadiz* in 1978 (O'Sullivan, 1978), the *Sea Empress* in 1996 (Law and Kelly, 2004), the *MV Erika* in 1999 (Bordenave *et al.*, 2004) and the MV *Prestige* in 2002 (Mairal, 2016), resulted in the tracing of mystery oil spills that did not appear to have a contemporary provenance back to historic shipwrecks (Michel *et al.*, 2005a). There was a push to remediate the oil leaking from these vessels in light of public and political pressure as well as environmental and economic incentives (Girin, 2004), and for these wrecks to be managed in accordance with the way in which modern polluting events are managed. Key wrecks identified at this time included the USS *Mississinewa*, *the* SS *Jacob Luckenbach*, and HMS *Royal Oak*.

The USS *Mississinewa* located in the Ulithi Lagoon in the Federated States of Micronesia was one of the first wrecks of this kind to be identified (Monfils, Gilbert and Nawadra, 2006). The vessel sank in 1944 carrying nineteen million litres of oil and gasoline (Gilbert and Nawadra, 2003; U.S. Navy, 2004), and remained undiscovered until April, 2001. In August, 2001 a typhoon disturbed the wreck causing oil to leak into the surrounding lagoon (Gilbert and Nawadra, 2003; U.S. Navy, 2004). The U.S. Navy conducted immediate temporary remediation work in 2001 and subsequently removed the remaining oil in 2002 (approximately fifteen million litres) after a full assessment of the wreck had been made (U.S. Navy, 2004).

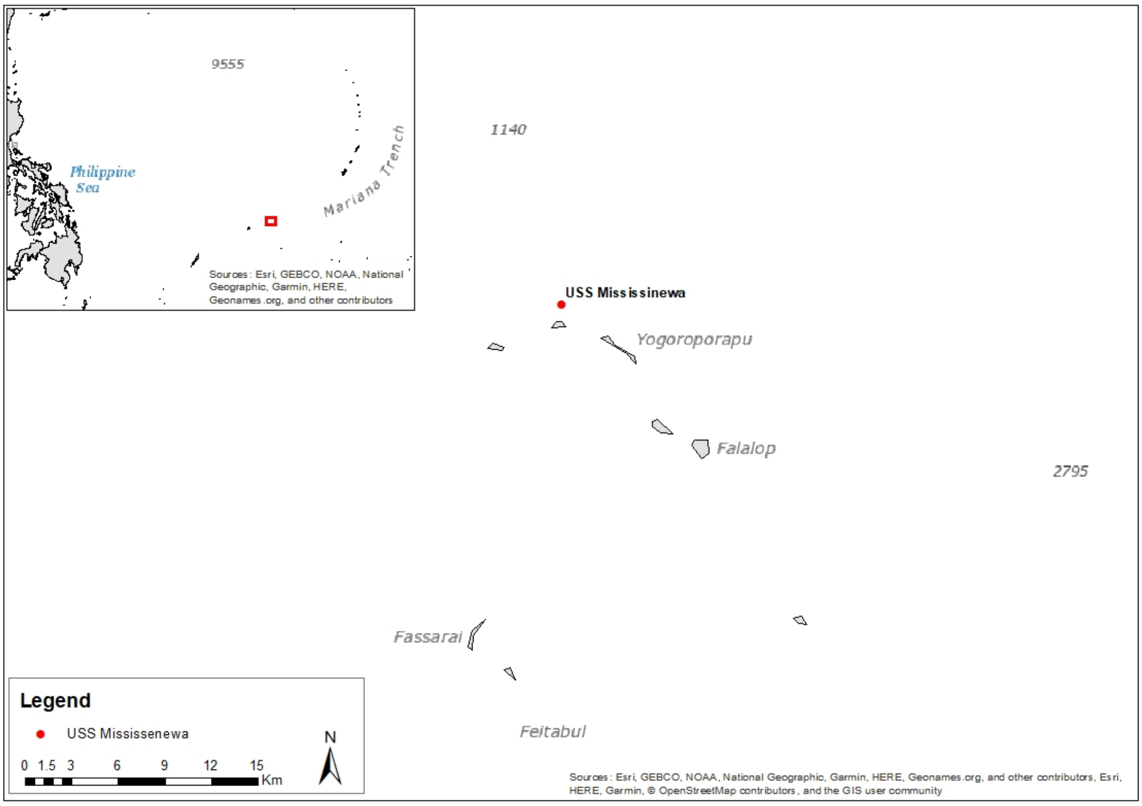

Figure 7 Location of the USS *Mississinewa* (author's own image).

In 2002 oil "fingerprinting" tests identified that the SS *Jacob Luckenbach,* a cargo ship carrying heavy fuel oil that sank in 1953 off the coast of San Francisco, was the culprit of ten years' worth of environmentally damaging polluting incidents in the region (Hampton *et al.*, 2003; McGrath *et al.*, 2003). Oiling events were found to correspond to strong storm related activity and heavily affected bird populations (McGrath *et al.*, 2003), with estimates of 18,291 dead seabirds at nearby Point Reyes between 1997 and 1998 alone (Hampton *et al.*, 2003). The clean-up operation involved divers spending up to a month living in a pressurised chamber during the oil removal process (Hampton *et al.*, 2003) and cost in the region of nineteen million US Dollars (Hampton *et al.*, 2003; Albertson, 2004).

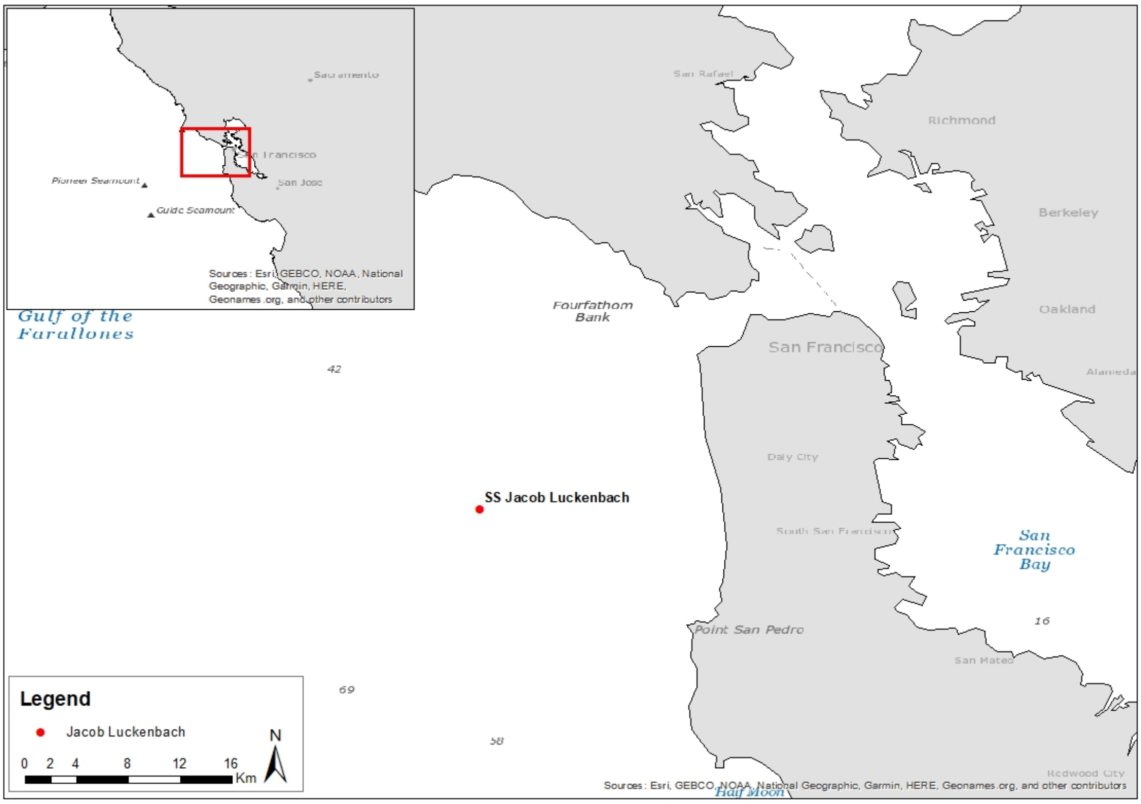

Figure 8 Location of SS *Jacob Luckenbach* (author's own image).

During the late 1990's in the UK the wreck of HMS *Royal Oak*, which sank in October 1939 in Scapa Flow, Orkney, after being torpedoed by a German submarine (Rowlands, 2001), was found to be leaking 1.5 tonnes of oil into the waters of Scapa Flow a week (Michel *et al.*, 2005a), affecting the local fishing economy particularly severely. At one stage it is thought that the Royal Oak accounted for 96% of all of the oil pollution within British waters (Forrest, 2012). The MoD removed the majority of the oil from the wreck through hot tapping the vessel in 2001. Due to the location of the vessels oil bunkers and the position of the ship upside down on the seabed not all of the oil was able to be removed during this operation, and the MoD returns regularly to remove the remaining oil as it makes its way up through the wreck (Michel *et al.*, 2005a). The site is protected under the Protection of Military Remains Act 1986 with an annual remembrance ceremony held above the wreck, the wreck also plays a significant role in Orcadian society and the generation of Orcadian identity (Travers, 2015).

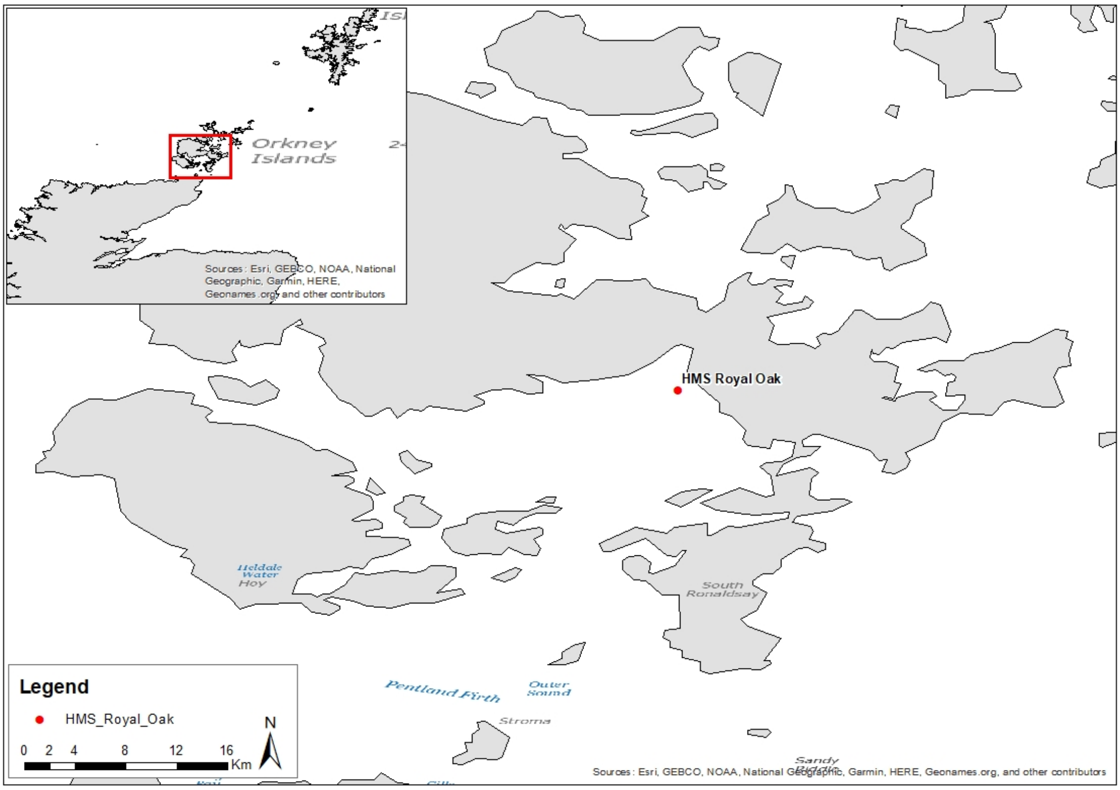

Figure 9 Location of HMS *Royal Oak* (author's own image).

In dealing with these legacy shipwrecks the mitigation measures implemented were understandably reactive due to the lack of prior awareness of their polluting potential at the time of discovery. An understanding of the consequences resulting from legacy polluting wrecks generated the requirement to better understand and quantify the scope of the issue and the level of threat that is actually posed by such vessels (Albertson, 2004; Buckingham, 2004), rather than focusing only on understanding the loss of human life or financial consequences of shipwrecks as previous research had done (Girin, 2004). This point is further addressed in later in this chapter however, there are other pollutants that require discussion before we return to this point.

2.1.2 Hazardous Noxious Substances

With increased globalisation there has been a rise in the quantity and frequency of goods shipments often including cargoes of hazardous noxious substances (HNS). While shipwrecks incidents involving vessels containing HNS are relatively rare in comparison with those containing oil, between 1987 to 2007 there were approximately 100 incidents (Mamaca et al. 2009), this is likely to increase as shipments of these materials is increasing at an annual average rate of 3% (Vannoni *et al.*, 2017). HNS is defined by the Protocol on Preparedness, Response and Co-operation to Pollution Incidents by HNS, also known as the OPRC-HNS Protocol (which entered into force in 2007, although not ratified by the UK), as any substances other than oil which, if introduced into the marine environment are likely to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea. This definition is broad and encompasses many different chemicals, including but not limited to, vegetable oils, acids, alkalis, corrosive gasses and volatile organic compounds (Neuparth *et al.*, 2011; Harold *et al.*, 2014; Cunha, Moreira and Santos, 2015). It is necessary to understand the threat posed and issues associated with wrecks that contain these materials as they have the potential to be more dangerous than oil related incidents (Mamaca *et al.*, 2009; Purnell, 2009).

In comparison to oil containing wrecks, research into the effects and management of polluting HNS wrecks is relatively nascent. Recent work has focused on providing a risk priority for HNS based on their predominance in previous spill incidents (Cunha et al. 2015), based on their public health risks (Harold *et al.*, 2014), or based on their environmental toxicity (Guillén *et al.*, 2012; Rocha *et al.*, 2016). However, risk assessments for hazardous chemicals are often frustrated due to the lack of available information regarding the effects of chemicals in sea water (Neuparth *et al.*, 2012; Cunha *et al.*, 2016), or due to misleading information being provided on shipment manifests (Purnell, 2009). Evidence of environmental impacts of previous HNS spills is minimal as environmental monitoring in the aftermath of HNS spills has been limited (Purnell, 2009; Radović *et al.*, 2012; Cunha, Moreira and Santos, 2015) and therefore there are substantive gaps in our understanding of HNS properties, effects and fates in seawater (Neuparth *et al.*, 2012; Cunha *et al.*, 2016; Rocha *et al.*, 2016). Cunha et al (2015) identified that out of 119 spills analysed in their study, only 24 included some information on environmental or biological monitoring (Cunha et al. 2015, p516). This is further complicated by the lack of homogeneity in sampling methodologies and strategies between these studies, and minimal implementation of post-spill studies as the majority were only conducted during the spill itself, as well as a lack of baseline data for environments prior to a spill incident occurring (Neuparth *et al.*, 2012)

The wide range of chemicals that can be considered HNS means that there is significant variation in the effects and behaviour of potential HNS (Neuparth *et al.*, 2012; Harold *et al.*, 2014; Vannoni *et al.*, 2017), however, most can be split into four main categories, although some chemicals may exhibit more than one of these properties:

Table 2 Properties and behaviour of HNS as summarised from Cunha et al. (2016)

Type	**Properties/Effects**
Dissolvers	Dissolvers such as Acrylonitrile can have a high acute toxicity risk as once dissolved they are readily bioavailable in the water column.
Evaporators (and gases)	Evaporators (e.g. benzene or cyclohexane) can form toxic clouds which perform in the same manner as gasses. Exposure time is short and they have little persistence over time, therefore it is evaporating chemicals which pose a high toxicity or which present an explosive hazard which are of greatest concern.
Sinkers	Non-toxic sinkers such as cereals are persistent and can cause vegetation and sediment smothering resulting in benthic mortality.
Floaters	Floaters such as vegetable oils often behave in a similar fashion to oil and cause similar effects.

Dissolvers and sinkers are most likely to have the highest impact on the marine environment, dissolvers are more likely to affect fish, marine mammals and other organisms that live within the water column, while sinkers will affect benthic fauna and impact on "bottom feeding" animals (Rocha et al. 2016). In contrast, evaporators pose the greatest risk to human health as they are airborne and can be inhaled. Floaters perform in a similar manner to oil pollution with similar associated risks and management procedures (Cunha et al. 2016). Floaters are most likely to cause issues in intertidal zones. Within these broad categories it is those HNS that pose a bioaccumulation risk, high toxicity or potential for persistence that pose the greatest risk to the environment and to human health (Cunha *et al.*, 2016; Rocha *et al.*, 2016).

In UK waters there have been approximately ten HNS shipwrecks between 1991 and 2011 (Cunha et al. 2016 – see also Ciimar Hazardous and Noxious Substances Spill Incidents for UK HNS shipwreck details), with a greater number of containers containing HNS also lost from vessels during this time. The spilled materials included *inter alia,* sunflower oil (the *Kimya,* 1991), palm nut oil (the A*llegra,* 1997), styrene (the *Levoli Sun*, 2000), timber (the *Ice Prince*, 2007), explosives (the *Napolii*, 2007), and various pesticides (the *Ever Decent*, 1999). These shipwrecks are relatively recent and therefore much of the spilled materials were mitigated or removed at the time of the incident. However, there is little information available regarding the number of legacy shipwrecks that pose a HNS threat within UK waters. A shipwreck that sank in WWI, off Beachy Head in Sussex, is being investigated as a potential cause of a gas cloud which affected an area of the South Coast of England around Birling Gap on the 27th August 2017 (Weaver, 2017). It is not currently confirmed if the wreck was the source of the gas that caused eye and breathing issues for beachgoers in the area, and it would have required a substantial chemical release from the wreck in order to create such a cloud. If the wreck is subsequently confirmed as the culprit it raises significant concerns that similar HNS incidents might occur as other legacy wrecks that contain HNS degrade.

In addition to carrying cargoes of chemicals many ships have in the past utilised anti-fouling systems containing hazardous compounds. Historically chemicals such as Arsenic, mercury, and dichloro dithenyl tricholroethane (DDT) were used to coat the hulls of ships to prevent marine organisms from growing on the hull. However, the introduction of the very effective organotin tributyltin (TBT) in the 1960's which acted as a fungicide, bactericide, insecticide and wood preserver, meant that by the 1970's TBT was the primary choice for anti-fouling and was found on most seagoing vessels (IMO, 2002). Concern arose regarding the use of TBT due to its persistence in the marine environment and its effect on marine organisms and shellfish in particular (Alzieu, 1991; Waite *et al.*, 1991; Antizar-Ladislao, 2008). TBT contamination was linked to high mortalities and malformation in oysters resulting in the near collapse of shellfisheries in some areas of France (Alzieu, 1991, 2000). The introduction of the International Convention on the Control of Harmful Anti-fouling Systems of Ships 2001, which entered into force in 2008 resulted in the prohibition of TBT being used in anti-fouling (Antizar-Ladislao, 2008). Shipwrecks that sank before 2008 may therefore have coatings which present a HNS hazard in relation to the localised environment. TBT was also introduced into the marine environment from legacy terrestrial sources (Antizar-Ladislao, 2008) so determining if the pollution of this kind is related solely from specific shipwrecks is likely to be difficult.

With the prohibition of TBT copper and Irgarol (cybutryne) became the predominant anti-foulants utilised to protect ships (Van der Tak, 2009)and while significantly less damaging than TBT they are still have a toxic effect on marine organisms. Research conducted in 2007 estimated that approximately 46 tonnes of copper and 852 kg of Irgarol may have leached from antifouling paints on active vessels into the sea of the Netherlands' Continental Shelf in during a single year (Van der Tak, 2009). When taking into account the additional quantities of material from sunken vessels as well as on a broader regional scale the values are likely to be significantly higher for the North Sea area.

To fully investigate the risks from polluting shipwrecks containing HNS would be the content of an additional thesis. In addition, given the variability of HNS that might be present in shipwrecks it is necessary to assess these on a wreck by wreck basis rather than through an overarching assessment process. Likewise remediation methods and strategies are necessarily dictated by the type of HNS and will therefore need to be determined on a case by case basis. Attempting therefore to make generic recommendations and undertaking further generalised study of these wrecks in this thesis would be unsuitable, it is simply necessary to note that there are shipwrecks that might pose an HNS threat both alone and also in conjunction with other potential pollutants. The EU has an HNS policy for managing polluting HNS incidents (European Maritime Safety Agency, 2007) including those relating to shipwrecks, in the UK the policy for HNS incidents is included within the UK’s Marine Pollution Contingency Plan (Marine Management Organisation, 2016) these are further discussed alongside the legislation that relates to HNS pollution in Chapter 3.

2.1.3 Heavy Metals & Waste Electronic Equipment (WEEE)

Heavy metals such as mercury, lead, zinc, nickel, cadmium and copper can be polluting in the marine environment, having a toxic effect on marine organisms when present in large concentrations. Through a process of bio-accumulation through the food chain heavy metals can therefore become harmful to human health via ingestion of seafood, and in rare cases through direct exposure and subsequent poisoning from the metals themselves (Bosch *et al.*, 2016).

These metals can form part of a cargo or as part of the wreck itself. Possibly the oldest example of a shipwreck containing heavy metals is a shipwreck in the Red Sea near Sharm-el-Sheikh, wrecked on a reef in approximately AD1600, with bronze bowls containing mercury amongst its cargo (Raban, 1973). The wreck was surveyed and investigated in 1972, however, the mercury was a source of interest for the archaeologists as an artefact of trade, not as an environmental pollutant and as far as can be discerned no further studies of the site have been conducted. In contrast the German submarine (U-864) which sunk in 1945 close to Bergen, Norway, carrying approximately 67 tons of mercury (Hg) (Forrest, 2012; Rua-Ibarz *et al.*, 2016; Ndungu *et al.*, 2017) has been the source of some considerable concern to the Norwegian government and is subject to extensive monitoring. While some of the mercury was released at the time of sinking, an unknown but potentially significant quantity remains in canisters within the wreck. It is estimated that approximately 5g of mercury is leaking from the vessel annually, and sediments contain raised levels of mercury to a radius of 100m from the wreck (Ndungu *et al.*, 2017). An ongoing monitoring strategy is in place for the wreck and the Norwegian government is currently determining the future of the vessel to prevent further contamination of the surrounding environment.

In addition to heavy metals carried as cargo, in recent years concern has been raised regarding the polluting potential of waste electronic equipment (WEEE) which contain heavy metal components and compounds capable of leaching into the surrounding environment. With an increase in shipping of electronic appliances, and the widespread use on modern vessels of on-board computing and electronics, the potential for WEEE to pose an environmental threat as a result of shipwreck is likely to also increase. Legislation is in place to control the recycling of electronic waste in the UK, and there are international conventions that are in progress but not yet in force specifically relating to the recycling of WEEE in ships (The Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009). However, little consideration has been given to what should be done regarding shipwrecks that contain these materials. Indeed the only study that has expressly concerned itself with WEEE from shipwrecks is that conducted by Hahladakis et al. (2013) who constructed lab based simulation of the wreck of the *Sea Diamond* , which sank off the coast of Santorini in 2007, and measured the release of heavy metals from various forms of WEEE into the environment from the shipwreck. They found that four of the ten metals tested resulted in higher than permissible concentrations in seawater, leading them to conclude that shipwrecks containing WEEE should be subject to salvage and recycling to prevent heavy metal contamination to the environment (Hahladakis et al. 2013, P262). Given that the experiment was conducted in a laboratory scenario rather than in conditions expected in the marine environment it is not possible to determine if this level of contamination would be identified on the site itself which is subject to currents and tides providing a non-stagnant environment.

Research conducted by the OSPAR Commission in 2007 analysed the effects of heavy metals leaching into the environment from anodes of zinc, aluminium and cadmium which are designed to protect ships hulls from corrosion. The research identified that roughly 145 tonnes zinc, 12 tonnes aluminium and 72 kg cadmium had leached from anodes to the sea in a single year within the Netherlands continental shelf area (Van der Tak, 2009). These estimates were calculated from active vessels and not from additional shipwreck sources meaning the values are likely to be higher than those given once shipwrecks with similar systems are included. The lack of available research into this issue from shipwrecks demonstrates that further research into the potential contamination from WEEE is required in order to better understand potential environmental damage arising from such pollution, particularly on a regional and global scale.

2.1.4 Explosive Remnants of War

A significant proportion of legacy potentially polluting wrecks date to the Second World War, this is as a result of the increase in shipping during this period, and due to naval warfare, and anti-shipping devices such as sea mines being widespread. Many of the wrecks from this period contain unexploded ordnance (UXO) or explosive remnants of war (ERW) which pose a contamination or polluting threat. For ease of understanding the term ERW will be used henceforth as this is an overarching term that includes fused munitions that were deployed but failed to function as intended (referred to as UXO), munitions that were fused but never fired (e.g. weapons stored or transported as part of armouries on board a vessel), or munitions that were unfused (e.g. in order to be disposed of at sea). ERW pose different levels of hazard depending on their component parts, manufacturing methodology and treatment prior to disposal or as a result of wrecking. ERW not only poses a threat to human life and ships if detonated (Hollyer, 1959; Keil, 1961; Vendhan, 2003; Okun, 2012; Szturomski, 2015), they also pose a threat to marine mammals and sea life which are affected by the impact and noise generated during a detonation (Young and Naval Surface Warfare Center, 1991; Joint Nature Conservation Committee (JNCC) UK, 2010; Danil *et al.*, 2011; Koschinski, 2011). ERW may also contain chemicals which can be toxic to the environment and to human health, in the form of chemical weaponry such as mustard gas and phosphorus (both persistent in the marine environment (Christensen, Storgaard, Hansen, Baatrup and Sanderson, 2016; Greenberg, Sexton and Vearrier, 2016), Adamsite or Lewisite (arsenic containing compounds which pose a bio-accumulation threat (Greenberg, Sexton and Vearrier, 2016)), or thanks to the explosive material itself (e.g. trinitrotoluene (TNT) or cyclotrimethylenetrinitramine (RDX)) which are highly toxic to fish (Craig and Taylor, 2011; Koide, Silva and Dupra, 2016; Chatterjee *et al.*, 2017).

The most well-known ERW containing shipwreck within UK waters is the SS *Richard Montgomery*, a US Liberty ship that grounded on a Sandbank off Sheerness in the Thames Estuary on the 20th August 1944 whilst waiting to join a convoy across the English Channel. The ship was being utilised as a munitions transport vessel and contained in the region of 7000 tons of munitions at the time of sinking (Wyse and Leary, 2016). Approximately half of the cargo was salvaged before the wreck was fully submerged, leaving an estimated 1,400 tons of munitions remaining within the wreck (Maritime & Coastguard Agency, no date). Given the hazardous nature of the wreck, and its potential threat to towns in the region, it is designated under the Protection of Wrecks Act 1973 which includes an exclusion zone around the site, and the condition of the wreck is monitored every year through surveys of the hull.

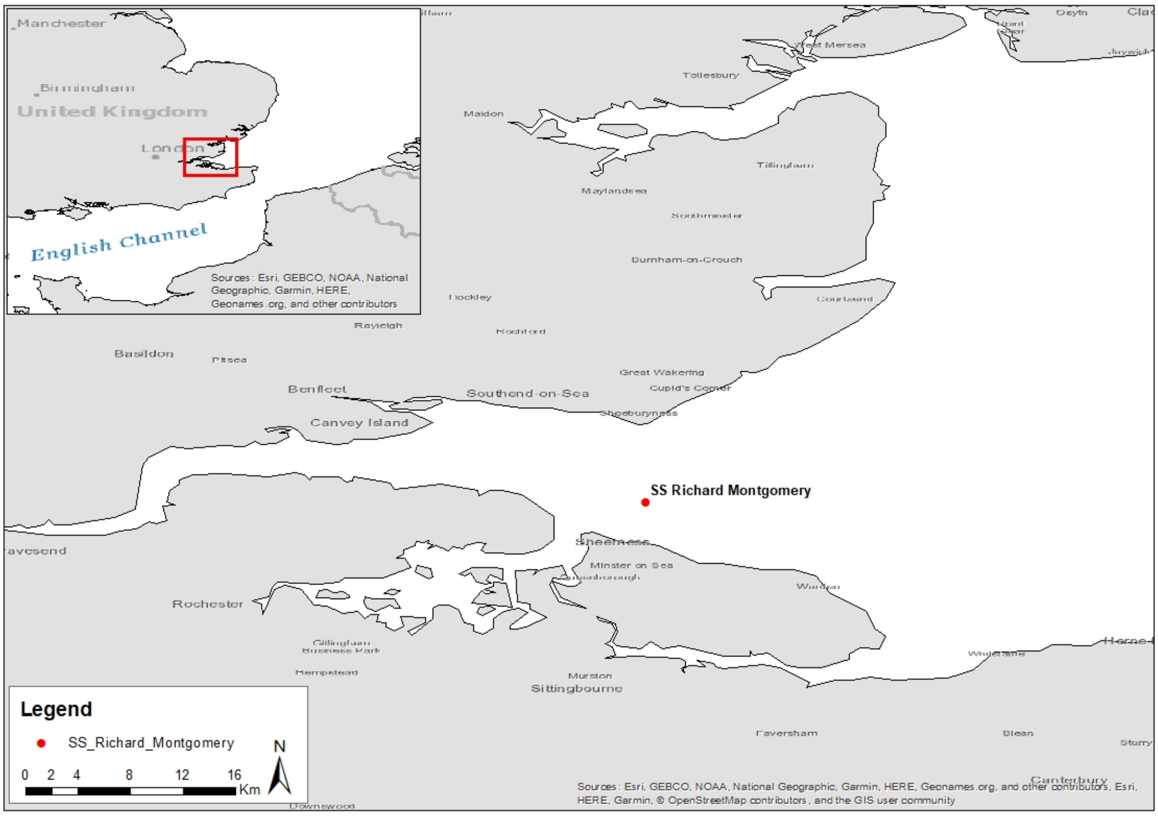

Figure 10 Location of the SS *Richard Montgomery* (author's own image).

Figure 11 Site of the *SS Richard Montgomery* (image Maritime and Coastguard Agency, Open Government Licence)

In addition to wrecks such as the SS *Richard Montgomery*, there are a number of munitions dumping sites located around the UK. At the end of WWII there was a surplus of munitions in the UK that needed to be disposed of and dumping these at sea was the most practicable method at the time. Disposal of chemical weapons by scuttling ships containing these munitions was undertaken in the UK's Atlantic waters between 1945 and 1956. In a four phase process chemical weapons sealed in containers were loaded onto 24 ships which were then scuttled at water depths of 500 to 4,200m (Bowles, 1976; OSPAR, 2005) (see also section 5.3.6.3). Records of the dumping phases is variable although it is estimated that 120,000 tons of mustard and phosgene munitions were disposed of during this time. During Operation Sandcastle (Phase 3) undertaken between 1955 and 1956 14,000 tons of Tabun munitions, 300 tons of arsenical compounds and 3 tons of toxic seed dressings were disposed of in this manner on board the *Empire Claire*, the *Vogtland* and the *Krotka* at a depth of approximately 2,500m (Bowles, 1976). Interestingly Bowles (1976) writing for the MoD states that,

> "…at the depths where the ships were scuttled, seawater movement is very slow. Any chemicals released at these depths would not present a health hazard."(Bowles 1976 p3).

Recently, mustard gas has been found to be leaking from munitions dump sites in the Belgian North Sea (Crisp, 2019). New research has also identified the environmental impacts of, and recorded increased encounters with, chemical munitions in the Baltic (Szarejko and Namieśnik, 2009; Christensen, Storgaard, Hansen, Baatrup, Sanderson, *et al.*, 2016; Greenberg, Sexton and Vearrier, 2016; Czub *et al.*, 2017; Gordon *et al.*, 2018). As a result, there has been a growing awareness of the issue of chemical munitions and their potential environmental impact more widely. The UK is therefore likely to find itself (and indeed already is to some extent) in a position where questions regarding these chemical weapon laden shipwrecks are being asked, and will need to examine their potential environmental impact. With increasing development of the seabed and ever increasing technological advancement, the depths at which these munitions were considered to be unproblematic are now being accessed more frequently. It is therefore no longer sufficient to believe that munitions at great depths pose little to no human or ecological health hazards.

Attempts have been made to try and determine the level of threat and the likelihood of an explosive event involving a shipwreck containing munitions, with the majority of this work focusing on the SS *Richard Montgomery* (Wyse and Leary, 2016) however, as with most ERW related assessments there are significant variables that mean accurate prediction is near impossible. Whilst suspected spontaneous detonation of ERW in the marine environment has been recorded in the UK's Beaufort's Dyke munitions dumping site (located in the Irish Sea) by the British Geological Society's seismic sensors (Ford, Ottemöller and Baptie, 2005), no explosions of this kind have been recorded elsewhere and none have been recorded relating to explosions of ERW within shipwrecks. It is estimated that a million tons of conventional (non-chemical) munitions were dumped in Beaufort's Dyke by the UK military between 1945 and 1973 (Bowles, 1976). Given the sheer quantity of explosive material located within Beaufort's Dyke these “spontaneous” explosions account for a very low percentage of the overarching volume of ERW. In addition there is no recorded information of any external influences such as fishing activity or pipeline installation which might have caused ERW to detonate; the data has only been inferred from seismic records. Therefore, while it is possible, it remains unlikely that UXO will spontaneously detonate in the marine environment and while the wrecks containing UXO are structurally sound and subject to no outside interference there should be minimal risk of an ERW related incident. The current best practice is to leave such wrecks in situ and maintain a monitoring programme. Removal of ERW from shipwrecks or shipwrecks containing ERW is likely to be more dangerous and more environmentally damaging than simply leaving it in place (Beddington and Kinloch, 2005; OSPAR, 2005). There is some debate as to whether this is a suitable strategy in the long term, particularly as it is essentially a bet between whether a shipwreck will degrade faster or slower than its contents of ERW. However, to fully explore the implications and arguments associated with this would be the work of an entire thesis in itself, and is therefore beyond the scope of this work. Suffice to say that ERW is a potential pollutant and must be taken into account when assessing potentially polluting wrecks, particularly in relation to naval shipwrecks and those sunk during both World Wars. Potentially polluting wrecks with an ERW threat in UK waters are further discussed at section 5.3.6.3.

2.2 Legal Requirements & Responsibility

The *Torrey Canyon* and subsequent oil spills resulting from tanker accidents (such as the *Amoco Cadiz* in 1978 (O’Sullivan, 1978), the *Sea Empress* in 1996 (Law and Kelly, 2004), the MV *Erika* in 1999 (Bordenave *et al.*, 2004) and the MV *Prestige* in 2002 (Mairal, 2016)) identified a need for changes to international environmental and shipping legislation. Greater emphasis was placed upon preventing environmental damage during salvage and laws were introduced or amended to enable coastal states to intervene should the interests of their state be affected by a polluting incident, or to prevent these polluting incidents from occurring in the first place. However, the majority of these environmental laws were not explicitly designed to be retrospectively applied to historic shipwrecks (Faure and Hui, 2003; Dromgoole and Forrest, 2008; Dromgoole, 2013).

In addition to the difficulty in applying modern polluting laws, there are a number of issues surrounding the application of other modern laws to legacy polluting shipwrecks. These include inter alia; determining ownership of legacy vessels and the problem of abandonment (Roach, 1996; Bederman, 2000; Vadi, 2013; Triay, 2014; Rachmana, 2015), determining who is liable for legacy polluting vessels (Jacobsson, 2007; Liddell, 2014; Isfarin and Triatmodjo, 2015; Stroo, 2016), the use of salvage law in the remediation of legacy shipwrecks and the conflict between salvage and heritage laws (Wilder, 2000; Bowman, 2004; Doran, 2012; Dromgoole, 2013), the application of sovereign immunity to polluting state vessels (Dehner, 1995; Bederman, 2000; Harris, 2008; Spielman, 2009; Coker, 2014), and jurisdictional and enforcement rights between flag and coastal states.

To date the only research into the liability from legacy shipwreck in the UK has been that undertaken by Liddell (2014). It is therefore necessary to not only determine what constitutes a polluting shipwreck but also to draw out the legal regime surrounding polluting shipwrecks within the UK. Understanding the relevant laws that apply to potentially polluting legacy shipwrecks and their various pitfalls is key to management and mitigation of these wrecks. The ability and the impetus for relevant parties to remediate a wreck is dependent on their legal requirement and jurisdiction to do so. There are some key questions that currently remain unanswered:

1. Is there a legal definition of pollution from wreck?
2. Is there a requirement to remediate polluting wrecks?
3. Who is responsible for remediating polluting wrecks?

In order to answer these questions a full review of admiralty, environmental and heritage legislation relating to wreck was undertaken as part of this research. Chapter 3 presents the analysis of that legislation and identifies those pieces of legislation that relate to determination of what a polluting wreck is, to the requirements to remediate wreck, to liability for pollution from wreck and to management of wreck.

2.3 Quantification

It is clear that there is a potential threat from potentially polluting wrecks globally. Consequently, several studies have attempted to determine how many wrecks there might be globally that could be a source of pollution. Michel et al (2005) estimated that there were 8,569 polluting vessels globally. The database of vessels that was used to determine this number was derived from numerous sources including both the Atlantic, Mediterranean & Indian Ocean (AMIO) and Secretariat of the Pacific Regional Environment Programme (SPREP) polluting wreck databases. It is likely, however, that this number is greater in reality due in part to the fact that they only included wrecks that had oil pollution, and due to the nature of shipwreck databases and conflicts between sources (further discussed at Chapter 3). Several countries have begun looking at the number of polluting wrecks within their state waters and there have been regional partnerships between the French and Italians (Development of European guidelines for Potentially Polluting shipwrecks (DEEPP) - (Alcaro *et al.*, 2007)) and countries in the Pacific (SPREP - (Gilbert and Nawadra, 2003; Monfils, Gilbert and Nawadra, 2006)) to quantify the number of wrecks in their regional waters.

A review of this literature identified the polluting shipwreck numbers shown in Table 3, this shows that there are additional wrecks that are not included in Michel et al.'s database, most notably in Greece, Norway and Sweden. With no oversight of Michel et al.'s database it is impossible to update the shipwreck numbers to make a revised estimate of the global number of potentially polluting wrecks as we cannot determine what wreck information has been included from what country. The database contains information on tank vessels of greater than 150 GT and non-tank vessels of greater than 400GT. As Michel et al. acknowledge, there are a vast number of smaller vessels that might have a localised pollution potential that are therefore not included within this database.

As part of this thesis an attempt was made to identify and quantify the number of potentially polluting wrecks globally through analysis of existing shipwreck databases, review of previous quantification work undertaken by other parties and nations, and through requests for shipwreck information from other nations. Not all states have conducted research into the problem of polluting wrecks, and some states have, for various reasons, been reluctant to publish the results of their research, or to provide shipwreck information to this project. Requests for wreck information to various national bodies with responsibility for maintaining national databases were unanswered. Table 3 therefore presents a partial view of the number of shipwrecks globally based on information gathered from various papers, presentations and reports.

The largest database of global shipwrecks is held by wrecksite.eu (*Wrecksite*, no date) and features 185,950 wrecks across the globe using data obtained from national hydrographic offices. Wrecksite is a commercial site primarily aimed at wreck diving and historical enthusiasts. Given the commercial nature of the database, it was not possible to obtain a copy of their database. Even had this been possible a significant amount of additional work would have been required to conduct further archival research to identify and pull out additional information relating to these shipwrecks in order to determine their polluting potential, all of which would require more time than a three year PhD could allow. There is a real and pressing need for a non-commercial global database of shipwrecks, even one that holds basic information such as shipwreck name, location and date of sinking and which could be used for research and policy purposes to quantify the global threat from polluting shipwrecks and for a host of other archaeological and historical research.

As others have found, at present it is only really possible to understand these shipwrecks at a national level where the resolution of environmental, economic, social and shipwreck datasets is usually suitable and the datasets are available (Church and Warren, 2008; Masetti and Calder, 2014; Landquist *et al.*, 2016; Ventikos *et al.*, 2016). As a result it was deemed that a global assessment of potentially polluting wrecks was technically unfeasible and the decision was made to reduce the scope of the research to a more focused study of UK based shipwrecks.

There is no publicly published work detailing the number of potentially polluting wrecks in UK waters, however, some research into the potential numbers has been undertaken by the UK government. The MoD kindly provided a copy of the current research that has been conducted by the UK government and a full analysis, review and refining of the quantification of UK potentially polluting wrecks was undertaken as part of this thesis and is discussed in Chapter 4.

Table 3 Numbers of Potentially Polluting Shipwrecks Globally

No of PPWs	**Scope/Scale**	**Reference**	**Tonnage**	**Pollution**
8569	Global	Combined output of various databases & sources of information (Michel *et al.*, 2005b).	Non-tankers 400GT <, Tankers 150GT.	
3854	Pacific & East Asia	SPREP database (Monfils, 2005; Monfils, Gilbert and Nawadra, 2006)	Non-tankers 400GT <, Tankers 150GT	Oil, Chemicals, Munitions.
3950	Atlantic, Mediterranean & Indian Ocean	AMIO Database (Monfils, 2005)	>1000GT	Oil, Chemicals, Munitions.
573 (607 in AMIO)	USA Waters	RULET Database (derived from RUST database) (Symons *et al.*, 2014)		Oil
432	France & Italy	DEEPP Project (Alcaro *et al.*, 2007)	All Vessels	
402 (142 in AMIO)	Greece	(Ventikos *et al.*, 2013)		Oil
280	Iraq	(Kamm, 2014).	Unknown	Oil, Chemicals, Munitions.
221	Danish EEZ (excl. Faroe & Greenland)	Danish Wreck Register (Rytkönen, 2019)		

No of PPWs	Scope/Scale	Reference	Tonnage	Pollution
380 (305 in AMIO)	Norway	Wreck Program (1990's) (Rytkönen, 2019)		
347 (106 in AMIO)	Sweden	Miljorsisker Fran Fartygsvrak 2011 (Rytkönen, 2019)	Unknown	Unknown
14	Estonia	Estonian Wreck register (Rytkönen, 2019)		Oil
114	Finland	Finnish Wreck Website Hylyt.net (Pohjale Ry, 2015) & SWERA (Svensson, 2010)	Unknown	Oil

2.4 Risk Assessment

As a result of the call to develop a pro-active approach to polluting wrecks several studies have been undertaken which attempt to risk assess polluting vessels. Risk assessments are designed to help us make sense of the uncertainties posed by a certain action, activity or situation by defining the probability of a likely outcome occurring and the consequences of that outcome. They are used in business and by governments to aid in decision making around how to prevent, minimise or mitigate against unwanted outcomes.

Historically, risk management decisions were based on common sense, knowledge, and trial and error (Covello and Mumpower, 1985, p. 116). However, the study of risk theory and management emerged as a scientific field in the late 1970's (Aven, 2016). This new scientific field generated highly technical quantitative methods for assessing risks. As a result, society and governments moved from reactive risk management to a planned and forecasted risk management process and public expectation is now that risks will be identified, analysed and mitigated against pro-actively rather than re-actively.

> "This change in perspective implies that something *can* be done about most risks. Paralleling this is a change in perspective implying that something *should* be done- derived in part from changing ideas about the rights of individuals to live their lives free of risks imposed on them by others and about the role of government in protecting individuals from such risks" Covello and Mumpower, 1985, p. 118

This expectation that risks will be managed by the government or by others with the relevant responsibility results in policy development based on risk assessments to ensure that risks are appropriately managed.

There are different perspectives on risk and this usually depends on the area within which you are working, e.g. statistics/policy/social sciences etc. Riesch (2013, p35) states that there are a number of different questions we could ask about risk, namely:

- Why are we uncertain?
- Who is uncertain?
- What is the effect of the uncertainty/risk?
- How is/should it be represented?
- What are we uncertain about?

In the context of potentially polluting wrecks many of the above are applicable. As previously discussed we are uncertain about the risk from potentially polluting wrecks because we do not know how many wrecks might pose a potential risk. Despite previous attempts to understand the risks from potentially polluting wrecks we remain uncertain about the likelihood and prospective impact of pollution from wrecks. This uncertainty arises from a lack of reliable data, lack of wider research and the nature of the marine environment. We are uncertain if there is a legal requirement to remediate them, if they contain pollutants, when or if they are likely to pollute, and what their potential environmental and social impact might be. The effect is that we also therefore remain uncertain about how to manage them.

Risk assessment is an attempt to define uncertainty through probability, however, there are some uncertainties that can be assessed quantitatively, some qualitatively, and some we cannot evaluate (Riesch, 2013). Philosophy of risk has focused on two main interpretations of probability; aleatoric or ontological probability which relates to uncertainty in the system, and epistemic probability which is uncertainty arising from incomplete knowledge (Gillies, 2000; Riesch, 2013).

In relation to potentially polluting wrecks, epistemic uncertainties might be not knowing the location of the wreck, not knowing its condition or what cargo it was carrying. While aleatoric uncertainties are those one off chance events that might cause pollutant release such as storms or collisions with other vessels, or the way in which the marine environment uniquely interacts with each wreck to cause corrosion and release of pollutants. Determining the risk posed by polluting shipwrecks is therefore complicated by the various unquantifiable and variable factors that need to be fed into the risk assessment process.

Initial risk assessments for potentially polluting wrecks (Michel *et al.*, 2005b; Monfils, Gilbert and Nawadra, 2006) were based around the concept of Risk being the Probability of an event occurring (pollutant release from wreck), and the prospective impact of that event (Consequence):

R = P x C

This methodology is commonly used in risk assessment however, determining probability and impact can be problematic and relies on expert elicitation. This rather simplistic method for determining risk does not take into account the various uncertainties associated with knowing when or how a wreck is likely to pollute, the condition of the wreck etc. Nor does it allow for a level of confidence to be ascribed to the resulting assessment.

Others have built on this to use Bayesian methodologies for assessing the risk (Montewka et al. 2013; Overfield & Symons 2009; Symons *et al.*, 2014), however, the Bayesian approach does not take into account where probabilities are partially or wholly unknown. Bayesian models are aimed at addressing epistemic probability as they allow for uncertainty in the system but do not allow for uncertainties arising from lack of knowledge.

Researchers in Sweden have since developed a probabilistic risk assessment method (known as VRAKA) (Landquist *et al.*, 2013, 2014, 2016; Landquist, 2016) using fault tree models in order to determine the probability of oil release from vessels. This builds on the Bayesian approaches but aims to reduce some of the uncertainties. It should be noted that the VRAKA risk assessment has been adopted by various Baltic States, as well as the Interreg DAIMON (Decision Aid for Marine Munitions) and North Sea Wrecks projects (*North Sea Wrecks*, no date; Tengberg *et al.*, 2017; Maarten *et al.*, 2019) as being the current best practice assessment. However, the risk assessment is likely to be time consuming and expensive when applied to individual shipwrecks.

Work undertaken on Greek shipwrecks (Ventikos *et al.*, 2013, 2016) identified that the use of fault tree models is potentially problematic in determining the probability and risk assessment of polluting wrecks as it does not take into account various aleatoric or epistemic uncertainties associated with pollutant release. Instead Ventikos et al. propose the use of fuzzy logic in determining the risk associated with polluting wrecks as this allows for these uncertainties to be included in the assessment process without skewing the results. While their assessment did produce interesting results and accounted for uncertainties within the process, they mainly focused on assessment of individual shipwrecks rather than aggregated shipwrecks, meaning that there was sufficient data to assess those specific wrecks appropriately. Additionally the process was entirely theoretical and not “ground truthed” against any existing survey data.

The issue with the use of fault tree models was also confirmed in a study undertaken on the SS *Richard Montgomery* by Wyse & Leary (2016), who utilised a similar fault tree methodology, where “despite attempts to quantify the event probabilities themselves there was insufficient information to do so with any reasonable degree of accuracy…for many of the 170 individual events described by the bow-tie diagrams and fault trees, no probability assessment could be made" (Wyse and Leary, 2016). The original work undertaken in the USA by Overfield and Symons (2009) also used a fuzzy method for risk assessing these wrecks, although this is not expressly stated in their methodology. More recently Alexander (2019) has stated that owing to the various aleatoric and epistemic uncertainties associated with the SS *Richard Montgomery*, that "proper risk analysis is well-nigh impossible". It is therefore likely that this also applies to potentially polluting wrecks more widely.

Various work has been undertaken which tries to reduce some of the epistemic uncertainties associated with potentially polluting wrecks, for example, attempts have been made to quantify the amount of oil likely to be found within shipwrecks (M. Overfield, 2005; Monfils, 2005; Overfield and Symons, 2009) however, it is incredibly difficult to accurately determine the amount of remaining oil on a vessel prior to undertaking invasive investigation. Therefore determining the scope of oil leaking from a specific wreck and its impact on the environment (which includes *inter alia* the quantity of oil) is harder, as is estimating the relative cost vs benefit of having to remove oil of an unknown quantity.

Efforts have also been made to understand when a wreck might break down and cause pollution through examining the corrosion rates of vessels, with studies conducted on various shipwrecks in different environments (M. L. Overfield, 2005; Medlin *et al.*, 2014; Moore, 2015; Macleod, 2016). Significant work has been produced monitoring and examining the corrosion of the wreck of the *USS Arizona,* at Pearl Harbor, in particular (Storlazzi *et al.*, 2004, 2005; Wilson, Carr and Murphy, 2006; Wilson *et al.*, 2007; Johnson *et al.*, 2014). From these various studies it is understood that while it is possible to determine the corrosion regime for an individual shipwreck, the values and rates do not transfer to other shipwrecks as the conditions involved in shipwreck corrosion vary greatly and are dependent on factors such as water depth, location, ship construction and orientation, the types of biological life that the wreck supports (Moore, 2015). Thus there is no universal rule to determine which shipwrecks are likely to degrade first, and this information cannot be fed into the risk assessment process to determine their level of risk based on their condition. The majority of the risk assessments undertaken simply assume the worst case scenario, under the precautionary principle, that all of these ships have the same potential to pollute in terms of their condition.

Other studies have attempted to improve our knowledge of the environmental impacts (Rogowska, Wolska and Namieśnik, 2010; Henkel *et al.*, 2014; Faksness *et al.*, 2015; Birkhead, 2016; Ndungu *et al.*, 2017; Renzi *et al.*, 2017) and economic impacts (Montewka et al. 2013; Overfield & Symons 2009; Michel, et al. 2005) of polluting shipwrecks, as well as oil spill modelling

(Comité Maritime International, 1994; Gilbert and Nawadra, 2003; Bergstrøm, 2014). While other focus on the technological solutions for oil removal and clean-up (Macleod, 2002, 2016; M. L. Overfield, 2005; Russell *et al.*, 2006; Wilson, Carr and Murphy, 2006; Wilson *et al.*, 2007; McNamara *et al.*, 2009; Johnson *et al.*, 2014; Traverso and Canepa, 2014).

In the UK some work has been undertaken by the MoD to identify the potentially polluting wrecks for which they are responsible both within UK waters and abroad (Dellino-Musgrave & Merritt 2011), however, little has been published. Monfils (2005) and the SPREP project identified that the UK government was likely to be responsible for 51% of WWII potentially polluting wrecks, the number of wrecks the UK may have to manage and remediate is therefore significant when including wrecks from prior and post-WWII. In light of the UK's potential responsibility for these wrecks UK government departments, including the MoD's Salvage and Marine Operations group (SALMO), have commissioned desk based research and a series of risk assessments to determine the number of potentially polluting wrecks for UK flagged vessels and vessels in UK waters, and their prospective risk. The UK risk assessments have been developed independently from those undertaken above and there are various issues associated with uncertainties in the models. These include:

- Unknown location of wrecks
- Unknown quantities of pollutants
- Unknown condition of wrecks
- Unknown timeline of structural collapse leading to pollution
- Unknown economic impact of a pollution event
- Unknown social impact of a pollution event
- Unknown environmental impact of a pollution event

It is the aim of this thesis to examine whether it is possible to adequately risk assess potentially polluting wrecks in UK waters with the available data, whether there are epistemic uncertainties that can be reduced to produce better risk assessments, and whether any risk assessment is suitable for informing ongoing management decisions in respect of wreck or if the aleatoric uncertainties render such risk assessments futile. An in-depth discussion of the UK risk assessments and an analysis of the shipwreck databases associated with each assessment is presented in further detail at Chapter 4.

2.5 Sociology of Risk

Over time there has developed an understanding that many of the factors that influence risk assessments and thus resulting management decisions are considered through value based assumptions rather than scientific facts alone (Hansson, 2012). As a result there are now three broad approaches to risk, the scientific approach that deals with statistical and probabilistic methods for measuring and understanding risk (discussed above), the psychological approach which examines peoples beliefs and perceptions of risks and is focused on how the individual responds to risk, finally there is the cultural approach which understands how such beliefs and perceptions are influenced by social and cultural factors (Moller, 2012).

Public perception of risk in areas where they have little knowledge of the risk is found to be driven by their trust in the risk manager rather than the risk of the event itself (Huijts, Midden and Meijnders, 2007). Keller *et al.* (2012) identify that trust in a risk manager is driven by three factors, whether the risk managers shared the public's values, whether they were perceived to be competent and whether they were open and honest with the public (p6). It is therefore beholden on those managing risk to ensure that they are perceived as competent, and that they communicate effectively and openly with the public regarding risk management and mitigation.

There is also significant evidence to show that emotions determine a person's risk decision making and perception of risk which can be influenced by number of factors including how they perceive the fairness of mitigation measures and where responsibility for management of the risk lies (Keller *et al.*, 2012; Finucane, 2013). External narratives such as news and media stories also impact on a person's risk perception, and drive emotional responses to risk tolerance and acceptability as well as decisions people make regarding their own safety, with strong emotional triggers resulting in people ignoring both the probability and magnitude of a potentially risky event (Finucane, 2013).

Evidence and experience gained from existing mitigation and management of polluting shipwrecks show that it is often social and political interests in shipwrecks that have the greatest impact on the management strategies for dealing with such shipwrecks (MacLeod, 2008; Moshenska, 2010; Forrest, 2012; Travers, 2015). Despite this, few of the existing risk assessments or proposed methods take into account social and political factors that, while not directly contributing to oil release from a polluting vessel, will affect the strategy of mitigation that results from the risk assessment.

None of the risk assessment work around potentially polluting wrecks has examined stakeholder risk tolerance and perceptions of risk. Understanding the perceptions and risk appetite of the stakeholders involved in polluting shipwrecks is key to understanding what mitigation strategy is appropriate in terms of social acceptability, even where scientific understanding might suggest a specific route to remediation.

The way in which stakeholder involvement might affect how a polluting shipwreck is managed might include pressure by local communities or the wider public to mitigate shipwrecks that are not considered to be a priority in the results of the technical risk assessment. In some areas local identities are strongly tied to the shipwrecks and therefore these communities are likely to want to be involved in the consultation process and ongoing management of the wreck, as evidenced in Orcadian identity formation involving the wreck of HMS *Royal Oak* (Travers, 2015). Other factors include polluting shipwrecks as underwater memorials or 'war graves', dictating how the shipwreck is managed, an example of this is the ongoing management of the USS *Arizona*.

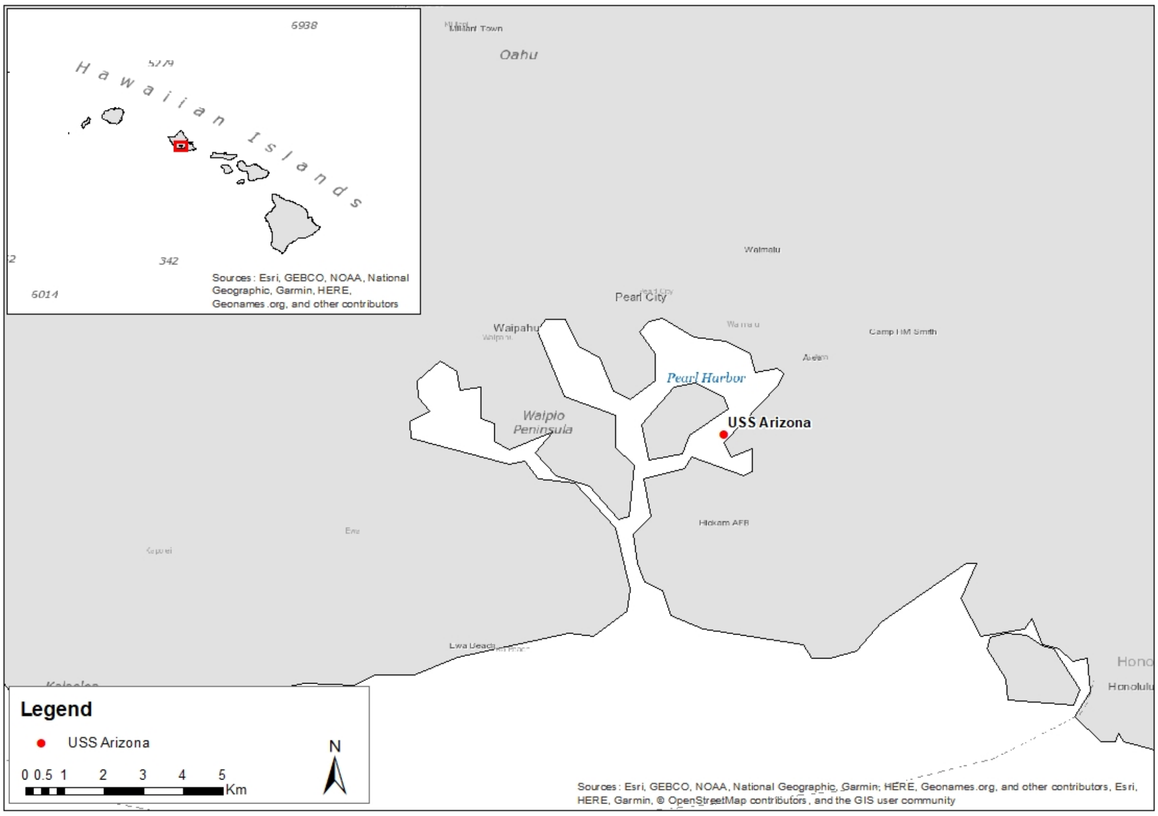

Figure 12 Location of the USS *Arizona* (author's own image).

The USS *Arizona*, sunk during the Japanese attack on Pearl Harbor in 1941, is leaking approximately nine litres of oil a day, however, the oil bunkers of the USS *Arizona* are currently buried beneath the sediment and it would therefore be extremely difficult to access to remove the oil remaining on board without compromising the structure of the wreck (Wilson *et al.*, 2007). The vessel was designated a war memorial and those who served aboard the vessel are permitted to have their ashes interred in the wreck on their death (Delgado, 1992). Due to its status as a monument and gravesite the relatively small amount of oil emitted daily is considered to be an acceptable level of contamination to the surrounding environment, supported by the difficulty in safely remediating the wreck in light of the potential social and political issues that might arise if the wreck were to be damaged during the remediation process (MacLeod, 2008). The National Park authorities that are responsible for managing the wreck are now faced with the ongoing degradation of the wreck and are looking at methods to halt or at least decrease the rate of corrosion in order to preserve the wreck and its status as a national monument for as long as possible (Russell and Murphy, 2010).

Figure 13 Remains of the USS *Arizona*.(Image by slworking2 is licensed under CC BY-NC-SA 2.0).

In light of the above it is clear that whilst the technical aspects are clearly important, if they are not considered in the context of the wider social and political environment then the management and mitigation strategies that result from these assessments are likely to be unsuccessful, have limited application or require revision once social and political demands are experienced. Recent developments in risk management involving the use of game theory attempt to address the issue of multiple stakeholder perceptions (Rass and Schauer, no date; Hausken, 2002; Rajbhandari and Snekkenes, 2011), however, to date these have not been used in conjunction with potentially polluting wreck risk assessments. In order to look at whether this might be applicable we first need an understanding of the stakeholders with an interest in UK wrecks. In order to address this imbalance an analysis of various UK stakeholders and their interest in wreck is presented at Chapter 5 and this includes a discussion of how changes in public interest over time may affect shipwreck management strategies.

2.6 Cost Benefit Analysis

Cost benefit analysis (CBA) has traditionally formed part of risk management decision making (Arler 2006). CBA informs decision making by assessing whether undertaking a certain project or action will result in a net benefit (Olson and Wu, 2020). Cost benefit analysis stems from business risk management and is based on determining the financial cost and benefit of decisions through determination of the market value of the effects of the decision. The methodology has been more widely adopted and is now used to assess the impact of environmental and public policy decisions, which are assessed by monetising and quantifying potential effects of a decision on society (Groeneveld, 2020). Most recently this has become an inherent part of ecosystem service assessments for the management of the marine environment (Ferreira, Marques and Seixas, 2017).

In relation to polluting wrecks, CBA can help us determine if one mitigation strategy is likely to be more beneficial than another. Particularly where there is a financial cost that can be calculated in relation to undertaking or not undertaking remediation. In many of the risk assessments that have previously been undertaken the cost benefit of remediating a wreck has been calculated by determining the cost of environmental pollution clean-up vs. the cost of oil removal methods. The estimated economic cost of wreck remediation can be difficult to determine as it depends on environmental conditions at the wreck, condition of the wreck, quantity and type of pollutant, location of the wreck, available resources, logistics etc. (Etkin, 1999). However, Matt Skelhorn of the MoD SALMO has kindly provided details and figures for research he has undertaken into the estimated, or completed remediation costs for specific British wrecks.

At present the MoD have remediated two wrecks, the RFA *Darkdale* and HMS *Royal Oak*. The oil from RFA *Darkdale* in St Helena was removed in 2015 at a cost of around £7.5 million. While the oil remediation operation on the wreck itself was relatively simple, the remote location of the wreck resulted in relatively high remediation costs due to logistical considerations. HMS *Royal Oak* (discussed previously at section 2.1.1) is an ongoing project, with current estimates for the oil removal work (which started in 2000) standing at approximately £4 million. While the location and access to the wreck is operationally simple, the fact that the wreck is protected under the Protection of Military Remains Act 1986, and the complex arrangement of oil tanks within the wrecks means that remediation of the wreck has spanned several years and is likely to span several more. Estimates for remediation work to HMS *Prince of Wales* and HMS *Repulse* in the Java Sea were around £20 million to remediate both wrecks. However, both wrecks were illegally salvaged prior to any remediation work being possible, resulting in little oil remaining within the wrecks (further discussed at section 5.4.1). The RFA *War Mehtar* off East Anglia was estimated at a remediation cost of £10 million, due in part to the depth of the wreck, however, it was discerned that very little oil remains on the wreck so remediation was not required (Skelhorn 2019. pers. comm. 13 August).

Skelhorn also compiled estimates of the costs of clean up and compensation for oil polluting wrecks in the event of an oil leak, using data from remediated wrecks, building upon work conducted by Etkin (1999), and using the compensation costs paid out under the International Oil Pollution Compensation funds since 1999 (IOPC Funds, 2019), these funds are further discussed in the next chapter.

Skelhorn's research shows that the costs of pre-emptive remediation are significantly less than the costs that might be expected if a leak from legacy wreck occurs (Table 4). Therefore at face value the cost-benefit analysis in this case would support pro-active remediation or polluting wrecks, rather than waiting for a wreck to leak and then remediating it. However, this is purely a financial assessment, and does not take into account other impact factors.

Therefore while CBA is undoubtedly has a place in supporting decision making, it should be used as one tool among many as market valuations are not the only influence on decision making (Arler, 2006). Rarely are the more qualitative impacts of wreck pollution considered. These all require a certain amount of specialist judgement and are not necessarily financially quantifiable. CBA is problematic where there are factors that need to be assessed socially that do not have a market value (e.g. loss of habitat, loss of heritage, loss of life, loss of amenities), economic values are instead assigned in a number of different ways such as "willingness to pay" for certain amenities (Georgiou *et al.*, 1998). In assigning a monetary value to objects not normally traded on the market we are arbitrarily determining their value (Arler 2006). Assigning value to environmental resources that might be finite or unique is also problematic, particularly as we cannot know what importance or relative value will be assigned to these resources in the future (Hartzell-Nichols, 2012; Groeneveld, 2020). CBA also cannot assess conflicting stakeholder values or the impact of political influences on the decision-making process.

Table 4 Wreck Oil Pollution Remediation Costs (reproduced with permission of M. Skelhorn)

Vessel Name	**Project Year**	**Type**	**Date Lost**	**Location**	**Depth (M)**	**Bunker Type**	**Oil Removed (Tonnes)**	**Total Cost Of Operation**	**Estimated Clean-up & Compensation Costs ***
USS *Mississinewa*	2003	Tanker	1944	Micronesia	22	HFO	5676	£7.5 Million	£66.6 Million
Cleveco	1995	Tank Barge	1942	Lake Erie	21	HFO	1095	£4.5 Million	£12.9 Million
Norvard	2007	Unknown	1944	Norway	30	HFO, Diesel	441	£4.0 Million	£5.2 Million
HMS *Bittern*	2011	Destroyer	1940	Norway	152	HFO	90	£0.5 Million	£1.1 Million
RFA *Boardale*	2012	Tanker	1940	Norway	67	HFO	204	£0.4 Million	£2.4 Million
KMS *Eric Giese*	2012	Destroyer	1940	Norway	66	HFO, Diesel	192	£1.3 Million	£2.3 Million
RFA *Darkdale*	2015	Tanker	1941	St Helena	45	Light Crude	1730	£7.3 Million	£20.3 Million

*Based on a global average clean up and compensation cost of £11,738 per tonne of oil spilled – derived from Etkin (2009)

2.7 Summary

It is clear that there is a significant threat from legacy wrecks that contain polluting materials, however, quantifying the number of these wrecks is fraught with difficulty due to the lack and poor resolution of global datasets that relate to wrecks. Quantification forms the basis for wider risk assessment which enable risk management decisions to be made. Many attempts have been made to risk assess polluting wrecks globally, however, most of these risk assessments are likely to be highly inaccurate due to the various epistemic and aleatoric uncertainties that exist in relation to potentially polluting wrecks.

These uncertainties include unknown quantities of wrecks, unknown wreck locations, unknown quantities or types of pollutant, unknown condition of wrecks, and unknown impacts of pollution from wreck. While studies have attempted to reduce some of these uncertainties, in many cases they are focused on specific wrecks rather than the wider “catalogue” of potentially polluting wrecks (Rogowska, Wolska and Namieśnik, 2010; Henkel *et al.*, 2014; Faksness *et al.*, 2015; Birkhead, 2016; Ndungu *et al.*, 2017; Renzi *et al.*, 2017; Ventikos *et al.*, 2013, 2016; Wyse and Leary, 2016). These assessments are therefore limited to the specific environmental conditions around those particular wrecks and relate to the availability of data within certain states.

To date there has been little published regarding whether there is a risk from potentially polluting wrecks in the UK, how many wrecks there might be, what is known about these wrecks and how they are managed. It is therefore the aim of this thesis to review the work that has been undertaken by the UK government to quantify these wrecks, to review the risk assessments that have been undertaken in the UK and to suggest areas where we might be able to improve on these risk assessments through use of wider socio-economic and bathymetric datasets to reduce some of the epistemic and aleatoric uncertainties outlined above. This work also aims to look into the various social and political aspects that might impact wreck management and what stakeholder risk tolerance might look like in the UK as this has not been widely considered in other risk studies of potentially polluting wrecks. This thesis will examine whether the UK’s existing management of potentially polluting wrecks is suitable, and what could be done to improve upon the current work in the context of the work undertaken elsewhere as previously outlined in this chapter.

In order to determine if a management strategy is suitable and effective it is firstly necessary to understand whether there is a legal definition of a polluting wreck, whether there is a requirement to remediate or manage these wrecks, and if so who is responsible for their management and remediation. Understanding these legal aspects feeds into any risk assessments or decision making processes, it should form the basis of any work moving forward however, the legal regime in the UK as it relates to potentially polluting wrecks has not previously been examined. The next chapter aims to address this gap in the research through full examination of the UK's legal regime in relation to potentially polluting wrecks.

Chapter 3 Legislation and Policy

As demonstrated in the previous chapter in the interests of managing polluting shipwrecks appropriately it is necessary to determine what the legal responsibility is for managing polluting shipwrecks as well as the capacity and willingness of the responsible party to act in the event of a polluting wreck incident. In order to ascertain what must be done there is a need to understand what constitutes a polluting wreck, what obligations there are to remediate wreck or the pollution emanating from wreck, and what liabilities are associated with pollution from legacy wreck. While the legal regime around modern polluting shipwrecks has been extensively studied both in relation to international and UK law, the legal regime relating to legacy wrecks in the UK has had limited examination. This chapter therefore presents the first comprehensive review of the situation in UK waters (territorial and EEZ).

Prior to the late 1960's/early 1970's there was little in the way of international or UK environmental legislation to protect the marine environment. As discussed in Chapter 2 a series of large tanker oil spills such as that of the *Torrey Canyon* resulted in the introduction of environmental legislation in the 1970's which was designed to prevent ship source pollutants from entering the marine environment. More recently there has been a greater focus on creating good environmental status (although there is no consensus yet on what a "good environmental status" actually looks like in practice (Lyons *et al.*, 2017)) within the marine environment, with the implementation of marine licencing and marine protected areas; as a result legislation has developed to protect specific habitats and wildlife from pollution resulting from all activities at sea and on land that pollute the sea. There are several pieces of legislation that are applied alongside shipping legislation to provide a certain level of environmental protection in the marine environment and which might apply to polluting shipwrecks, which will be discussed in this chapter. How this environmental and shipping legislation interacts with existing cultural heritage legislation, as well as issues relating to ownership rights to vessels, will also be examined in order to highlight some of the additional legal issues surrounding polluting shipwrecks.

This chapter makes reference to a number of EU directives and regulations as this research was largely conducted while the UK was still in the EU. The UK left the EU on the 31st January 2020, however, this does not significantly change this research as under the European Union (Withdrawal) Act 2018 existing EU laws on 31st December 2020 have been retained in UK legislation. Additionally, many of the EU laws discussed in this chapter have already been written into UK law, and this is noted in the text where relevant.

3.1 UK waters

There is significant legal complexity associated with wrecks located in international and other states waters and the sheer quantity of wrecks that would require assessment globally means that this thesis is centred on understanding the risk and legal framework for those wrecks that are located within the UK's EEZ and territorial sea only. In the legislation the definition of UK waters is usually that of the UK's Territorial Sea (described below), however, the definition of UK waters used more generally in this thesis is all waters up to and including the UK's counter pollution zone (which is also the UK's Exclusive Economic Zone) as this is the area in which the UK government is required to manage and remediate pollution events.

The UK's Territorial Sea as determined by Article 1 of the Territorial Sea Act 1987 extends up to 12 nautical miles (NM) from the baseline. The UK's Exclusive Economic Zone (EEZ) extends beyond the Territorial Sea up to 200NM from the same baseline as the territorial sea (as set out in Article 2 of the Exclusive Economic Zone Order 2013). Article 76(1) of Part VI of the United Nations Convention on the Law of the Sea 1982 (UNCLOS) states that "The continental shelf of a coastal State comprises the seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin" and Article 76(5) of Part VI of UNCLOS clarifies that the continental shelf of a coastal state "shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured", and the UK's continental shelf is specifically defined in Article 2 of the Continental Shelf (Designation of Areas) Order 2013. The limits of the UKs Territorial Sea, EEZ and Continental Shelf are depicted in Figure 14.

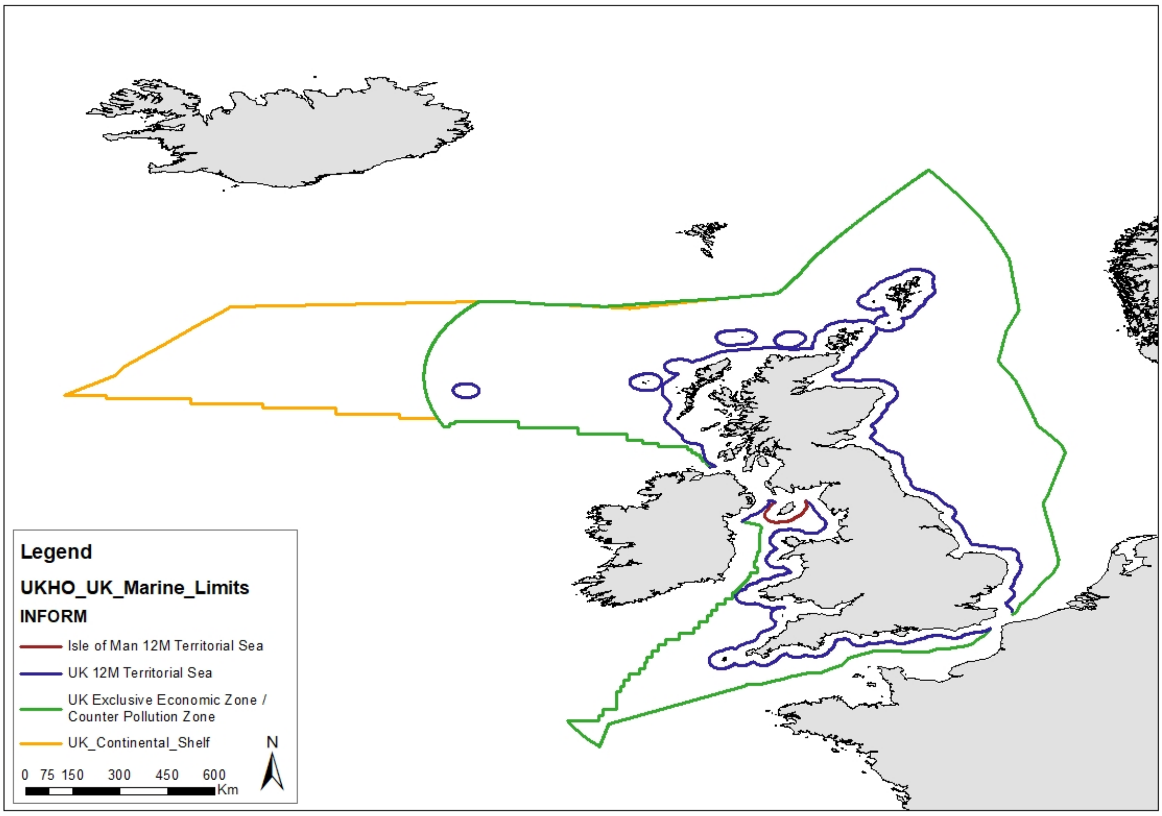

Figure 14 UK Marine Limits (author's own image).

3.2 What constitutes a polluting shipwreck?

3.2.1 Definition of pollution

Existing studies (discussed in Chapter 2) that explore the risks from polluting legacy shipwrecks are binary in that they consider a shipwreck to be polluting once there is evidence of contamination of any quantity, although action to remediate polluting has typically focused on wrecks with a high volume of oil or a high pollution risk. However, within environmental science the definition of pollutant is more nuanced, while all pollutants are contaminants, not all contaminants are necessarily pollutants (Chapman 2007). In this context, the term contaminant refers to a substance or item that, whilst not considered natural to the environment in which it is found, is low enough in concentration that it remains within the UK's regulatory limit for such a substance and therefore not considered to be polluting by law. In comparison, a pollutant is defined as a substance or item that is a contaminant which causes "adverse biological effects in the natural environment" (Chapman 2007) and also exceeds the concentrations within the environment that are permitted by law. We therefore need to understand the regulatory limits for oil pollution, heavy metals or any other contaminant that might be part of or emitted by a shipwreck to determine if the contamination resulting from the shipwreck has reached polluting levels before we can consider it to be a polluting shipwreck and whether it therefore warrants remediation.

There is no specific definition or concentration limit for what constitutes pollution in the marine environment in UK legislation. However, there is some international and European legislation that provides definitions for pollution within the marine environment and which we might use as a basis for discussions around pollution limits in the UK.

Art 1(1) (4) of UNCLOS gives us a definition of pollution within the marine environment as

> "the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities"

It is clear that legacy shipwrecks leaking significant quantities of oil, such as the USS *Mississinewa*, the SS *Jacob Luckenbach*, and HMS *Royal Oak*, are easily classed as polluting under this definition as they showed visible and measurable evidence that their cargoes were causing deleterious effects. However, neither this definition nor the directive itself provide us with values for how much oil (or other substances) is considered to have a deleterious effect and what counts as chronic or acute pollution. Additionally, we do not know if this applies to substances leaking from a single shipwreck as a polluting source or if it applies to a wider regional affect from aggregated shipwrecks. It is clear therefore that there is a need to determine exactly what constitutes a polluting shipwreck or group of shipwrecks.

At a regional level European environmental legislation relating to water policy and pollution provides additional definitions for pollution. Article 2(33) of the Council Directive 2000/60/EC establishing a framework for Community action in the field of water policy (EU Water Framework Directive), gives a definition for pollution as the

> “direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment.”

A similar definition for pollution is given in Article 2(2) of Council Directive 1996/61/EC concerning integrated pollution prevention and control and in Article 3(8) of Council Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Article 3(8) of the Marine Strategy Framework Directive expands on this definition by including pollution as being anything

> “which results or is likely to result in deleterious effects such as harm to living resources and marine ecosystems, including loss of biodiversity”

Article 3(29) of Regulation No 1107/2009 concerning the placing of plant protection products on the market determines that

> ‘biodiversity’ means variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this variability may include diversity within species, between species and of ecosystems;

In order to maintain biodiversity and to prevent substances from entering the water that might affect human health or various ecosystems, EU legislation identifying key anthropogenic substances that might cause harm in the environment and which require control, monitoring or prohibition were established, including; Decision No 2455/2001/EC establishing the list of priority substances in the field of water policy and amending Directive 2000-60-EC, Regulation No.1107/2009, and Regulation No.528/2012 making available on the market and use of biocidal products.

Annex X of Decision No 2455/2001/EC contains a list of substances that are considered to be priority substances and identifies which of these are also hazardous substances (See Appendix A). Many of these substances are likely to be found on or within shipwrecks, particularly lead, nickel and their compounds, however, the document does not provide limit values for these substances. The Council Directive 2006/113/EC on the quality required of shellfish waters also provides guidance on the required quality of shellfish waters in the presence of certain chemicals, though the guidance is typically vague. For example the requirement for petroleum hydrocarbons is that they must not be present in shellfish waters in quantities that would, “produce a visible film on the surface of the water and/or a deposit on the shellfish,” or “have harmful effects on the shellfish” (Annex I of the Directive).

The definitions in the regulations above are directly effective in the UK, however, directives are not part of UK law unless a statutory instrument introduces these definitions into UK law. However, they provide an indication of what levels of pollution might be considered reasonable by a court. It is useful to have an understanding of the wider definitions of pollution when considering the potential impact of wreck pollution.

3.2.2 Environmental Quality Standards

Whilst helpful, the guidance given in the decisions and directives previously discussed do not provide us with values to allow us to determine at what point a contaminant becomes a pollutant. Annex 1 of Council Directive 2008/105/EC setting environmental quality standards in the field of water policy (Directive on Environmental Water Quality Standards) does provide environmental quality standards (EQS) for surface waters (see Appendix B). The EQS in the directive are given in both annual average (AA) and maximum allowable (MA) concentrations where applicable, for the priority substances and chemicals identified in Article 16 of the EU Water Framework Directive, which should be adhered to in order fulfil the requirements of the same directive with regards to achieving good environmental status.

In the UK there are also EQS associated with permitting requirements for industries discharging into the UKs coastal waters, while these are predominantly designed to regulate pollution from land-based industries it is possible that if these are the limits for what is considered to be damaging to the environment and therefore a pollutant, that the same values might be applicable when determining if a shipwreck is polluting. These are relatively low concentrations as they are monitored through surface water samples not at the point of emission. The concentrations permissible within fish and crustaceans are significantly higher. In addition guidance and EQS are also provided by DEFRA to ensure that the UK complies with the Directive on Environmental Water Quality Standards (DEFRA, 2014).

The point at which a shipwreck leaking contaminants is considered to be polluting might therefore be determined in accordance with the values provided in both the UK EQS and those given in the Directive on Environmental Quality Standards Annex 1 in order to achieve the obligations to achieve a good environmental status laid out in Article 1(1) of the Marine Strategy Framework Directive and the subsequent definition of good environmental status in Article 3(5).

Accordingly, surface water samples in the vicinity of shipwrecks could be monitored in accordance with the recommended monitoring periods and methods detailed in the Directive on Environmental Water Quality Standards to determine whether a shipwreck is or is not polluting.

3.3 Is there a requirement to remediate polluting wreck?

UNCLOS dictates that States have an obligation to protect and preserve the marine environment and that in order to do so they may implement their own pollution legislation to prevent and manage pollution in the marine environment (Art 194). In addition, Article 197 Section 2 Part XII states that States must cooperate to protect and preserve the marine environment on a global or regional basis to create best practice/legislation to prevent pollution. Part XII of UNCLOS is primarily designed to impose obligations for States that conduct activities such as shipping, mining, oil and gas extraction and pipeline laying at sea to prevent damage in the marine environment; therefore, its emphasis is on ensuring suitable policies are in place to prevent pollution from occurring during such activities rather than on requiring states to remediate historic pollution. However, States have a duty to inform other States that might be affected by any pollution damage (Art. 198 Section 2 Part XII of UNCLOS). Therefore polluting shipwrecks within the UK that might cause a pollution problem for the wider North Sea, Irish Seas or English Channel may require notification to other states and collaboration in their remediation. This requirement for collaboration in the event of oil pollution is also implemented by the International Convention on Oil Pollution Preparedness, Response and Co-operation 1990 (as enacted within the Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998.

3.3.1 General environmental protection

The EU Water Framework Directive (Directive 2000/60/EC) requires member states of the EU to achieve good environmental status by 2020 (Art 1 (1)). In addition to these overarching pollution definitions, under the directive member states of the EU are required to achieve good environmental status by 2020 (Art 1 (1.)). Good environmental status is defined in the Marine Strategy Framework Directive as

> “the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations, i.e.:
>
> (a) the structure, functions and processes of the constituent marine ecosystems, together with the associated physiographic, geographic, geological and climatic factors, allow those ecosystems to function fully and to maintain their resilience to human-induced environmental change. Marine species and habitats are protected, human-

> induced decline of biodiversity is prevented and diverse biological components function in balance;
>
> (b) hydro-morphological, physical and chemical properties of the ecosystems, including those properties which result from human activities in the area concerned, support the ecosystems as described above. Anthropogenic inputs of substances and energy, including noise, into the marine environment do not cause pollution effects;" (Art. 3(5))

This directive was brought into UK law by The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 and Water Environment and Water Services (Scotland) Act 2003. Pollution from shipwrecks could be considered to be a limiting factor on a state being able to achieve good environmental status and therefore this might drive remediation requirements through implementation of the wreck removal convention or the waste directives discussed further in section 3.3.2.

Council Directive 2004/35/EC on environmental liability with regard to the prevention and remedying of environmental damage, (the Environmental Liability Directive) (which is transposed into English and Welsh legislation in the Environmental Damage (Prevention and Remediation) regulations 2015, and the Environmental Liability (Scotland) Regulations 2009 in Scotland), details requirements to prevent damage to protected species as detailed in Council Directive of 2 April 1979 on the conservation of wild birds (79/409/EEC), which has been subsequently replaced with Council Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds and the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Council Directive 92/43/EEC) as well as nationally declared areas and species. In addition, Article 5(1) of the Environmental Liability Directive states "Where environmental damage has not yet occurred but there is an imminent threat of such damage occurring, the operator shall, without delay, take the necessary preventive measures".

The Marine and Coastal Access Act 2009 also prohibits any damage to marine conservation zones as designated by the Marine Management Organisation (MMO), under Article 140(2) (d) anyone who "intentionally or recklessly destroys or damages any habitat or feature which is a protected feature of an MCZ" is considered liable in England, Wales and the UK EEZ. There are similar offences set out in Article 95 of the Marine (Scotland) Act 2010 (enforced by Marine Scotland within Scottish waters). While not likely to be applicable retrospectively i.e. to pollution events occurring in the past, this legislation is likely to apply to any pollution events from legacy shipwrecks occurring in the present.

Given the requirement for protection of these specific habitats, bird species, and conservation zones, and the obligation to prevent pollution occurring that might cause them damage, any shipwreck that might have the potential to cause environmental damage which includes, damage to habitats and protected species, water damage or land damage under the definitions in Article 3(1) of the Environmental Liability Directive, ought to be considered to be a high priority in relation to conducting assessment and subsequent remediation work.

3.3.2 Wreck removal and waste

The UK is a party to the Nairobi International Convention on the Removal of Wrecks 2007 (Wreck Removal Convention) which can be applied to legacy shipwrecks to some degree. In the UK the Wreck Removal Convention is enacted in the Wreck Removal Convention Act 2011, and sections 252 to 254, Part 9A and Schedule 11 of the Merchant Shipping Act 1995 (Tsimplis 2018). The Wreck Removal Convention imposes an obligation on the registered owner of a ship to remove hazardous wreck (as determined by the affected state) and/or gives the state powers to remove hazards that:

> (a) poses a danger or impediment to navigation; or
>
> (b) may reasonably be expected to result in major harmful consequences to the marine environment, or damage to the coastline or related interests of one or more states (Wreck Removal Convention 2007, Art 1(5))

A hazard in this instance might include the contents of the wreck or the wreck itself (Dromgoole and Forrest 2008).This is in addition to those powers granted under section 255 of the Merchant Shipping Act 1995 which enables harbour and conservation authorities to undertake removal of wrecks that present a hazard to navigation or other use of the stated areas. Whilst not strictly an obligation to remediate all polluting wrecks, there is the prospect that if a wreck is deemed to be a hazard by the relevant parties that the ship-owner may be required to remove or remediate the wreck.

In addition to the Wreck Removal Convention the UK is also a party to The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention). The OSPAR Convention carries obligations for contracting states to

> take all possible steps to prevent and eliminate pollution and shall take the necessary measures to protect the maritime area against the adverse effects of human activities so as to safeguard human health and to conserve marine ecosystems and, when

practicable, restore marine areas which have been adversely affected" (OSPAR Convention Article 2(1)).

The OSPAR Convention covers regulation and prohibition of pollution arising from terrestrial and offshore sources, as well as dumping in the marine environment. Of particular note however, Annex II Art 3(e) determines that dumping of wastes of any kind is prohibited excluding "vessels or aircraft until, at the latest, 31st December 2004". No reference is given anywhere else within the convention to vessels or aircraft in this manner, thus it is clear that shipwrecks and aircraft wrecks are considered within the OSPAR Convention to be dumped wastes. Given the restriction in Annex II Art 3(e) we can assume that any ship that sank after 31st December 2004 is considered to be dumped waste and must be removed or remediated, however, anything that sank prior to this while still considered to be dumped waste (as it is included within the dumped waste section of the Convention) is not subject to the convention and therefore does not require remediation under the OSPAR Convention. However, if we take from the OSPAR Convention that ships and aircraft are considered to be waste, under S.30 (F115, 30A) of the Control of Pollution Act 1974, it is an offence to allow any polluting waste matter to enter any territorial waters. It could be argued that this also applies to shipwrecks that sank after 1974 when the act was introduced. Contravention of this legislation results in fines or imprisonment. However, until a case concerning shipwrecks is brought to court the application of this legislation remains speculative. It is also not UK custom to raise wrecks regardless of the OSPAR requirements.

In *Commune de Mesquer v Total France SA* (2008) EUECJ C-188/07, it was determined that in the tanker *Erika* accident in 1999, oil that had mixed with water and sediments causing pollution along the coast was in fact considered to be waste under Council Directive of 15 July 1975 on waste (75/442/EEC). Within the directive wastes include "materials spilled, lost or having undergone other mishap, including any materials equipment, etc., contaminated as a result of the mishaps" (Annex I). This is significant because it means that it will apply to shipwreck oil cargoes that become emulsified in water and or interact with sediments, as well as any cargoes of HNS that might not be recoverable without further processing. The legislation applies at the point of the leak occurring and is not related to when the vessel sank. Therefore any pollution resulting from a legacy vessel that takes place in the present due to corrosion of the vessel or similar degradation is likely to be considered to be waste. It should be noted however, that neither of these directives include decommissioned explosives within their definition of waste, therefore the requirement does not extend to such materials, but might extend to explosives that were fused at the time of sinking. This directive has since been repealed to be replaced by Directive 2008/98/EC on waste (the Waste Framework Directive). Article 10(1) of the Waste Framework Directive requires that "Member States shall take the necessary measures to ensure that waste undergoes recovery operations". This directive has been transposed into UK legislation in the Environmental Permitting Regulations 2007 in England and Wales, and the Environmental Authorisations (Scotland) Regulations 2018. There is therefore an obligation for member states to recover waste under the directive, with additional requirements that this be undertaken in a manner to cause minimal harm to the environment (Art.13 of the Waste Framework Directive,).

As a general rule legislation cannot be retrospectively applied unless expressly designed to do so however, as Greenberg (2017 (7)) notes, there is a distinction between "legislating to alter adversely matters in the past", which is undeniably considered to be retrospective legislation, and "legislation to provide for future consequences of past events", which is not necessarily retrospective legislation. Therefore, while the Waste Framework Directive is unlikely to be retrospectively applied to damage or pollution caused at the time of sinking of a wreck, the legislation can potentially be applied to pollution from waste in the present, so any pollution event caused by degradation of a vessel or similar event occurring in the present is likely to fall within the scope of this legislation. However, this remains untested in law as no cases of this type have yet been brought to court. This also holds true for other legislation subsequently discussed and the liabilities associated with pollution events under the waste directives is further discussed at section 3.4.1

3.3.3 Pollution Prevention

The UK is a party to the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL 73/78). Annex 1 of the Convention prohibits discharge of oil from ships and tankers at sea. This is transposed into UK law by the Merchant Shipping (prevention of oil pollution) Regulations 1996. Given that this cannot be retrospectively applied to ships that sank before 1973/1978 it is unlikely to apply to the vast majority of potentially polluting wrecks. Additionally S131 of the Merchant Shipping Act 1995 prohibits discharge of oil into UK national waters landwards of baselines. However, again this is unlikely to be applicable retrospectively to legacy vessels.

In addition to vessels that sank in the course of their regular operational lifetime, the Prevention of Oil Pollution Act 1971 prohibits discharge of oil or mixtures containing oil into the UK territorial sea, and the fault lies with the occupier of the "land" which in the act includes anything resting on the bed or shore of the sea. It also defines "occupier" as the owner of the land or in the case of a railway wagon or road vehicle means the person in charge of the vehicle and not the occupier of the land on which the vehicle stands. While this does not specifically make statements relating to shipwrecks it is likely that a shipwreck would be treated in the same manner as a road vehicle.

Therefore it is probable that the ship-owner or operator would be liable in the event of a discharge of oil from the shipwreck. It should be noted that the act does not apply to Government ships. It also states at section 6(1) that, in the event of an oil leak or discharge, it is a defence to prove:

> that neither the escape nor any delay in discovering it was due to any want of reasonable care and that as soon as practicable after it was discovered all reasonable steps were taken for stopping or reducing it.

Therefore, provided owners of wreck are showing reasonable care and take reasonable steps to remediate any leaks, then they are unlikely to be prosecuted.

The requirement to remediate wrecks is not necessarily transparent. While legislation that is utilised to prevent pollution from shipping appears to not apply to the issue of legacy shipwreck pollution, there are aspects of legislation such as the Wreck Removal Convention and the waste directive which are aimed at preventing pollution or hazards from wrecks. In addition, general obligations exist under UNCLOS and Council Directive 2004/35/EC towards maintaining, protecting and preserving the marine environment that could be used to demonstrate a requirement to remediate polluting wrecks. At present no cases have been brought to court to press obligations to remediate legacy wrecks within the UK territorial sea or EEZ ; until this is done, there will remain some ambiguity with regards to applicable legislation. However, given the move towards better environmental protection in the marine environment, it would be difficult to imagine an outcome where no obligation to remediate wrecks exists, particularly given the evidence presented in this section where obligations can be inferred from existing legislation.

3.4 Compensation and Liability for polluting Wreck

3.4.1 Compensation and Liability Conventions

The regime for contemporary oil polluting shipwrecks is fairly well determined and is clearly explained in the UK’s National Contingency Plan for marine pollution from ships and offshore installations within the UK EEZ (further discussed at section 3.6.2 (Maritime & Coastguard Agency, 2014)) and has been examined in detail by others (De La Rue and Anderson, 2009; Tsimplis, 2014; Zhu and Zhang, 2016; Love, 2017). Liability in the event of an oil spill from shipping is covered by the International Convention on Civil Liability for Oil Pollution Damage 1992 (the 1992 CLC), the International Oil Pollution Compensation Funds (IOPC Funds), consisting of the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage 1992 (the 1992 Fund Convention) and the Protocol of 2003 to the International

Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage, 1992 (the Supplementary Fund Protocol). These are enacted within Chapters II and IV of Part VI of the Merchant Shipping Act 1995. Liability arising from bunker oil pollution is covered by the International Convention on Civil Liability for Bunker Oil Pollution Damage 2001 (the Bunkers Convention) and further detailed in Section 154 of the Merchant Shipping Act 1995 (MSA 1995). A flow chart determining contemporary shipwreck pollution liability for specific vessel types and oil types is shown in Figure 15.

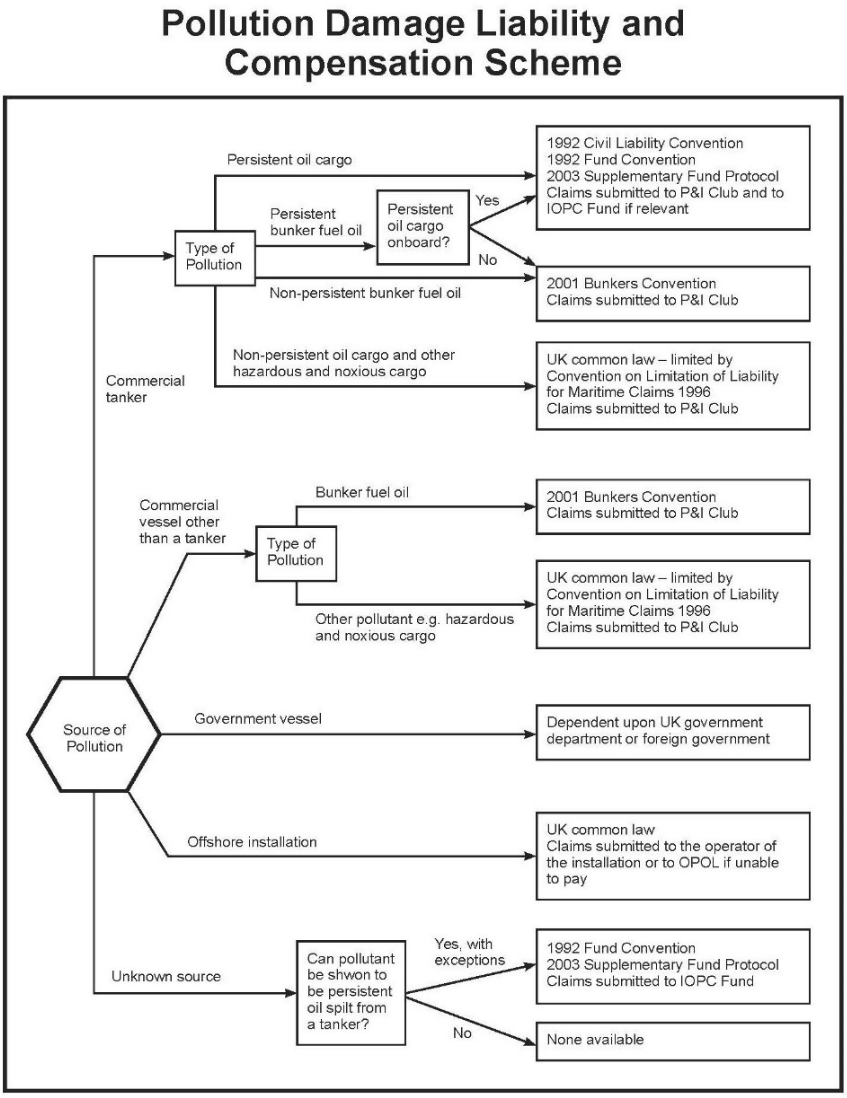

Figure 15 The Pollution Damage Liability and Compensation Scheme for contemporary ship related oil spills.
(Contains public sector information licensed under the Open Government Licence V3.0.)

At present, HNS and certain oils are not covered by the conventions above but are subject to common law and liability is based in tort or delict. Liability for pollution under tort is further discussed at section 3.4.2

Liability for oil pollution is based on the polluter pays principle, and the 1992 CLC, the IOPC Funds and the Bunkers Convention establish a principle of strict liability on the part of ship-owners. Liability is limited to an amount calculated in relation to the tonnage of the ship, and these liability conventions carry requirements for compulsory liability insurance (Maritime & Coastguard Agency, 2003; Jacobsson, 2007; Tsimplis, 2014; Zhu and Zhang, 2016). Therefore the ship-owners of any vessels that sank after the introduction of these liability conventions are liable for any oil pollution that falls within the scope of the conventions. The conventions have time bars within which claims for compensation must be brought, the 1992 CLC and the IOPC Funds have a time bar of three years from the date when damage first occurs within which a claim must be made, or six years from the date of the first incident which caused the damage. The 1992 CLC also determines that if a series of damaging incidents occur then the time bar is a six year period from the first occurrence. The 1992 CLC defines pollution damage as;

> "(a) loss or damage caused outside the ship by contamination resulting from the escape or discharge of oil from the ship, wherever such escape or discharge may occur, provided that compensation for impairment of the environment other than loss of profit from such impairment shall be limited to costs of reasonable measures of reinstatement actually undertaken or to be undertaken;
>
> (b) the costs of preventive measures and further loss or damage caused by preventive measures." (Art.1 (6)).

In Section 154 (MSA 1995) the liabilities for oil pollution from vessels not covered by the other conventions are detailed, and it is stated that the registered owner be liable for damage caused outside the ship within the territory of the UK and for any preventative or remedial costs associated with a discharge or escape within UK territory. Section 154(5) states that this applies to vessels which are not seagoing and therefore this could be argued that this applies to shipwrecks, as these are no longer seagoing vessels.

It is unlikely that the oil pollution liability and compensation regimes discussed above can be applied to pollution arising from legacy shipwrecks in the past, as this would fall within the "legislating to alter adversely matters in the past" definition of retrospective legislation previously discussed (Greenberg, 2017). Additionally it is unlikely that they are applicable to pollution arising from these wrecks in the present, in part because the liability conventions only apply if the incident that caused the ship to be a wreck also caused the pollution (Zhu and Zhang, 2016). The inclusion of time bars within the conventions also means that it is unlikely that the conventions will apply to legacy wreck as they most probably caused some form of oil pollution event at the time of sinking, which would be taken into account when determining the six year cut off point for the 1992 CLC and the IOPC funds. Furthermore, the requirements under these conventions for ship-owners to have compulsory insurance in the event of a polluting incident cannot be applied to legacy wrecks, and the time bars within which a claim can be brought within each convention are likely to prevent claims for pollution from legacy wreck arising due to the length of time between the wreck sinking and the present day. The liability conventions are therefore only relevant to shipwrecks that sank recently or in present day incidents, and only to those shipwrecks of a certain size that cause pollution from the specific materials or oils detailed in the scope of these conventions (for example non-persistent oils and HNS are exempt under the 1992 CLC and IOPC Funds).

In addition, exemptions for liability exist under the liability conventions and under the Merchant Shipping Act 1995 if the contamination results from an act of war, civil war, insurrection or a natural phenomenon, or if it is from a government ship (Art.155 of MSA 1995, Art. 11 of 1992 CLC). Given that the vast majority of polluting shipwrecks date to the war periods, it is unlikely that liability for pollution from shipwrecks sunk during wartime through enemy action would confer liability for pollution that is occurring in the present from such wrecks. This is likely to be particularly problematic where the cause of pollution is not necessarily the cause of sinking.

Under the Wreck Removal Convention (as discussed in section 3.3) the registered ship owner is responsible for the full costs of wreck removal where the wreck is deemed to be a hazard. However, the Wreck Removal Convention has a time-bar of six years from sinking of the vessel (Art. 13, and S.255(h) MSA 1995). Therefore the Convention cannot be applied to legacy polluting wrecks that sank prior to the six year limit. The powers afforded to the state to remove or require removal of the hazard remain extant in relation to legacy wrecks, but it is likely that the state will bear the costs of any removal of legacy polluting wreck under the Wreck Removal Convention. In the UK the extent of the convention's jurisdiction includes the UK's territorial waters and the UK EEZ (Tsimplis 2018, p275).

In addition to the obligations to prevent environmental damage set out in section 3.3, the Environmental Liability Directive carries liability for damage to the environment. Under Article 3(1) liability rests with an "operator" and applies to:

> (a) environmental damage caused by any of the occupational activities listed in Annex III, and to any imminent threat of such damage occurring by reason of any of those activities
>
> (b) damage to protected species and natural habitats caused by any occupational activities other than those listed in Annex III, and to any imminent threat of such

> damage occurring by reason of any of those activities, whenever the operator has been at fault or negligent.

Operators are the persons who operate or control the occupational activity. Occupational activities listed under Annex III of the directive are primarily activities controlled by permits and do not include pollution from shipwrecks so the directive is unlikely to specifically apply in this instance. However, Art 3 (1) (b) clearly allows for activities outside the scope of those given in Annex III. Liability arising under this directive for pollution arising from legacy shipwrecks is likely to be considered only in those cases where damage occurs to protected species and natural habitats, but not to the wider definition of environmental damage, which includes water and land damage. It should be noted that this convention covers liability for HNS and non-persistent oil damage in addition to oil pollution from legacy wrecks, as these are outside the remit of other liability conventions.

Under Article 140(4) of the Marine and Coastal Access Act 2009 and Section 94(2) of the Marine (Scotland) Act 2010 anyone causing damage to habitats or killing protected animals within a marine conservation zone or contravenes a marine conservation order is liable;

> (a) on summary conviction, to a fine not exceeding £50,000;
>
> (b) on conviction on indictment, to a fine.

This is therefore only likely to apply to shipwrecks located within MCZ's and the liable person could be the ship-owner, charterer, and owner of the cargo or anyone who interferes with the wreck and causes a polluting incident that damages the MCZ. This legislation only applies to UK territorial waters.

As discussed at section 3.3, the Waste Framework Directive, was successfully utilised in *Commune de Mesquer v Total France* (2008) to convey liability for oil pollution from the wreck to the charterer and oil producer as it was determined that oil mixed with water falls within the definition of waste under the directive. In which case it may be that, subject to whether the vessel is chartered and the terms of the charter party of a legacy vessel, liability will potentially rest with the owner of the cargo and the charterer, and not the vessel owner as per other liability regimes. This is likely to be applicable for shipwreck source pollution that occurs in the present as it is applicable only once oil (or another substance) is released and mixes with water or sediment, until that point it is not waste as it is possible to recover the contaminant, and the contaminant is likely to have value. Interestingly, if the contaminant has value then it is potentially subject to the International Convention on Salvage 1989 (Salvage Convention), which is implemented in the UK through the Merchant Shipping Act 1995, and liability for removal of the substance is likely to be subject to the requirements of that convention.

The Salvage Convention is applicable to legacy polluting shipwrecks as these wrecks may still be subject to salvage activities to raise or remediate them (particularly in light of the wastes directive detailed above) however, at present there is no financial reward in relation to pollution remediation for legacy wrecks so there is no motivation for salvors to act in this capacity. As will be discussed later in this chapter, many of the legacy wrecks will have protection against unlicensed salvage through cultural heritage legislation. Nonetheless, the salvage convention confers a duty to salvors to protect the marine environment during salvage operations and under English Law salvors are liable for environmental pollution that occurs as a direct result of negligence during salvage activities (Schedule 11 (Art 8 (b) & Art 14 (5)MSA 1995).

Special compensation is available under Schedule 11 (Art 14) of the MSA 1995 for salvors that prevent or minimise environmental damage during salvage operations where the financial reward from the salvage of the wreck is not forthcoming. Calls by salvors to receive a separate environmental award have previously been rebuffed on account that ship-owners or their insurers presently pay the environmental costs under the modern liability conventions (Tsimplis, 2018, P255; Liu, 2017). However, in the case of salvage of hazardous legacy vessels or their pollutants which may not be subject to existing liability conventions, it may be that the award of an environmental nature becomes more appealing to States as it essentially transfers liability for remediation from the ship-owner to the salvor (Liu, 2017). It is likely to be of particular interest where ownership of wreck is not possible to establish, or where ship-owners do not have the ability to pay for remediation of legacy wreck due to the lack of requirement for insurance for environmental liability at the time of sinking. It is also likely to have negative implications for underwater cultural heritage if introduced, which is further discussed at section 3.5.

3.4.2 Common Law

In the UK liability for HNS and pollutants not subject to the other conventions previously discussed (such as non-persistent oil cargo) are subject to common law and based in tort in England and Wales, or delict in Scotland (Maritime & Coastguard Agency, 2014; Tsimplis, 2014). Given that liabilities from HNS and non-persistent oil spills are primarily based in common law (subject to any cases to the contrary in respect of those liability conventions previously discussed), claims arising from pollution from other sources not specified or covered by existing conventions (such as pollution arising from legacy shipwrecks) might also be based in tort or delict. Arguments have also been made that human rights legislation can be used in relation to claims arising from environmental damage caused by shipwreck pollution however, these would likely be based in tort in the first instance (McKay, 2005). To discuss the full application of common law and tort in the UK to potentially polluting wrecks is not possible within the limits of this thesis, however, an overview is provided in this section in order to demonstrate that even outside the limits of statutes and conventions liability for pollution may still be attributed under common law.

The standard action in tort is negligence, which arises from a breach of duty of care. The case of *Donoghue v Stevenson* (1932) AC 52 introduced the requirements for determining negligence which are that the claimant was owed a duty of care by the tortfeasor (person committing the act), that the claimant suffered damage, and that there was proximate cause. A three part test to determine the presence of a duty of care was presented in the case of *Caparo Industries PLC v Dickman* (1990) UKHL 2, namely; was the harm reasonably foreseeable, was there a degree of proximity between the claimant and defendant and finally, is it fair, just and reasonable to impose a duty of care. In the case of potentially polluting wrecks that have been on the seabed and where their contents and propensity for pollution is known, the potential harm for pollution could be determined as reasonably foreseeable, although the exact effects of any polluting incident are hard to predict. Establishment of a degree of proximity is rather harder to define, indeed it is likely that this would depend on a case by case basis, simply damaging the environment in general would not be a close enough relationship to warrant establishment of a duty of care. Finally, whether it is reasonable to impose a duty of care in the case of polluting shipwrecks is likely to be complicated as historically it has been difficult to access or remediate polluting shipwrecks, however, modern technologies offer increasing access to even the deepest parts of the seabed meaning that remediation of shipwrecks is no longer beyond our capabilities, and therefore it may now be just and reasonable to expect a duty of care in relation to potentially polluting wrecks. An alternative to negligence is a claim under nuisance or trespass, however, it is clear from available case law that any claims arising under tort of any kind for shipwreck pollution will be determined on a case by case basis, and as yet no case has been brought before the courts in relation to legacy polluting shipwrecks in the UK (Liddell, 2014).

3.5 Shipwrecks as Underwater Cultural Heritage

Many have written regarding the complexities of the legal regime surrounding shipwrecks as underwater cultural heritage (UCH) (Fletcher-Tomenius and Williams, 1998; English Heritage *et al.*, 2004; Dromgoole, 2013; Firth, 2014; Lowther, Parham and Williams, 2017; Williams, 2017; Lowther *et al.*, 2018; Roberts, 2018; Perez-alvaro, 2019). It is not the intention of this chapter to delve into the myriad debates that exist in this area of study, nonetheless it is necessary to briefly explain the main pieces of legislation that exist in the UK relating to shipwrecks as heritage as they potentially impact on management of potentially polluting wrecks. These are the Protection of Wrecks Act 1973, the Marine (Scotland) Act 2010, the Protection of Military Remains Act 1986 and the Ancient Monuments and Archaeological Areas Act 1979 (English Heritage, 2004; Marine Scotland Information, 2016).

The Protection of Wrecks Act 1973 authorises the Secretary of State to designate a restricted area around a particular wreck and grant licences for specific activities associated with that wreck (English Heritage, 2004; Historic England, 2015). Designation can include dangerous wrecks as well as those with a cultural and historical significance (Ministry of Defence, 2013), however it is limited to wrecks located within the UK territorial waters (12NM). Designation under the Act provides excellent protection both for the wreck and for the surrounding environment in the event that the wreck might cause pollution, as the wreck is heavily monitored both by the licencing authority but also by the licensee(s) to the wreck. However, the act only applies to those specific wrecks that are designated, additionally the act is location based, thus and any wreck protected must have a known location. Therefore there are thousands of wrecks that remain outside the scope of the act either on account of not having been designated or having no known location but only a record of their sinking. In addition the act of designation of a wreck may infringe on the possessory or ownership rights of salvors and others who might have already been engaged with the wreck unless they are the licensee (English Heritage 2004, p18). The designating authority would need to work closely with the owner of any designated potentially polluting threat to enable the owner to conduct appropriate management and mitigation of any pollution threat. It should be noted that this legislation only applies in England and Wales. The Protection of Wrecks Act 1973 has been repealed in Scotland and wrecks are instead protected as Historic Marine Protected Areas under the Marine (Scotland) Act 2010 (Marine Scotland Information, 2016).

The Protection of Military Remains Act 1986 is designed to prevent disturbance to designated military sites and applies within UK territorial, UK EEZ and international waters. Under the act “controlled sites” are area based designations encompassing the remains of a military aircraft or vessel sunk or stranded in military service less than two hundred years ago, and “protected places” are the remains of aircraft or ships, designated by name, that sank in military service after 4th August 1814 (English Heritage, 2004). It is an offence to conduct unlicensed salvage, unlicensed diving, or tamper with a protected wreck in any way (Ministry of Defence, 2013). While excellent in terms of protecting historic military wrecks, the act does not automatically apply to all military shipwrecks and unless they have been expressly designated they are still at risk from salvage and other interference. Designation under the Protection of Military Remains

Act 1986 means that archaeological investigations of the site cannot take place without a licence granted by the MoD. Lowther *et al.* (2018) have highlighted that there is a restriction diving operations at controlled Protection of Military Remains Act 1986 sites, but that the term diving operation is not well defined and might also include prohibition of ROV use to locate and inspect wrecks designated under the scheme (Lowther *et al.*, 2018, p. 26).

In addition to the statutes that are directly aimed at preservation of wrecks, the Ancient Monuments and Archaeological Areas Act 1979 has also been used to protect shipwrecks that have an archaeological or historical significance within UK territorial waters (Dromgoole, 1989; English Heritage, 2004). Under the act a site is scheduled as a monument of national importance. It is an offence to demolish, destroy, damage, remove, repair or alter the monument without permission of the Secretary of State (English Heritage, 2004). The act is somewhat constrained as it relies on a specific location and object designation therefore cannot be blanket applied to shipwrecks of a certain age or era. Additionally diving is permitted on sites protected under the act and therefore monitoring of interference with a site is likely to be difficult where recreational diving takes place alongside illegal interference with the site.

As well as the above legislation that is explicitly designed to protect underwater cultural heritage, the Marine and Coastal Access Act 2009 and Marine (Scotland) Act 2010 have also been introduced. Under these Acts a marine licence is required for designated activities (as detailed in Part 4, Ch1, S66 of the Marine and Coastal Access Act 2009 and Article 21 of the Marine (Scotland) Act 2010) within the UK's EEZ the purpose of which is to protect both the environment and the UK's cultural heritage from damage and pollution.

Both Acts carry a requirement for any marine licenced activities to take into account the environment where;

> "Any reference to the environment includes a reference to any site (including any site comprising, or comprising the remains of, any vessel, aircraft or marine structure) which is of historic or archaeological interest." (Section 115 (2) Part 4 Marine and Coastal Access Act 2009, and Section 64(2) Part 4 Marine (Scotland) Act 2010)

Similarly designations of Marine Conservation Zones (MCZ's) under the act must also take into account not only the protection of the habitat and protected species but also the social impact of designation on any site of historic or archaeological interest (Art. 117, (8))

Art. 151 (8) of the Marine and Coastal Access Act 2009 discusses the role of fisheries and conservation authorities in relation to marine environmental matters which are defined as;

> “(a) the conservation or enhancement of the natural beauty or amenity of marine or coastal areas (including their geological or physiographical features) or of any features of archaeological or historic interest in such areas, or
>
> (b) the conservation of flora or fauna which are dependent on, or associated with, a marine or coastal environment.”

It would appear that there is an equal weight placed on the conservation of natural resources as well as those of an historical and archaeological nature within MCZ’s. This is potentially problematic for licencing and local authorities where polluting wrecks might cause conflict between the ability to manage these features alongside one another. However, the use of “or” rather than “and” within the article would also seem to leave this open for authorities to choose which of these takes precedence in any problematic scenario involving the likes of a polluting shipwreck. It is highly likely in such an instance that the protection of flora and fauna would trump that of the archaeology or a site of historical importance.

Finally, while not yet a party to the United Nations Convention on the Protection of the Underwater Cultural Heritage 2001 (the UNESCO Convention), the UK government does follow a policy of adherence to the Annex to the convention, the “Rules concerning activities directed at underwater cultural heritage”(Roberts, 2018). The UK complies with the rules set out in the Annex as well as the some of the UNESCO convention itself through implementation of the statutory instruments previously described in this section, as well as through marine licencing requirements under the Marine and Coastal Access Act 2009 and Marine (Scotland) Act 2010 (Historic England, 2015). However, it should be noted that the UK does not fully meet the full requirements of the UNESCO Convention and there is currently no reporting duty for the discovery of underwater cultural heritage other than the requirement under section 236 of the Merchant Shipping Act 1995 to report wreck to the Receiver of Wreck.

3.6 Wreck Ownership

Determining ownership of wreck is often complicated and a proportion of wrecks will have no identifiable owner or are likely to have been wholly abandoned. Others will have identifiable owners but these might be individuals who do not have the capacity or resources to remediate their wrecks and in many cases would be bankrupt by a liability claim which would leave the government to pick up the bill for the work.

An owner of a vessel that sinks will likely in most cases have insurance which covers the loss, the insurer will pay out to the owner and should at that point take ownership of the wreck. One key ownership issue is the transfer of liability to insurers through abandonment.

When a ship is declared lost a ship-owner will issue a notice of abandonment to the insurer or to the world at large. Under the Marine Insurance Act 1906 section 63(1) the insurer is "entitled to take over the interest of the assured in whatever may remain of the subject-matter insured, and all proprietary rights incidental thereto", however, they are not obligated to do so. Meanwhile the case law also supports that a ship-owner does divest himself of his property once abandoned to the underwriters as in the case of Barraclough V Brown (1897) (Gauci, 1995). Therefore potentially a wreck will become "res nullius" (not owned) unless negligence can be identified as the cause of sinking, as in the case of Dee Conservancy Board v McConnell (1928), where liability for damage caused by the stranded vessel remained with the vessel owner following negligence on their part (see also The Ella (1915)). However, there remains significant debate regarding the nature of abandonment in relation to liability for oil pollution (Gauci, 1995)

If an historic polluting wreck is deemed to be "res nullius" then the state would be liable for any costs associated with remediation of that shipwreck on account of being unable to determine ownership of the wreck. Where no owner is identified then the national contingency response is implemented, as discussed previously, which is taxpayer funded. This is less likely to be a concern with modern shipwrecks as they are usually subject to salvage at the point of any pollution event, and are subject to strict liability for the registered owner as detailed earlier in the chapter. However, in relation to legacy vessels it is a key concern. In addition to the issues of abandonment, there are problems associated with cultural heritage legislation and ownership rights to legacy wreck (Roach, 1996; Rachmana, 2015)

Wrecks can also themselves be sold on for salvage by the owner or insurer after they have sunk and there is usually no central register of these transactions. Therefore the owner at the time of sinking and immediately after sinking may no longer be the current owner. In many cases wrecks can be sold on multiple times and there may be different owners for various parts of the wreck e.g. an owner for hull and machinery and a separate owner for cargo etc.

Establishing ownership of potentially polluting wrecks in order to attribute liability is complicated issue and is largely dependent on the specific details of the contract under which the ship has been engaged and any actions on behalf of interested parties to sell, claim or abandon part, or all of the wreck (Bederman, 2000; Walker, 2000; Vadi, 2013; Rachmana, 2015). A brief overview of some of the main wreck owners in the UK is presented below, alongside an analysis of their current management strategy for wrecks.

3.6.1 Ministry of Defence

The MoD has a large portfolio of wrecks within the UK EEZ. Wrecks that sank in military service during the World Wars make up a significant proportion of the legacy wrecks in the UK's EEZ (see section 4.2.6.2 & 4.3.1.2) although some of these were subsequently sold for salvage after the war to private owners. Within the MoD there is a split of management responsibilities for various aspects of wreck:

- Navy Command HQ has responsibility for managing MoD owned wrecks.
- MoD Salvage and Marine Operations (SALMO) manage (on behalf of Navy Command HQ) the environmental and safety concerns relating to MoD owned wrecks.
- The Joint Casualty and Compassionate Centre (JCCC) has responsibility for the management of human remains within MoD wrecks.
- The UKHO which is a trading fund of the MoD keeps a record of locations of wreck identified during hydrographic survey work, which it disseminates for navigational safety purposes in admiralty charts.

In addition to the Protection of Military Remains Act 1986 discussed above at section 3.5 which enables the MoD to designate wrecks to prevent diving or other activities taking place, the MoD also has wreck management policies that relate to legacy potentially polluting wrecks.

The Protection and Management of Historic Military Wrecks Outside UK Territorial Waters (MoD and DCMS, 2014) is a joint policy document between the Department for Culture, Media and Sport (DCMS) and the MoD which states that Military wrecks are considered to be Sovereign Immune and therefore a look but don't touch policy applies to military wrecks. Where wrecks have been protected under the Protection of Military Remains Act 1986 the conditions of the designation must be adhered to. It also states that anyone wishing to investigate historic military wrecks must agree to uphold the general principles of the UNESCO Annex, and must where applicable obtain a licence from the relevant marine licencing body. However, there are a number of cases where this policy has not been applied appropriately and there is little in the way of enforcement of the policy where interference with non-designated military wrecks takes place.

Joint Service Publication 430 was a policy that included specific guidance for remediation of historic wreck pollution and their management, however, this policy was superseded on the 3rd January 2019 and the replacement policy does not provide any policy guidance in relation to historic wreck pollution. However, MoD SALMO does have an agreement with Navy Command HQ to:

> Manage on behalf of the NCHQ owner the environmental and safety concerns, site surveys and interventions (if required) associated with all MOD owned shipwrecks keeping the Wrecks Database up to date, including permanent preservation of wreck assessments. Provide ship wreck SME advice and assistance as requested to the 3rd Sector Heritage team. Provide expert advice on wreck management, salvage and related issues to the Department for Transport, Foreign and Commonwealth Office and other government departments (Skelhorn, M. Pers. Comm. 2020).

An additional MoD policy *JSP 418 Management of environmental protection in defence* states "it is MOD policy to comply with the provisions of relevant environmental legislation" and that "Potential pollution risk shall be identified and appropriate management procedures, put in place to effectively minimise risk" (Ministry of Defence, 2010, p. 2). While this does not specifically refer to polluting wrecks it does identify that given some of the environmental legislation discussed above relates to polluting legacy wrecks then the MOD's policy is to risk manage potential pollution from these wrecks.

The responsibility for identifying potential pollution risk for MoD wrecks falls to MoD SALMO who have conducted various risk assessments and quantification exercises in order to try and understand the risk posed by their wreck portfolio and to determine appropriate management strategies for these wrecks. These are further discussed in Chapter 5. To date the MoD have conducted two remediation exercises to remove oil from wreck, the first from HMS *Darkdale* in St Helena, and the second from HMS *Royal Oak*, a project which is ongoing. In undertaking this work the MoD has shown that it is complying with the above wider MoD environmental policy and that they are considering the potential pollution risk from their vessels, as well as managing any wrecks that pose an immediate pollution threat.

3.6.2 Department for Transport

The Department for Transport (DfT) also owns a large number of wrecks within the UK EEZ, being largely responsible for the merchant fleet and any wrecks that were insured by the government under war risks insurance during the World Wars. DfT also own a number of wreck cargoes as the successor to a number of now defunct government departments. At present DfT has no formal policy relating to management of polluting wrecks, a response from the department to a Freedom of Information request (Appendix C) stated that any pollution from wrecks would be dealt with by the counter pollution team at the MCA. As a an executive agency of the DfT the MCA has no formal policy or agreement with DfT to manage legacy polluting wrecks, but are required to respond to pollution incidents more generally as per their responsibilities detailed in the UK's

National Contingency Plan which sets out the arrangements for managing pollution, or the threat of pollution from ships and offshore installations.

Historically, the DfT, through the MCA, in conjunction with the MoD has undertaken a risk assessment of their wrecks in the Potentially Polluting Wrecks 3 work discussed at section 4.2.2. However, since that work was undertaken there has been no additional research or action taken to address the issue of their polluting wrecks. This has changed recently and, following an email enquiry to the department, the DfT has provided a statement regarding the future management of their potentially polluting wrecks:

> The Department for Transport is aware of the over-arching environmental risk of its 4,500 WW1 and WW2 wrecks portfolio. It is therefore planning a proactive management approach collaborating with appropriate HM Government partners, and has secured funding to put out a future tender for an environmental pilot audit survey on the portfolio. The aim of this survey will be to generate an understanding of the scope and scale of the environmental risk associated with DfT WW1 and WW2 wrecks, which will enable options for mitigation to be put in place. The Department is also conducting a digitisation project of the records of its wrecks portfolio, currently only accessible on paper, which will facilitate the effective completion of the environmental audit pilot survey through more efficient record access. This project has been temporarily paused due to the contractor's Covid-19 business restrictions, and DfT are looking to resume this work at the earliest opportunity. (see Appendix C).

This therefore marks a step forward for DfT towards managing the risks posed by their vessels. However, there is still significant discrepancies across government in their approach to potentially polluting wrecks. The work proposed by DfT, in particular the digitisation of their wrecks records, may help feed additional data into the original PPW4 risk assessments to give a better understanding of what cargo their wrecks were carrying, the circumstances of their loss and any subsequent salvage that may have remediated them in the past. This would assist in resolving some of the epistemic uncertainty that persists in the existing risk assessment.

3.6.3 Treasury

The Treasury owns a number of wrecks and wreck cargoes that were either directly owned at the time of loss or that have been inherited from now non-existent government departments. While the treasury has exerted ownership control and rights through the issuance of salvage contracts on wrecks they own, and payment of salvage awards on wreck reported to the Receiver of Wreck, they do not currently have a policy for active management of their wrecks or cargoes. Given the nature of their cargoes it is unlikely that they pose a pollution problem, however, they may be associated or contained within wrecks that do pose a pollution risk, and therefore any salvage licences issued against their cargoes should take this risk into account and also be issued in conjunction with the wreck owner if it is not themselves.

It is worth noting that the Crown Estate is a non-ministerial department of HM Treasury and manages much of the seabed in the UK's Territorial Sea as well as rights to natural resource of the UK Continental Shelf (Firth, 2014). While owners of wreck are likely to be responsible for remediating wreck, ownership of wreck does not convey ownership of the seabed on which a wreck rests, therefore pollution resulting from a wreck that breaks down and which pollutes the sediment may become an issue for the seabed owner as well as the wreck owner. Subsequently, the Crown Estate may find itself with a significant polluting problem from wrecks that have degraded already and those that might degrade in the future.

3.6.4 Civilian & Commercial Wreck Owners

There are countless non-governmental owned wrecks, some of which will be owned by insurers, by shipping lines, by salvage companies or by individuals. These wrecks are largely un-managed unless the wreck is designated as a protected wreck or activity at the wreck (such as salvage) is licenced under the Marine and Coastal Access Act 2009 or the Marine (Scotland) Act 2010. Owners of one or a few wrecks are unlikely to have considered potential environmental pollution from their wrecks, and are also unlikely to have the means to assist with any clean-up of pollution from such wrecks. These wrecks form a small percentage of the overarching potentially polluting wreck inventory, so the potential risk is reduced, however, in the event of a polluting incident the management of pollution arising from these wrecks is likely to fall within the remit of the counter pollution team at the MCA. Costs may be attempted to be recovered from the wreck owner but the likelihood of success in this regard for legacy wrecks is minimal as ownership of legacy wreck is often difficult to determine, it is more likely that the tax payer would end up covering the remediation costs for these wrecks.

3.7 Other Management Bodies

3.7.1 Maritime and Coastguard Agency

The MCA, as an executive agency under DfT, administers parts of the Merchant Shipping Act 1995 the function of the Receiver of Wreck in relation to wreck and salvage across the UK and which covers some aspects of polluting wreck management as well as wider management of wrecks. The

RoW is also responsible for managing dangerous wrecks designated under the Protection of Wrecks Act 1973 section 2 (such as the SS Richard Montgomery, discussed at section 2.1.4) and managing temporary designations of wreck under the act during specific incidents in order to manage pollution (such as the MV Braer). As previously discussed in section 3.4.1 the MCA counter pollution team have a responsibility to respond to pollution arising from wreck in accordance with the national contingency plan (NCP), this potentially includes responding to pollution from legacy wreck where no owner can be identified.

3.7.2 Heritage Bodies

While heritage bodies do not have management policies relating to polluting wreck, there is a possibility that wreck might be considered to be historically or archaeologically important and therefore would require specific management strategies that take into account their heritage aspect.

There is no single UK-wide government agency that governs the heritage management of wrecks (Firth, 2014). Historic Environment Scotland, CADW (Wales) & the Department for Communities (Northern Ireland) are responsible for scheduling and licencing access to wreck sites within Scotland, Wales and Northern Ireland respectively. In England the DCMS is responsible for scheduling wreck sites, however, Historic England is the government's statutory advisor relating to historic wreck and is responsible for the day to day management of the sites. Each heritage body has their own set of policies and procedures in relation to scheduling and management of wreck sites.

In most respects however, the various policies for managing wrecks as heritage assets also apply to the management of potentially polluting wreck. The first aim is to gather as much information as possible on the wreck, then to determine the condition of the wreck and the nature of the environment around the wreck. The primary difference would be that many wreck management plans aim for non-intrusive management and monitoring of the wreck. This would clearly not be possible for a potentially polluting wreck which would require remediation. That said, licenced excavation activities are approved on a number of historic wrecks at which point the remediation of the wreck is controlled and recorded in a similar manner. Therefore negotiation between heritage bodies and those responsible for remediating wreck is likely to remove any disparities between heritage and pollution remediation policies for wreck management and there is scope for the policies to work in conjunction.

3.7.3 Marine Licencing

As previously discussed in section 3.5 some work conducted in the marine environment requires a licence. This includes any remediation work aimed at polluting wrecks. Marine licencing in the UK within the 12 nautical mile limit of the UK's territorial sea is devolved, with the responsibility for managing marine licencing resting with the MMO in England, Marine Scotland, Natural Resources Wales, and the Department of Agriculture, Environment and Rural Affairs (DAERA) in Northern Ireland. The MMO also manages marine licences in the UK outside the 12nm of the territorial sea with the exception of Scotland where Marine Scotland administer the licences. Marine licencing takes into account both the heritage value of wrecks and any potentially negative effects on the environment that might occur as a result of work undertaken. Therefore a marine licence is unlikely to be given on a wreck that poses a potential pollution risk, unless it was for work to remediate the wreck by a competent authority or contractor. This affords a level of protection to prevent pollution from wrecks that might occur due to external interference with a wreck such as salvage. It also means that the heritage aspects of a wreck will be discussed in conjunction with any prospective remediation methods in order to ensure that cultural heritage is not lost in trying to prevent pollution.

3.7.4 Port, Harbour and Lighthouse Authorities

As previously mentioned in section 3.3.2 Port, Harbour and Lighthouse authorities have their own powers in relation to management of wrecks within their statutory areas. This includes the power to remove wreck that poses a hazard either in terms of navigation, pollution or to other port and harbour operations. Clearly where this relates to potentially polluting wrecks their powers afford a facility for remediation of either pollution from a wreck or the wreck in its entirety. Port, Harbour and Lighthouse authorities have a vested interest in ensuring that pollution does not affect their infrastructure or impact on navigation.

3.8 Summary

In determining what constitutes a polluting shipwreck it is noted that there are variations on the definition of pollution within the legislation. However, many of the hazardous substances that are controlled by environmental legislation can be found in wrecks and the definitions of pollution are sufficient in scope to include contaminating shipwrecks and their contents within their overarching meaning.

Environmental quality standards, while predominantly aimed at managing and monitoring pollution from industries, would appear to be the best available guidance for determining at what point contaminants from shipwrecks become polluting, and therefore at which point a shipwreck might require remediation. Accordingly, it would be beneficial to implement more widespread wreck monitoring and water sampling studies in the vicinity of shipwrecks that are deemed by risk assessment to be potentially polluting.

It is clear that while an explicit requirement to remediate polluting shipwrecks is not present in the legislation applicable to historic polluting wrecks, there is a general state requirement to protect the marine environment and to prevent pollution under UNCLOS. States are also required to achieve good environmental status within their waters under EU legislation. The presence of polluting shipwrecks within the UK EEZ is likely to adversely affect the ability of the UK government to achieve good environmental status within the EEZ, and may in fact contravene the requirements to prevent pollution under UNCLOS.

On a more localised level oil and other hazardous substances leaking from shipwrecks can be considered to be waste in certain circumstances under the EU waste directive, there is a requirement to remediate any pollution arising from such waste, and in addition liability for remediation of the effects of any such waste may exist for the charterer or cargo owner under the convention.

Furthermore there is a requirement under Environmental Liability Directive and UK legislation to protect certain species and birds from pollution, where pollution from wrecks causes harm to such species and birds there is a requirement for remediation of the damage and liability assigned to the operator which could conceivably be construed as the ship-owner or charterer.

Contemporary liability and compensation schemes such as the 1992 CLC, the IOPC Funds and the Bunker Convention are not applicable to legacy wreck pollution in part due to the time bars associated with them, but also on account of retrospective legislation being generally non-permissible. The same applies to liability under the Wreck Removal Convention. Liability will instead, most likely be assigned under common law through tort for oil, HNS and other pollutants associated with shipwrecks, however, as no cases have been brought before the courts for polluting legacy shipwrecks the outcome of such cases remains to be seen.

Determining ownership of wreck in order to assign liability is a complex issue, partially due to issues associated with ship-owners issuing notices of abandonment which are then not accepted by the insurer even though they recompense the ship-owner for their loss. This issue of abandonment is likely to cause particular issues for legacy wreck ownership determination, and ultimately it may be that for many wrecks that require remediation it will fall to the state to bear the costs of any required works.

Further issues relating to ownership are likely to arise in the application of cultural heritage legislation to potentially polluting wrecks that carry environmental liabilities. Some heritage legislation also places limitations on the property rights of wreck owners, who in the event of a polluting incident would under normal circumstances be liable for the pollution.

In light of the obligation to remediate wrecks and the liabilities associated with pollution from wrecks it is clear that management of potentially polluting wrecks is necessary, however, at present the management of polluting wrecks is largely dependent on who owns the wreck and therefore management of pollution from wreck is not consistent across UK wrecks. Civilian owners are potentially unaware of their responsibilities and may not have the ability to pay for remediation while government wreck owners currently have very different management strategies. The MoD is aware of the risks posed by their legacy wrecks and has had policies in place to manage these, as well as having conducted work to remediate some of their wrecks. However, the DfT seemingly has no pro-active policies or management strategies in place to manage polluting wrecks, instead they are relying on the MCA under the National contingency plan to deal with pollution from wreck as it occurs. As has been discussed previously at section 2.6 this reactive strategy is likely to be far more expensive than a pro-active strategy and is likely to result in greater environmental damage than if a pro-active remediation strategy is undertaken. Finally there are a number of other management bodies that might have an impact on how polluting wrecks are managed and these need to be taken into account when considering the management strategy for potentially polluting wrecks.

While it is clear that there is both a threat from potentially polluting wrecks and a need to manage these wrecks, it is not clear how many wrecks pose a potential pollution problem. Therefore, it is also difficult to say at this stage what remediation and management actions might be considered to be reasonable for a wreck owner to take in order to demonstrate that they have taken all reasonable precautions to prevent pollution leaking and to remediate any leaks that do occur as this will to some extent be determined by the scale of the problem which remains unknown.

It is therefore necessary to understand the scale of the potentially polluting wreck issue in UK waters, what risk assessments have been undertaken in the UK, and how these might be improved upon to remove some of the uncertainties that were identified in section 2.4. The next chapter seeks to quantify the number of potentially polluting wrecks in UK waters and critically examines work undertaken in the UK to date.

Chapter 4 UK Quantification & Risk Assessment

As previously discussed in section 2.3 the global number of potentially polluting wrecks is difficult to determine as there is no single global database of wrecks. Therefore any quantification of wrecks must be undertaken at a regional level. Understanding the scale of the potentially polluting wreck problem is key to determining appropriate management strategies as the number of wrecks will determine the feasibility of management solutions.

This research therefore aims to review the existing wreck databases in the UK and seeks to refine these to produce a more accurate understanding of the number of potentially polluting wrecks in UK waters. This will in turn enable us to have a clearer indication of the feasibility of wreck management in the UK, and what can reasonably be expected of wreck owners.

A key part of this work is also to understand what wreck threat and risk assessments have already been undertaken in the UK, and whether these assessments are reliable, appropriate and useful for management decision making. The output of these risk assessments has a direct impact on the ability of management stakeholders to make decisions regarding which wrecks may require remediation, and which do not. A review and critical analysis of the existing UK risk assessments is presented in this chapter.

4.1 UKHO Shipwreck Database and Survey Coverage

The United Kingdom Hydrographic Office (UKHO) holds a database of shipwrecks for UK waters containing 24,808 records in total (including foul ground and obstructions) (Figure 16). They kindly provided the database to this project as a comparative dataset against the MoD databases discussed subsequently. When filtered by wreck category to exclude foul ground and obstructions the database is reduced to 15,554 shipwrecks. However, as with most databases there are some wrecks encountered in the database that have been entered into the database as obstructions (and vice versa) so this number may not be entirely accurate.

The UKHO database is largely designed to identify obstructions and hazards to navigation, therefore, while this database contains useful information such as location, type of vessel, cause of sinking, depth of water etc. it does not always provide additional information required to assess polluting shipwrecks such as information on the type of cargo carried, amount of cargo, condition of the wreck, location of bunkers etc.

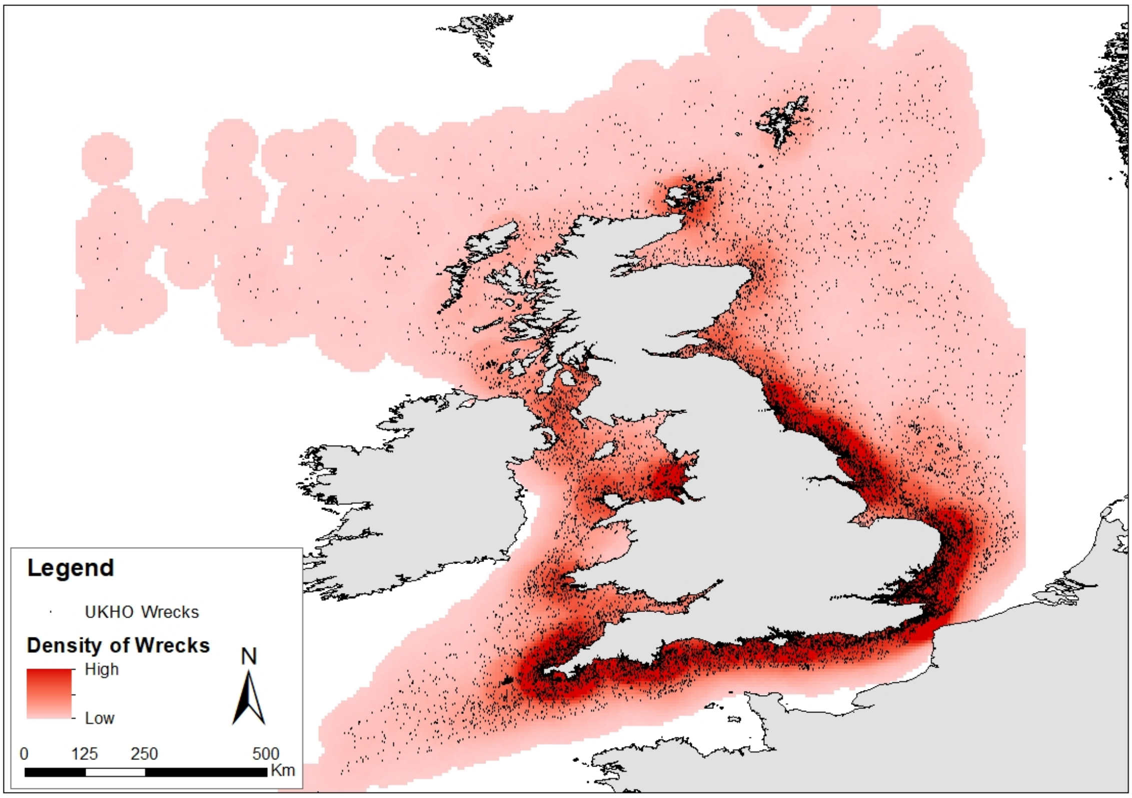

Figure 16 Map of the UKHO Shipwrecks and their density. (author's own image).

Wrecks are largely included in this database if they have been identified in the process of hydrographic surveying for navigation, therefore the majority of the wrecks identified are within surveyed areas and there is a lack of information regarding shipwrecks located outside of these surveys. Figure 17 shows the area of UK waters that have been surveyed by the UKHO and the type and level of coverage. Nearly half of the UK's waters are un-surveyed, or surveyed at a resolution that is not suitable for identifying wrecks, as a result it is likely that there are more shipwrecks in UK waters than identified in the UKHO data, however, the UKHO database gives us a good indication of the density of shipwrecks in the areas that have been surveyed.

A study conducted by Dellino-Musgrave and Guiden (2013) identified that there were a series of differences between the UKHO database and the National Monuments Record (NMR). They identified five areas of data conflicts, namely; attribute conflicts, one-to-many relationships, spatial conflicts, casualty records and obstructions. The study focused on areas subject to marine aggregate dredging and not the full UKHO and NMR databases. Their recommendations for de-conflicting the UKHO database included using standardised thesauri, additional desk based research and greater data sharing and linking between different shipwreck data providers. The UKHO database forms the basis for the subsequent MoD databases discussed at Chapter 4. The inherent inaccuracies in the database in relation to vessel ID are likely to have carried forward into those databases.

We derive information about shipwreck location and condition from the UKHO database without an indication of the measure of confidence in the data. Where a shipwreck has been surveyed multiple times the confidence in the fact that there is actually a shipwreck present is much higher than where lead line survey methods may have met an obstruction and recorded it as a wreck. Often such shipwrecks are given an identity based loose correlation with the log of a vessels last known position. Additionally, a single wreck may be recorded multiple times in the database as a result of different positioning methods being used over time. Basing a subsequent pollution risk assessment off such limited information is therefore problematic and there is no differentiation between shipwrecks located within surveyed data and those without the surveyed areas in the UKHO or MoD databases. The reality is that approximately 22% of the marine survey data (those areas surveyed with Swath Bathymetry in Figure 17) in the UK is potentially useful for archaeological assessment of shipwrecks. Often the wide line spacing of the collected datasets mean that data is not of a resolution that can be used to accurately assess a shipwreck's condition or provide detailed information about the surrounding environment, therefore the useful data from the UKHO and CHP surveys is likely to cover significantly less than 22% of UK waters.

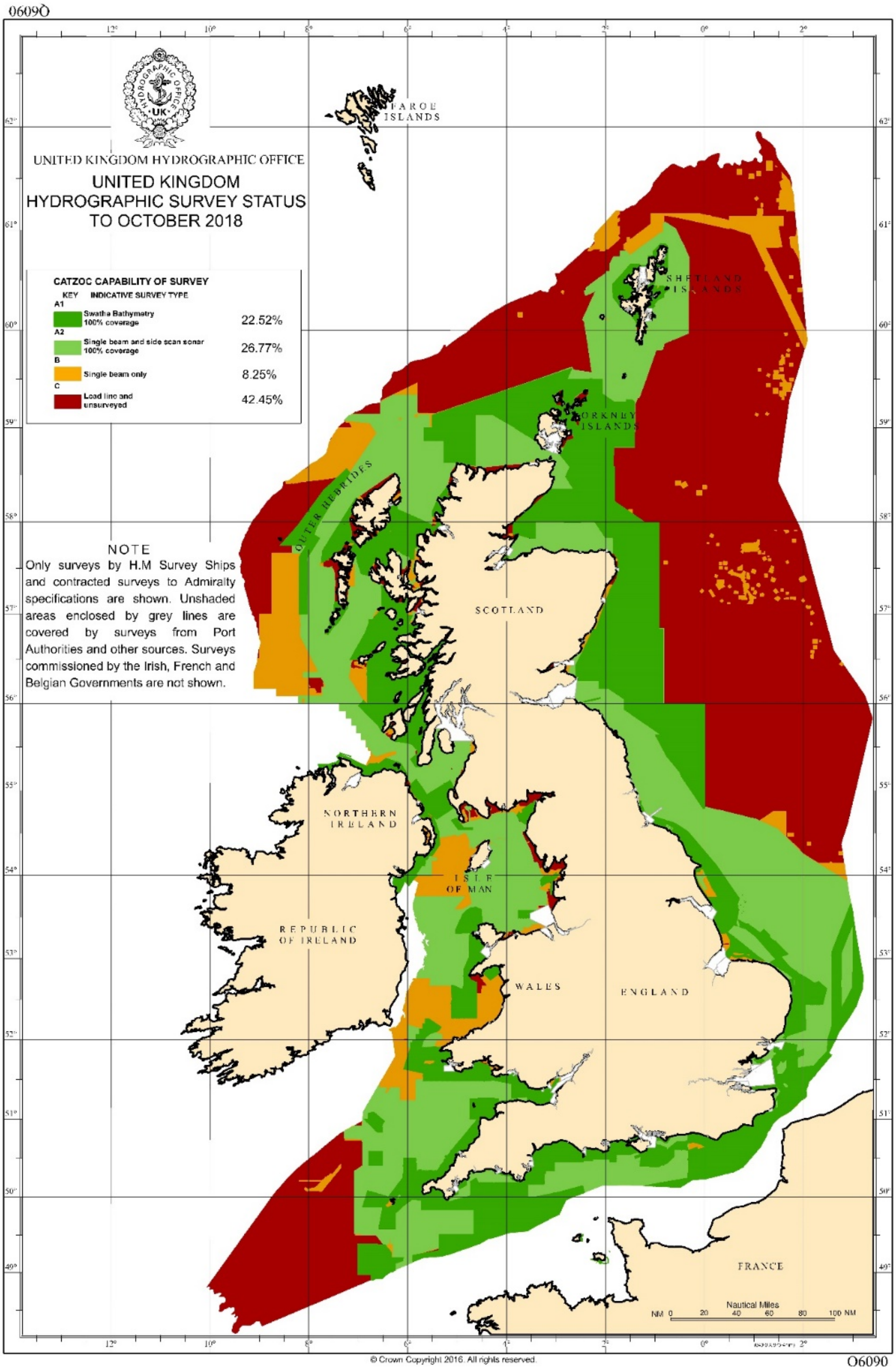

Figure 17 Chart showing UKHO surveyed areas

4.2 MoD Shipwreck Databases & Risk Assessments

As previously discussed in section 2.3 the MoD have conducted research into the number of potentially polluting wrecks in the UK and have undertaken various risk assessments on the data. The MoD has three datasets that result from this work namely the Master Wrecks Database (MWD), Potentially Polluting Wrecks 3 database (PPWD3) and Potentially Polluting Wrecks 4 database (PPWD4). There is also an additional risk assessment conducted by CEFAS which does not have a corresponding database. Table 5 contains a summary of the databases and risk assessments, and they are discussed in further detail below.

Table 5 Comparison of MoD shipwreck databases & risk assessments

Name	**Total Records**	**Records in UK**	**Risk Assessment/Creator**	**Scope**
MWD	5,742	Unknown	MoD (No Risk Assessment)	Global
PPWD3	25,765	9,898	Potentially Polluting Wrecks 3 (ABPmer, 2010)	UK and Ireland
PPWD4	23,498	9,938	Potentially Polluting Wrecks 4 (Maritime Archaeology Ltd and SeaZone Ltd, 2011)	Global
N/A	N/A	N/A	CEFAS Risk Assessment (Goodsir *et al.*, 2019)	Wreck Specific

4.2.1 Master Wrecks Database

The Master Wrecks Database (MWD) is a list held separately from the two risk assessed databases (PPW3 and PPW4) and contains records of wrecks that the MoD believe to be of particular interest or importance. The information in the database is collated from PPW4 and the following sources:

- Beddington and Kinloch, (2005) *Munitions Dumped at Sea: A Literature Review.* Imperial College Consultants Ltd. London.
- Colledge and Warlow, (2010) *Ships of the Royal Navy: The Complete Record of all Fighting Ships of the Royal Navy from the 15th Century to the Present*. Casemate Publishers & Book Distributors, LLC
- HMSO and Young, (1988) *British Vessels Lost at Sea: 1914-18 and 1939-45.* Patrick Stephens Ltd.
- Maritime Archaeological Sea Trust, (2017) *Royal Navy Loss List Complete Database.*

- The Historical RFA website (White, 2019)
- WWI & WWII service lists

While the database is useful for understanding the number of potentially polluting wrecks that might pose a significant pollution problem globally only 410 of the 5742 wrecks have latitude and longitude information for positioning (many of which have a low confidence of accuracy), these wrecks derive from the PPW4 database (186 wrecks) and the Historical RFA website (224 wrecks). The rest of the wrecks have no location information, this is largely down to the information sources largely relying on reported “as sunk” locations rather than “as found” locations on the seabed. As a result some of the wrecks have descriptions as being in UK waters but their exact location is unknown. The database has therefore not been subject to a risk assessment and is unsuitable for further detailed GIS analysis to assess condition of the wrecks as it is not possible to accurately situate them within their surrounding environment.

In order to identify that the MWD wrecks are a priority for the MoD, where there is correlation with the PPW3 & PPW4 databases a note was added to both databases so that this information is captured in further assessment of the datasets. The majority of the wrecks in the MWD do not feature in the PPW3 or PPW4 databases. It is therefore likely that the number of polluting wrecks in UK waters is higher than the number of records indicated in either the PPW3 or the PPW4 database. Given the number of wrecks in the MWD there could be up to 5,556 additional potentially polluting wrecks globally in addition to the 23,498 records already included in the PPW4 global dataset.

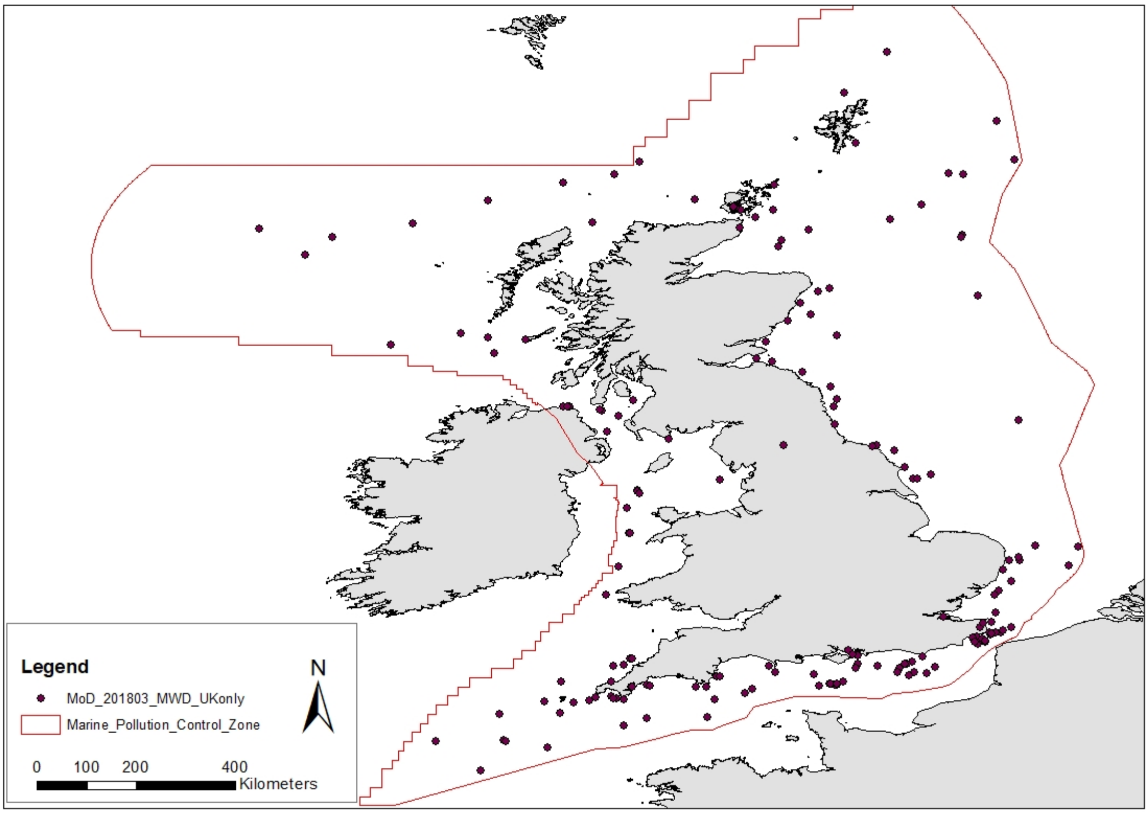

Figure 18 Distribution of wrecks with coordinates in UK waters from the MWD (author's own image).

4.2.2 Potentially Polluting Wrecks 3

PPW3 is a risk assessment with an associated database (PPWD3) was commissioned by the MoD, the MCA and DEFRA, and produced by ABP Marine Environmental Research Ltd. (ABPmer) with assistance from Maritime Archaeology Ltd (MA Ltd) (ABPmer, 2010). The database is derived from the UKHO database discussed at section 4.1 and contains records of wrecks in UK waters that sunk between 1870 and the present. Additional shipwreck locations and information was gathered from the national monuments register (NMR), national heritage databases and previous work conducted by Bournemouth University. Only 'Live' wrecks were included in the database which is in a GIS geodatabase format, and contains 25,765 records. When clipped to the UK counter pollution zone (CPZ) the database contains 9,898 records.

A comparison of PPWD3 against the UKHO database suggests that only 5,431 of the PPWD3 records correspond with a UKHO shipwreck location. This was assessed through assigning 150m search radii UKHO wreck locations in GIS and identifying PPW3 shipwrecks located within this distance. This allows a tolerance for wrecks that might have a position recorded at different parts of the wreck. Further investigation of the PPW3 database against the UKHO database identifies a consistent trend across the dataset where there is approximately a 120m to 500m difference in vessel location. This is most prevalent on wrecks on the east coast of the UK but does occur elsewhere in the dataset and the PPW3 wrecks are mostly located to the south west of the UKHO position. It is most likely that this is the result of a transformation error introduced at some point into the database during its input into GIS. Unfortunately it is not consistent across all of the wrecks in the database so cannot be automatically corrected, it would require manual checking of each position to determine accuracy.

The discrepancies in location information within the database is problematic because the risk assessment for the PPW3 data was conducted using a GIS scripted risk assessment. This means that the analysis was undertaken spatially in GIS and therefore any errors in vessel positioning are likely to have impacted on the risk assessment process and potentially resulted inaccurate risk values. Accurate location information is required in order to assess a wreck's impact on the surrounding environment, it may affect the severity of any pollution event and means that when a field investigation is carried out the search for the wreck has some hope of finding it within an expected area.

In order for a risk assessment to be conducted information regarding vessel type, propulsion, cargo etc. had to be obtained and entered into the database. 90% of the database was manually compiled by MA Ltd. Given the vast number of shipwrecks, a priority was afforded to wrecks with the highest polluting potential and not all wrecks were fully populated with additional data. This means that prior to the risk assessment being applied to the data a filtering of the dataset was already undertaken based on a series of assumptions made by ABPmer and MA ltd. This means that some potentially polluting wrecks may have incorrectly been afforded a low priority and no additional information added to the record. The resulting dataset is therefore not fully complete, and the risk assessment should not be considered an absolute authority on what wrecks may or may not pollute. Of the records in the database only 75% of the wrecks had enough information regarding their propulsion methodology and cargo to be assessed in relation to their pollution and safety risk. The remaining 25% could only be assessed on their safety risk (p24). A quarter of the database will therefore require population with additional data to enable adequate risk assessment, and the risk assessment will need to be re-run to include these wrecks to ensure that potentially polluting wrecks are not missed and that the assessment is in fact fit for use.

The risk matrix for the PPW3 assessment was as follows:

> Pollution Risk = Likelihood (of pollution release and impact) X Pollution Severity (amount & type of cargo)
>
> Safety Risk = Likelihood (of pollution release and impact) X Safety Severity (amount of explosives)(ABPmer, 2010 p18)

Given the age of the risk assessment the sources used to assess likelihood of impact (p20) are limited and dated, the risk assessment would benefit from the inclusion of more recent open source datasets that are available, and this is discussed further in Chapter 5. Unfortunately there is no confidence factor associated with each risk and the uncertainties associated with wreck condition, pollution amount etc. are not explicit in the risk assessment outcome.

The risk assessment was produced in GIS and maintained in a geodatabase format. It conformed to MIDAS heritage standards and MEDIN metadata standards ensuring consistent naming conventions throughout the dataset and clear metadata. ABPmer also created an importation tool to bring in UKHO wreck information but as they noted, any detailed updates to the risk assessment needed to be manually undertaken (p25). They also recommended further updates and population of the remaining 25% of wrecks that were unable to be assessed, however, it is unclear if this work was ever undertaken.

As a result of the difficulties in updating the database manually and having to re-run the risk assessment each time new information is added the PPW3 dataset is difficult to use and manage. Updating the database with new wreck information and the risk assessment with new spatial datasets to calculate likelihood of impacts is likely to be time consuming but is considered necessary if this risk assessment and database is to be used moving forward. Remediating the wreck location errors caused by co-ordinate transformation is also necessary to ensure that the subsequent risk assessment is accurate. The risk assessment would need to be re-run incorporating these amendments and updates.

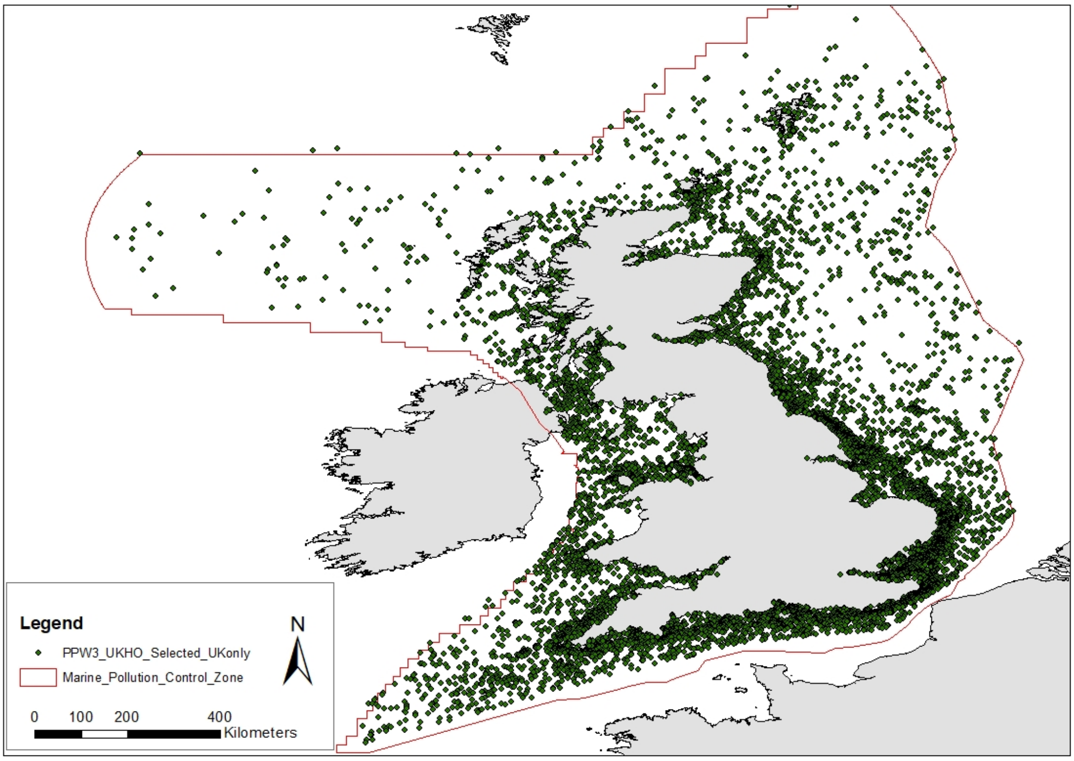

Figure 19 Potentially Polluting Wrecks 3 database, clipped to the UK Marine Pollution Control Zone. (author's own image).

4.2.3 Potentially Polluting Wrecks 4

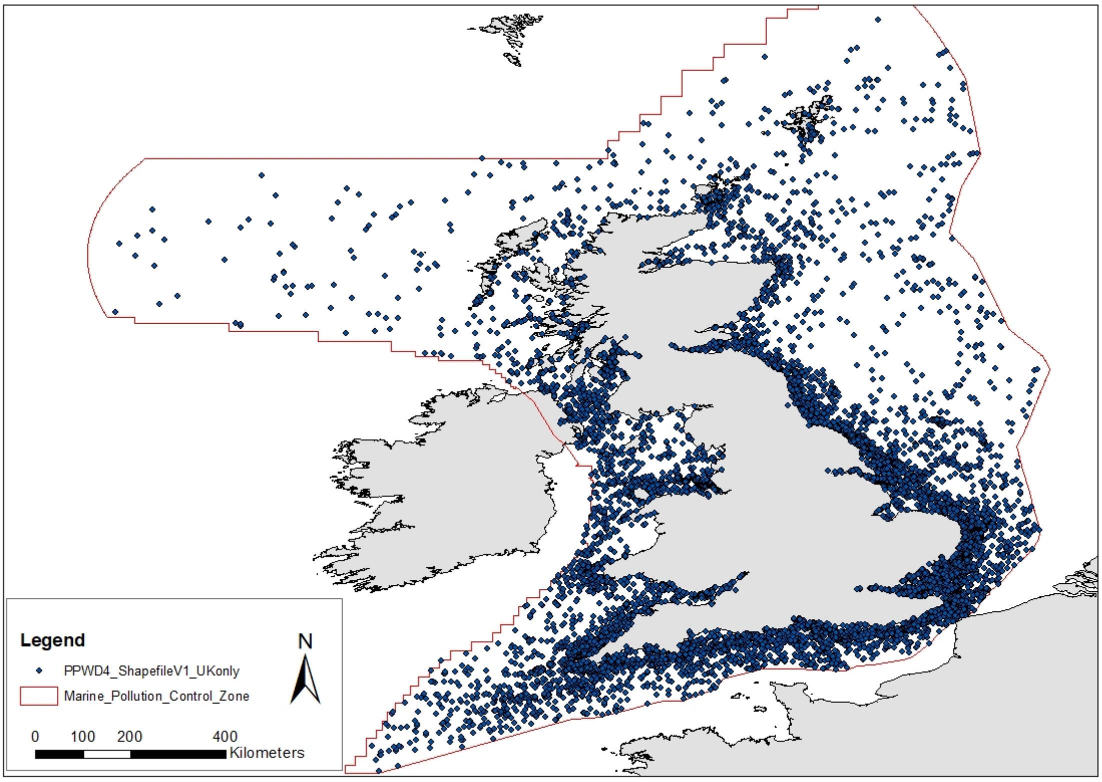

Figure 20 Distribution of PPWD4 shipwrecks in UK waters (author's own image).

Maritime Archaeology Ltd (MA ltd) in partnership with SeaZone Solutions Ltd (SeaZone) were commissioned to produce the Potentially Polluting Wrecks 4 Database (PPWD4) and accompanying risk assessment (Dellino-Musgrave and Merritt, 2011). PPW4 simplifies the PPW3 risk assessment and the database includes British military wrecks sunk from 1870 outside of UK waters that might pose a pollution threat.

The database was built using data from the PPW3 (ABPmer, 2010), UKHO, AMAP2 (SeaZone Ltd, 2011), Wessex Archaeology (2006) and Bournemouth University (Parham and Palma, 2007) databases. Unfortunately, as the database is largely based off the PPWD3 the positional errors that appear in that database for some of the wrecks also carries across into PPWD4. A total of 710 records of British military wrecks outside of UK waters were identified and included in PPWD4. Vessels were excluded from the database if they were leisure vessels, fishing vessels, had been salvaged or were not shipwrecks (e.g. debris or aircraft). Additional desk based research was conducted on military wrecks to determine if they posed a polluting potential, no further information was conducted on civilian vessels. There is therefore a possibility that some civilian vessels within the database may have a polluting potential but are not identified as there is not enough information associated with them in order to inform the risk assessment.

The database was compiled in Microsoft Access (MS Access) and can be viewed in GIS software, however, all edits to the database should take place in MS Access. According to the final report (Dellino-Musgrave and Merritt, 2011) the database contained 23,105 wrecks. However, the GIS shapefile for the wrecks provided by the MoD for this project contains 23,498 records. It is likely that this discrepancy has occurred during updates to the database by the MoD subsequent to the completion of the project by MA ltd. When the current database is clipped to the UK CPZ the number of records for the UK zone is 9,938 wrecks.

The PPW4 risk assessment features a Structured Query Language (SQL) based grading of risk variables and is therefore heavily reliant on the accuracy of the information entered into the database fields. Unlike PPWD3, PPWD4 does not follow the MIDAS heritage standards (English Heritage, 2012) and follows the naming conventions utilised in the UKHO database. Ostensibly this is so that the automatic update tool that was created alongside the database would be able to seamlessly sync with the UKHO database to add new wrecks identified by the UKHO to the database.

Unfortunately, the lack of naming convention and standards for the database means that over time as the database has been manually updated the fields have been populated with non-standard entries. This is evidenced in fields such as ‘Vessel Type’ where an “Armed Steamship” is also referred to as an “Armed SS”, parts of the vessel are described as “Bow section” and “Bow

Section only", and there are entries such as "cannon" and "cannon site" etc. It is also apparent in the Nationality field where British wrecks are described as "British", "Btitish" and "English". "Cyprus" and "Cypriot" wrecks appear as well as "Belgium" and "Belgian" etc. This also carries through to cargo type and quantities of cargo where the information is not consistent, often cargo quantities can be found in cargo type and vice versa. While MIDAS heritage standards might not be suitable for all fields in the database, standard vocabularies should at least be applied to the nationality and vessel type, preferably in line with the FISH thesauri (Forum on Information Standards in Heritage, 2019f) for vessel type and nationality (Forum on Information Standards in Heritage, 2019e, 2019c). Additional thesauri exist for circumstances of loss, maritime place names and cargo (Forum on Information Standards in Heritage, 2019a, 2019b, 2019d) which might also be applicable in this context. These inconsistencies in vocabulary are found throughout the database. Given the risk assessment is SQL based and reliant on consistent naming and data vocabularies the lack of standard vocabulary means that the risk assessment cannot currently be run on the database without the data being homogenised. It is therefore not possible to update the risk assessment as new information is added to the database, and as a result this undermines the initial value and utility of the automated UKHO update tool.

It is also impossible to undertake in depth statistical analysis of the database in GIS as a standard vocabulary is required to conduct statistical analysis using SQL scripts. The full database is too large to export and therefore data analysis can only be performed on parts of the database once it has been clipped to a region and exported (see section 4.2.6 for further analysis of PPWD4 in UK waters). The database requires full review and adjustment which can only be performed manually, due to time constraints a full clean-up of the database was beyond the scope of this thesis.

The risk assessment itself is a simplified version of the PPW3 risk assessment, with similar variables and risk ratings and is conducted in MS Access. The factors were divided between physical factors and environmental factors which were then weighted in accordance with expert input from the MoD. As with PPW3 the data for environmental factors was somewhat limited at the time of creation of the risk assessment and there are additional environmental factors that might be included based on current available datasets, this is further discussed at Chapter 5. The assessment produced three risk calculations namely, cargo risk, location risk and condition risk. The MS Access database was then brought into GIS and spatial analysis was conducted to determine the distance of wrecks from affected features or protected areas and this was included in the risk assessment. It is therefore not entirely clear which of the wrecks are considered to be highest risk as this information is not included in the values in the MS Access database (which are carried through to the GIS attributes table), but is based upon a combination of the risk values and expert opinion in relation to the spatial analysis in GIS. Ideally the risk assessment should be updated so that the spatial assessment becomes an inherent part of the risk assessment.

As with PPW3 the PPW4 risk assessment was conducted on all of the wrecks in the database, this includes wrecks that have a very low pollution potential based on their method of propulsion (e.g. sail/steam) and their cargo (e.g. soluble or natural materials). Therefore not every wreck within the database is likely to pose a pollution risk, or may only pose a localised hazard. Further refining of the database was therefore required in order to identify those with a polluting potential, this is discussed further at section 4.3.

4.2.4 CEFAS Risk Assessment

The latest risk assessment commissioned by the MoD was conducted by the Centre for Environment Fisheries and Aquaculture Science (CEFAS) (Goodsir *et al.*, 2019), it focuses on assessment of individual shipwrecks rather than conducting an overarching risk assessment for the whole shipwreck dataset. While it does not generate a database associated with the assessment and does not attempt to quantify the number of polluting shipwrecks it does build on the risk assessment values, and utilises the information provided, in the PPW3 database and risk assessment.

Due to the lack of standardisation in existing polluting wreck risk assessment methods nationally or internationally (p291) CEFAS were commissioned by MoD SALMO to design a risk assessment to provide a standardised approach. However, as has been discussed at section 2.3 the VRAKA assessment (Landquist *et al.*, 2016) appears to have been adopted in Europe as the industry standard by many of the Baltic and North Sea states. It is unlikely that CEFAS' risk assessment will be adopted as an overarching high-level risk assessment as it is wreck specific and the time it would require to run such an assessment on every potentially polluting shipwreck identified at the quantification stage would render it impracticable. However, the aim behind the CEFAS study was to provide a detailed in-depth assessment of a specific wreck, it is therefore ideal as a secondary assessment methodology for wrecks that have been identified in the VRAKA, PPW3 or PPW4 MoD assessments as high risk or requiring further investigation, as it will give a more focused, accurate and detailed assessment of risk from these vessels. At present, CEFAS' assessment is limited to modelling oil spills it excludes pollutants of other kinds, though there is potential that this could be expanded to include a wider range of pollutants.

An additional aim of the CEFAS risk assessment was to develop assessments that took into account multiple oil spill scenarios, as existing risk assessments largely only examine the worst case scenario, therefore there is the potential for nuance in the CEFAS assessment that is not present in many other risk assessment methods (with the exception of the work undertaken by Ventikos *et al.* (2016)). This is particularly helpful in the UK where to date where wrecks identified as leaking oil have released their oil in increments rather than in a catastrophic single oil release event. However, given that management strategies are often decided with the worst case scenario in mind under what is known as the precautionary principle, it may be that this level of detail in a risk assessment is not actually that useful for the overarching risk management decision making process and is of more use at the point where a wreck has already been identified as leaking. There is a cost associated with running three models and therefore it may not make economic sense to run all three if only one model is likely to be used to inform decision making.

CEFAS' risk assessment (or E-DBA) forms the first part of a three stage process that is current standard practice for MoD polluting wreck risk management.

1. The Environmental Desk Based Assessment (E-DBA)
2. On-Site investigations
3. Intervention/remediation and monitoring

In their assessment the *Overall risk = Likelihood of oil release score X potential severity of environmental impact score*. The values and information for the likelihood of oil release are taken from the PPW3 assessment. Three models were created to demonstrate the potential severity of environmental impact, using two different oil spill modelling software (p293). These oil spill models were then analysed spatially against locations of ecological and socio-economic resources to give the final values for the severity of environmental impact score. The use of spatial data (where available) and oil spill models provides a far more detailed and accurate assessment of the potential impact of a spill from a wreck than previous risk assessments. The modelling of socio-economic factors goes further than previous risk assessments to attempt to understand not just the ecological impact of a wreck but also the impact a wreck might have economically or socially. However, it fails to take into account the impact of socio-economic factors on the likelihood of oil release, it considers them only as factors that might be impacted by a leak rather than factors that might also cause a leak, e.g. fishing equipment might damage a wreck (Krumholz and Brennan, 2015; Brennan *et al.*, 2016), or divers might interact with wrecks in a manner that promotes pollutant release. For a truly comprehensive assessment these should be included in the calculation of the likelihood of oil release, inclusion of this information and further examples are discussed at Chapter 5.

Their risk assessment relies heavily on assumptions made about wreck condition taken from the PPW3 risk assessment. They recognise that there is poor data availability about wreck condition and recommend that further survey and verification of wreck integrity is required. A discussion of whether existing datasets can provide better information on the integrity and the structural condition of wrecks, as well as about environmental conditions in the region of these wrecks is discussed at section 4.4.2 below.

4.2.5 PPW3 & PPW4 Database Comparison

The PPW4 database contains 23,498 records. This is 2,267 records less than the PPW3 database. This is likely to be due to a large number of shipwrecks in Irish waters that are not necessarily British wrecks being included in the PPW3 database. However, when both databases are clipped to the UK CPZ the discrepancy in the number of shipwrecks is reduced to 40, with more shipwrecks within the PPW4 database than in the PPW3 database. This further emphasised the need to limit the assessment of the wrecks to UK waters where discrepancies in the databases were less significant.

The select by location feature of ESRI’s ArcGIS software was utilised to determine how the shipwrecks correlate across the two databases. Differences in the numbers of matching/non-matching wrecks is down to wrecks being added or removed based on different information feeding into the risk assessments for each database. Table 6 gives a breakdown of the comparative data between the two datasets within the UK CPZ. As demonstrated there are approximately 2,600 wrecks that do not correlate across the datasets.

Unfortunately due to the substantial differences in the databases in terms of their fields, unique ID’s and contents it was not possible to undertake database regression to determine exactly which records were included or not included in each database. This would need to be manually investigated and due to time constraints was beyond the scope of this thesis.

Table 6 Correlation of shipwreck locations across PPW3 and PPW4 databases

		Comparison dataset	
		PPW3	PPW4
Source dataset	PPW3	9,898 wrecks	7,307Matching 2,631 Non-Matching
	PPW4	7,319Matching 2,579 Non-Matching	9,938 wrecks

In order to move forward with an assessment of the UK’s wrecks it was decided that PPW4 provided the best dataset to work from as it contains 40 more shipwrecks than PPW3 within UK waters and is therefore likely to be more complete, additionally it has the most recent risk assessment (Maritime Archaeology Ltd and SeaZone Ltd, 2011).

4.2.6 PPWD4 Data Analysis

4.2.6.1 Vessel Tonnage

An initial examination of the 9,938 wrecks in the PPWD4 data for the UK CPZ shows that only 4,760 wrecks have information regarding their tonnage (47.9% of the database). Analysis of the dataset where over half of the dataset has no information regarding tonnage is not likely to be wholly accurate, however, it does enable us to draw out some potential areas for further investigation and concern. Of those 4,760 wrecks with data, vessels of less than 1000GT form 39% of the dataset with a total of 1,855 wrecks under 100GT. Vessels under 2000GT comprise a further 25% of the dataset (1,189 wrecks) (Figure 21). It is evident that while very large vessels are considered to have the highest impact when a polluting incident occurs, their frequency in the data is relatively low in comparison to the frequency of vessels of up to 3000 GT. Figure 22 shows the same data broken down into vessel tonnes rounded up to the nearest 100GT. It is clear from this chart that there is a trend where there are fewer wrecks in the database as vessel tonnage increases.

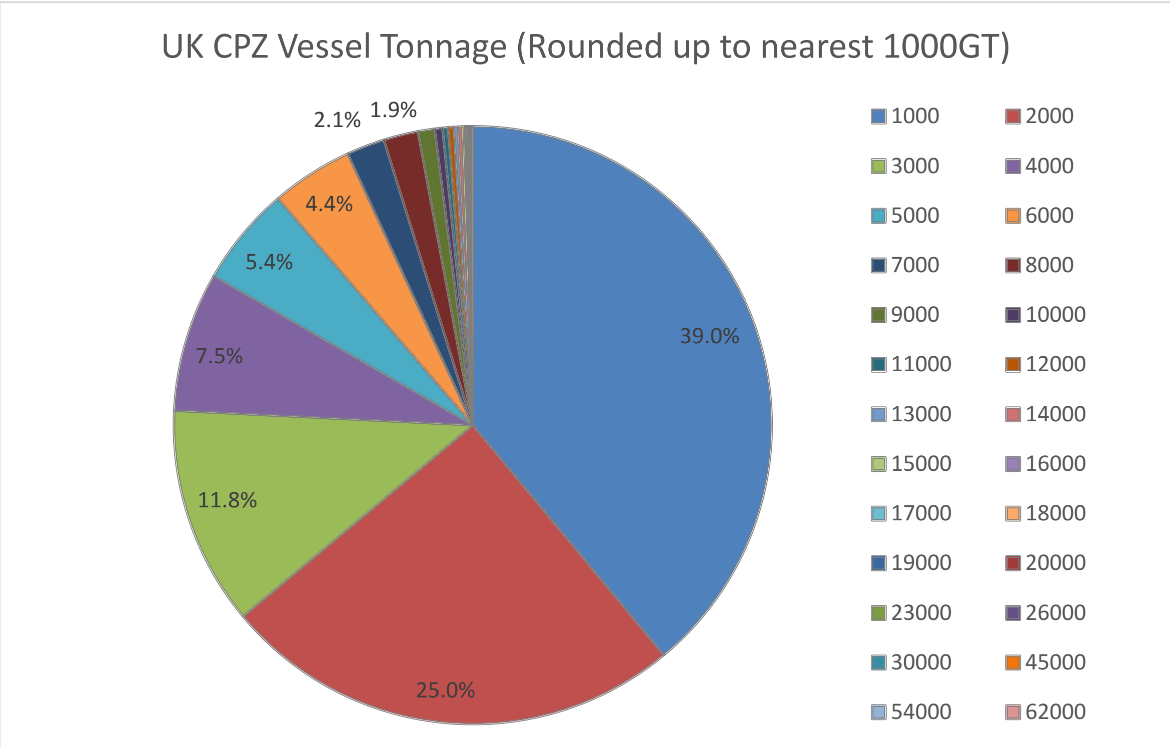

Figure 21 PPWD4 UK CPZ Vessel Tonnes (rounded to the nearest 1000 GT). (author's own image).

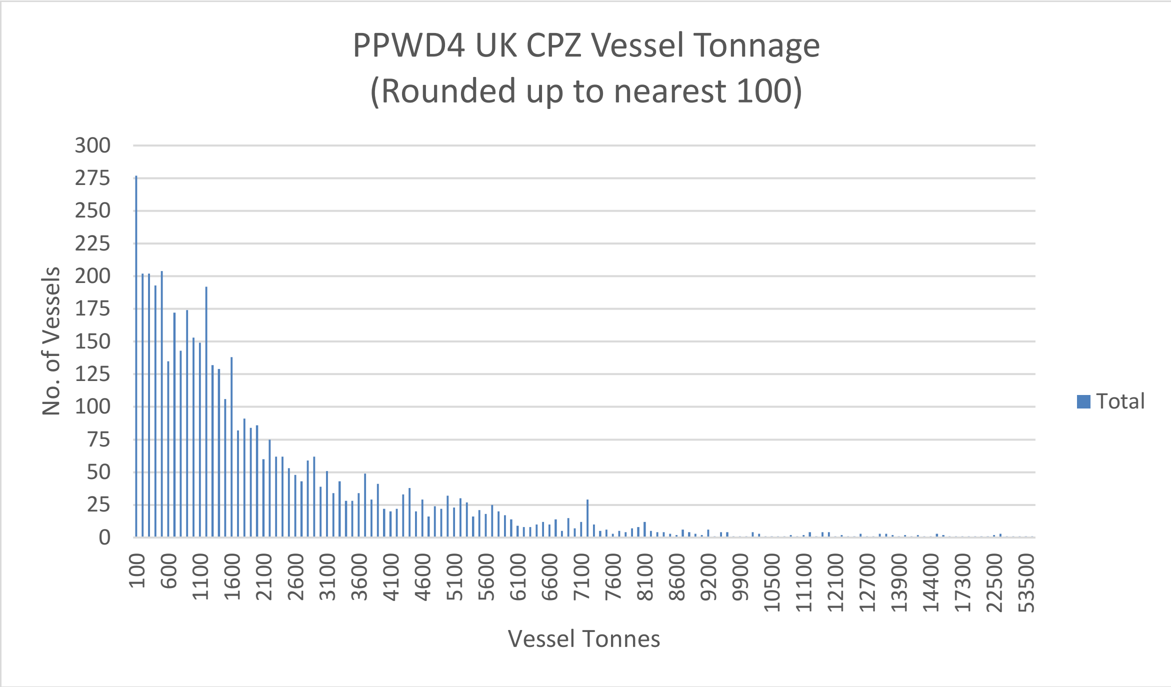

Figure 22 Vessel tonnage for PPWD wrecks in the UK CPZ (author's own image).

There are 277 wrecks with a tonnage of less than 100GT in the PPW4 UK CPZ, these would normally be removed from risk assessments as they are widely considered to be less of a risk than larger vessels due to their limited carrying capacity for polluting materials. However, the risk from vessels is also tied into the water depth as this determines whether pollution is likely to reach the surface and/or affect shore related sites which have a greater social and political impact than vessels that might pollute in deep waters. Research conducted by Ventikos et al. demonstrated that even vessels leaking a small quantity of oil can have catastrophic impact when located close to the shore in shallow water (2016, p. 11). Figure 23 shows that the vast majority of the wrecks with less than 100GT are situated in less than 50m of water and therefore are relatively close to the shore and to these sensitive sites. Additionally, a large proportion of these wrecks are situated in 30m of water and are accessible by sports divers, they are therefore vulnerable to human related impacts that might inadvertently cause a pollutant release. Conversely, these sites are also the most monitored sites as they are likely to be the most visible to the public who would report any pollution resulting from these sites, and the easiest to remediate based on their shallow depth. Therefore, provided there is an open conversation with diving groups and a facility for reporting any pollution from these sites they are relatively easy to manage.

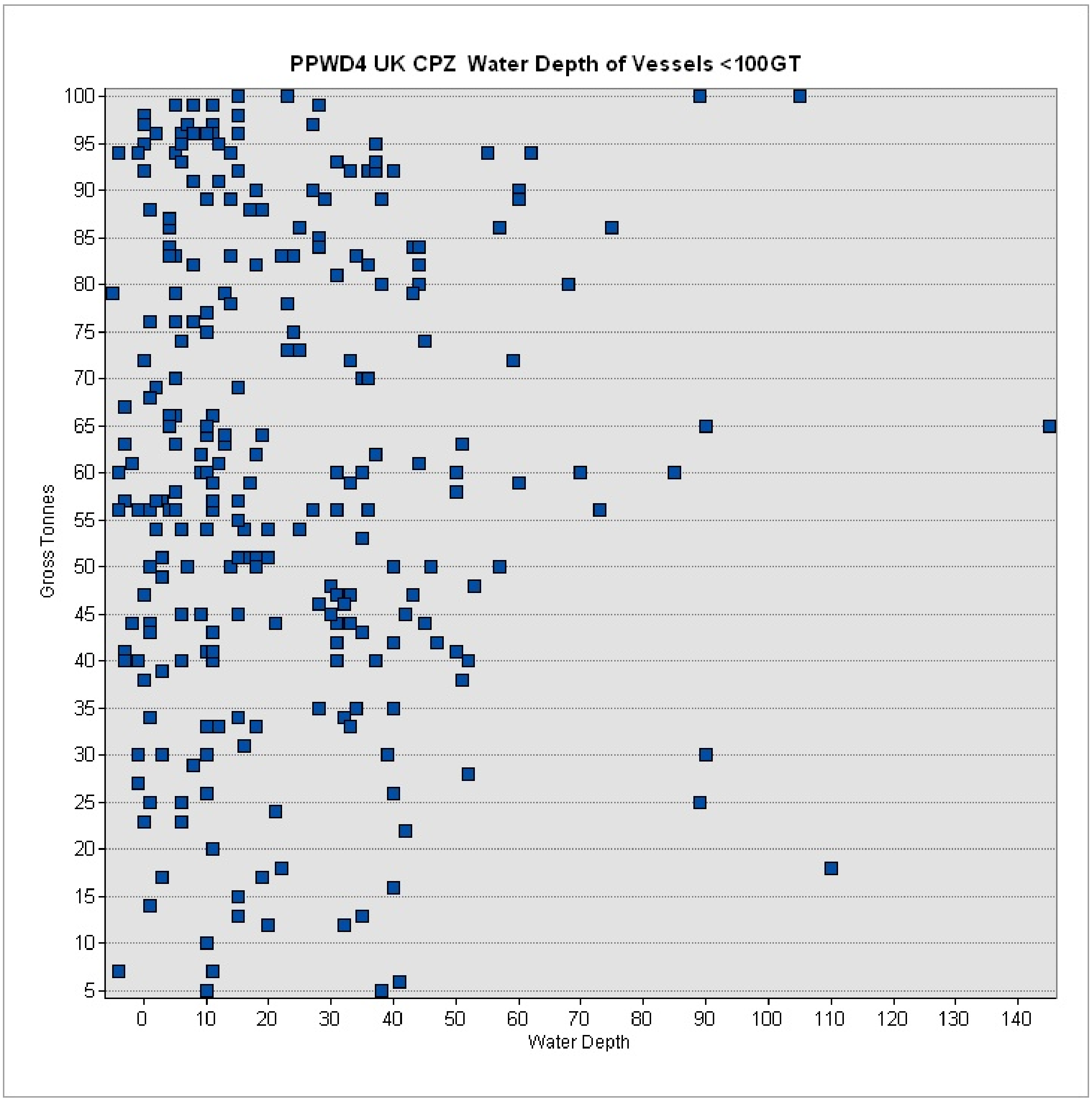

Figure 23 PPWD4 UK CPZ Vessels of <100GT by Water Depth (author's own image).

Given the number of vessels of less than 100GT there may be an aggregated risk from these vessels which could be significant, particularly if they are concentrated in a localised area. Figure 24 shows a heat map of the vessel density of vessels of less than 100GT within the UK CPZ from PPWD4. While the majority of the UK is unlikely to be affected by pollution from vessels of less than 100GT there is a particularly high concentration of these vessels in the approaches to the port of Liverpool, and on the east coast of the UK in the approaches to the ports of Hull, Great Yarmouth/Lowestoft and the Thames. These are therefore the regions most likely to be affected by aggregated pollution from vessels of less than 100GT. These are all sites of critical national infrastructure, so the impact of any pollution event is likely to be economically and socially significant, even from relatively small vessels (this is further discussed in Chapter 5). Fortunately, the likelihood of concurrent pollutant release from a group of vessels is low. Determining cause of pollution and attributing pollution to legacy wreck in these areas is likely to be difficult as pollutant spills are likely to be attributed to the high density traffic of modern shipping in these areas in the first instance.

A comparison with a heat map by vessel tonnage of all vessels in UK waters shows a far greater spread of wrecks throughout UK waters (Figure 25), however, the area of the Thames Estuary features the greatest density of vessels by tonnage and is therefore most likely to be affected by a polluting event from legacy wreck. Other areas of concern are the ports already discussed above, as well as parts of the South and Cornish coasts, and the Orkneys which also have a relatively high density of larger vessels. Both Cornwall and Orkney have been subject to wreck related oil spills (see Chapter 2) and support the evidence of the heat map regarding the importance of further investigation into wrecks in these regions.

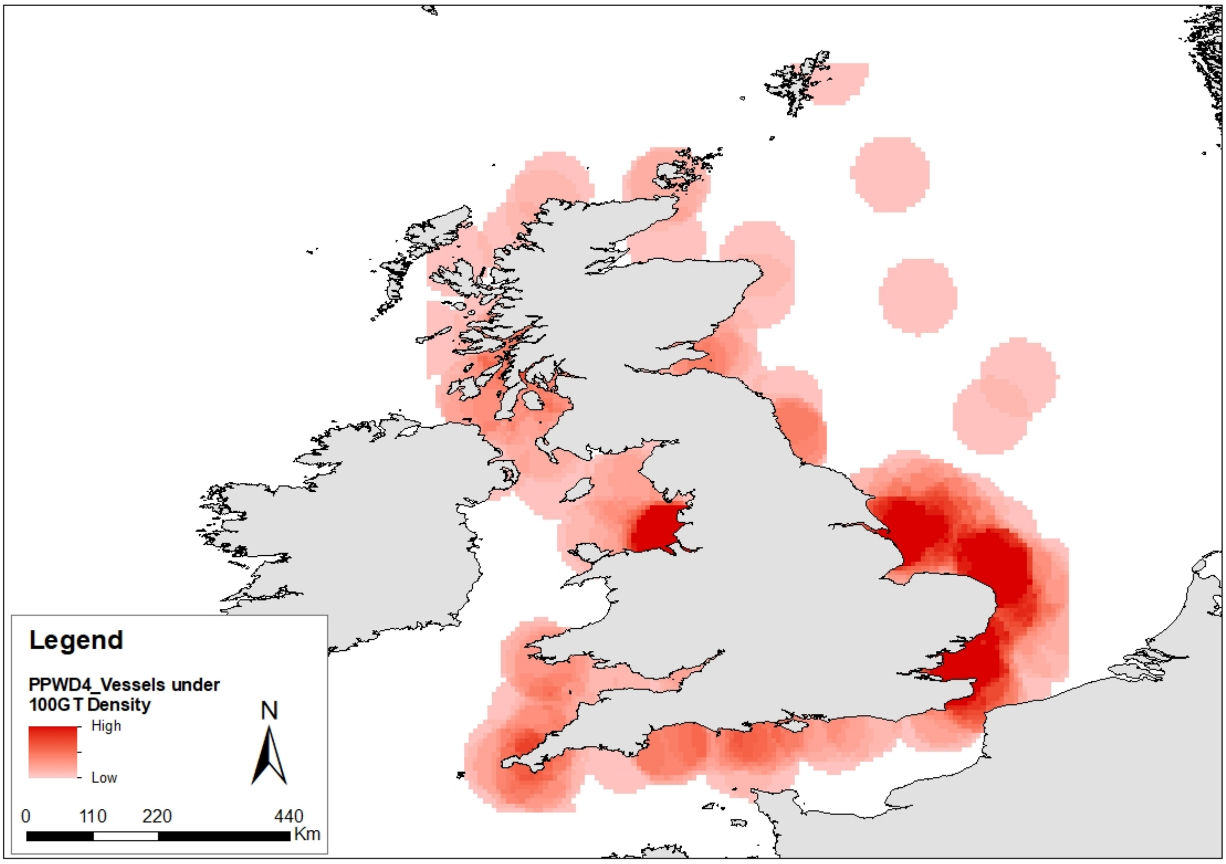

Figure 24 Heat map showing PPWD4 UK CPZ density of vessels of <100GT. (author's own image).

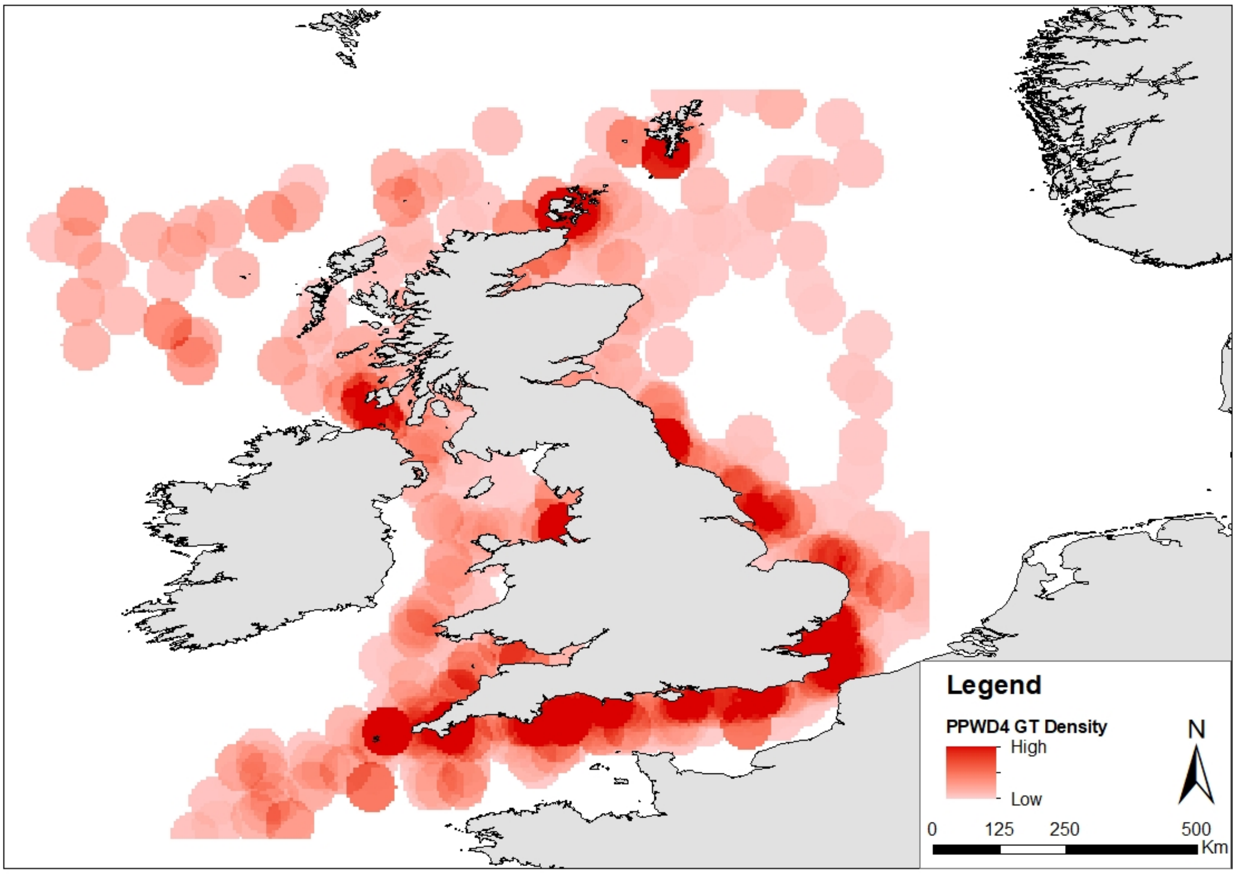

Figure 25 Heat map of PPWD4 UK CPZ Vessel density by tonnage. (author's own image).

4.2.6.2 Vessels by Year Lost

Approximately 42% (4, 179 vessels) of the PPW4 UK CPZ wrecks were missing information regarding the date of their loss. Examination of the vessels with dates of loss in the PPWD4 UK CPZ data demonstrates that the vast majority of wrecks in UK waters were lost in the First and Second World Wars (Figure 26). A total of 2,035 wrecks were recorded in the database as being lost between 1914 and 1918 (WWI), and 1,487 wrecks between 1939 and 1945 (WWII). The years featuring the heaviest losses were 1917 (732 vessels), 1918 (653 vessels) and 1940 (583 vessels) respectively. By comparison, a total of 2,237 vessels were recorded in the database as being sunk outside the World Wars between 1870 and 2010 in the UK CPZ, the number of wrecks sunk during WWI is only 202 wrecks short of the total number of wrecks sunk over 128 years (excluding the war years). The number of vessels lost in WWI was unprecedented. As this database is limited to UK waters and 42% of the database has no values for the year of loss, the numbers are likely to differ if considered globally and with a full dataset.

The nature of shipping at this time means that the majority of the wrecks sunk during both Wars are likely to have carried some form of armament. Wrecks sunk during these years are therefore likely to pose a pollution risk from ERW as well as any cargo or oil related pollution. If WWI and WWII are excluded from the data an average of 17.5 vessels are lost per year. The data peaks show that there is an above average number of wrecks sunk for several years after WWI, but that numbers of wrecks sunk after the end of WWII return to roughly around the annual average within a year. This is potentially due to the better technology and capability for de-mining available at the end of WWII resulting in less vessel losses occurring from legacy munitions. Unfortunately due to inconsistent vocabulary in the database for cause of vessel loss, it is not possible at the present time to fully analyse this connection. These wrecks are also likely to carry far greater social and political restraints on how they are managed due to their war related histories, and the potential for them to be considered by the public as "war graves", the implications of this is further discussed at Section 5.4.2.

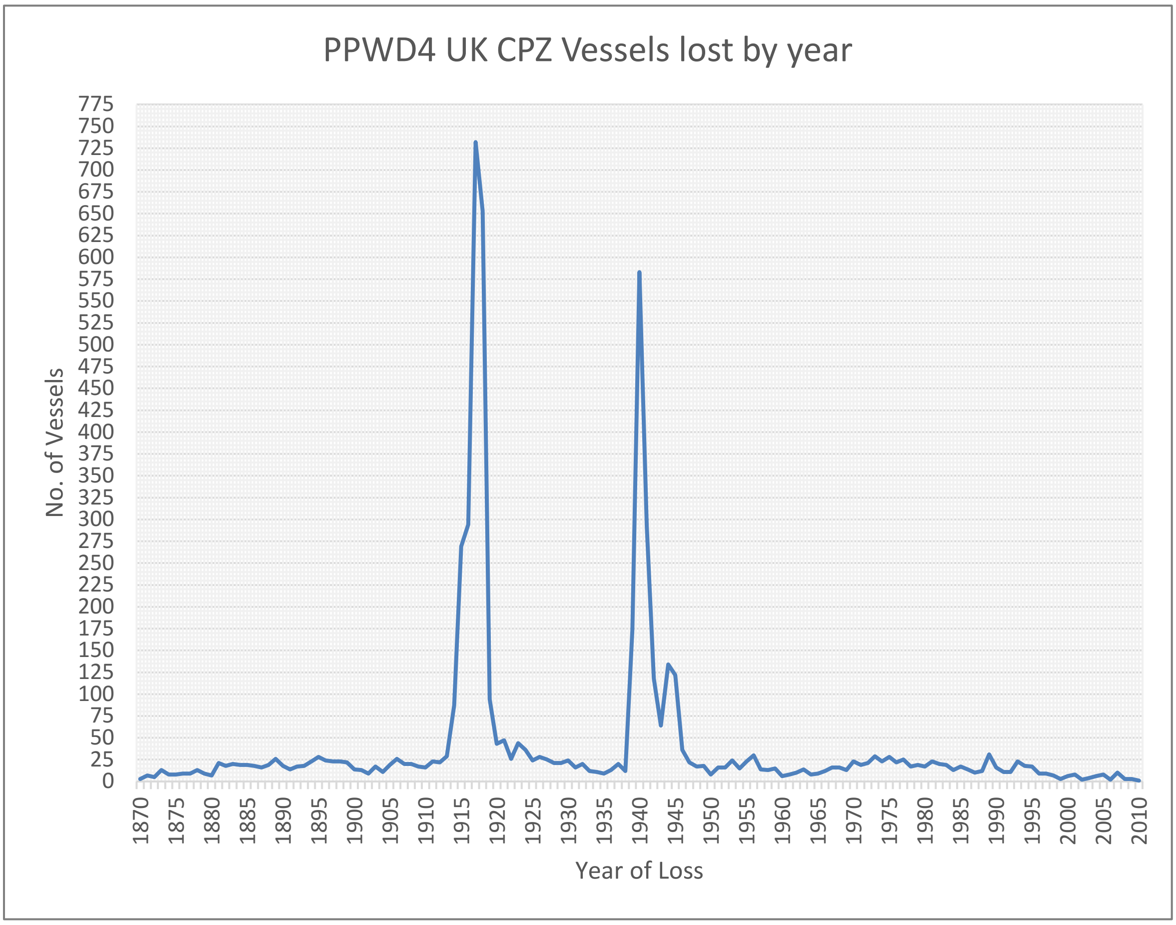

Figure 26 PPWD4 vessels lost by year in the UK CPZ (author's own image).

4.2.6.3 Vessels in CHP survey areas

Of the 9,983 wrecks in the PPWD4 dataset 7,223 are located within UKHO and Civil Hydrograph Programme surveyed areas (approximately 72.5% of the dataset). 27.5% of the wrecks in the database have no survey coverage and the locations of these wrecks is therefore unconfirmed. As previously discussed (section 4.1) only 25% of the CHP survey data is likely to have a suitable resolution for accurately locating and identifying a wreck, it is therefore likely that a large proportion of these wrecks require further survey or ground truthing in order to confirm their location and their identify. Without full examination of the available bathymetry for the UK, which is beyond the timescales available for this PhD thesis it is not possible to determine what percentage of the wrecks are covered by suitable resolution bathymetry data. Further analysis in the future of the available CHP datasets would enable us to determine which wrecks require additional survey, and which are suitably covered by an appropriate resolution of data.

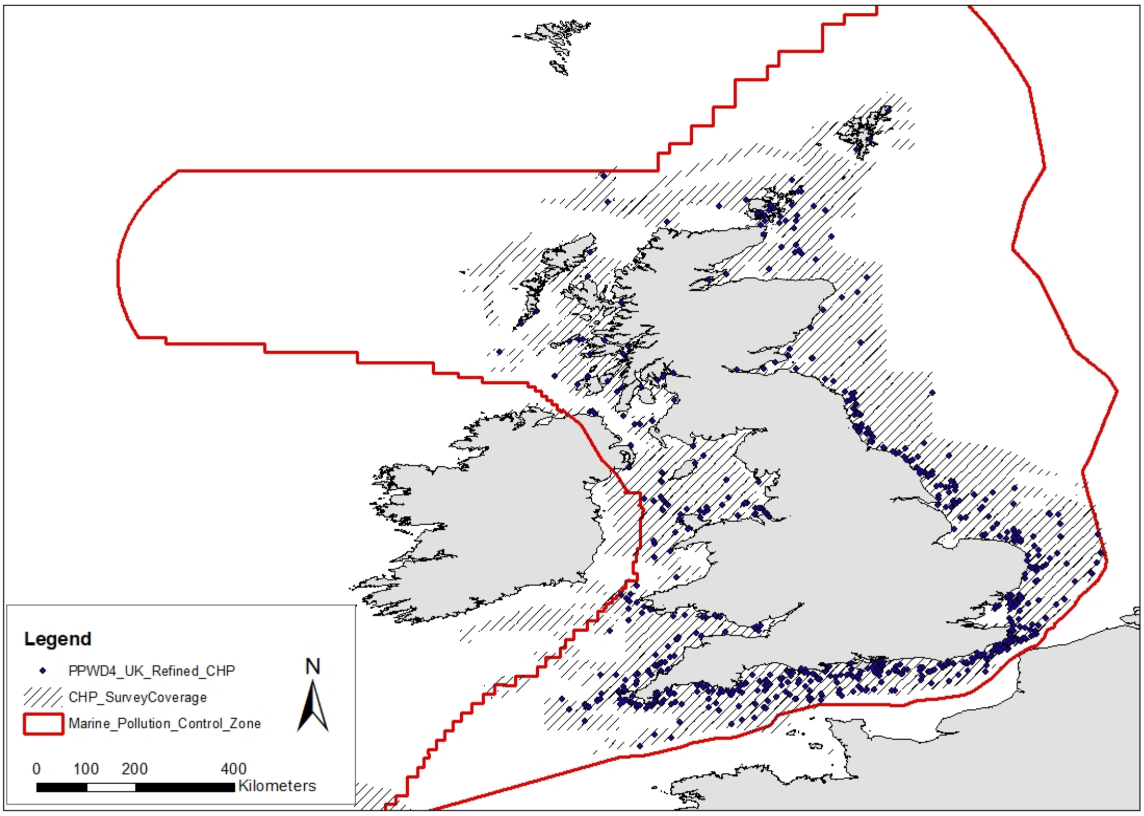

Figure 27 PPWD4 UK PCZ wrecks with CHP survey coverage (author's own image).

Due to inconsistent use of vocabulary in the PPWD4 database further analysis of the database would require full review of the database and amendment of the data in many of the fields. Due to time constraints this was not possible for the full 9,953 wrecks. However, as the database contains wrecks that do not necessarily pose a significant polluting potential, such as wrecks powered by sail and with a non-hazardous cargo, the decision was made to refine the 9,953 wrecks further based on the existing information in the risk assessment to give a more manageable dataset for review and further analysis.

4.3 PPWD4 Refinement

The first stage in refining the dataset from the 9,938 wrecks within the UK CPZ was to remove any wrecks identified by the UKHO as "dead" or "lifted" as these are unlikely to be present on the seabed. This resulted in a total of 7,929 wrecks to further refine.

The next step was to determine which wrecks had enough information to successfully inform the risk assessment process. Wrecks with null values for all of the following categories were removed from the list as without this information the risk assessment was essentially meaningless:

- Vessel width,
- Vessel length,
- Displacement
- Vessel Tonnage
- Cargo
- Capacity
- Fuel Type
- Cargo Type
- Cargo Tonnage

Wrecks that had information in at least one of the above categories were retained within the dataset.

The dataset was further refined by removing wrecks that were not oil powered and did not have a hazardous cargo. Any oil powered wrecks of less than 100 GT were then removed provided they had no hazardous cargo as wrecks of this size are deemed through other studies and by modern pollution legislation to be too small to have a significant polluting potential, although future studies may wish to include these based on the findings from section 4.2.6.1 . Any wrecks with a hazardous cargo were retained in the dataset. This resulted in 953 shipwrecks that are considered to have a polluting potential within the UK CPZ, a flowchart of this process is shown in Figure 28.

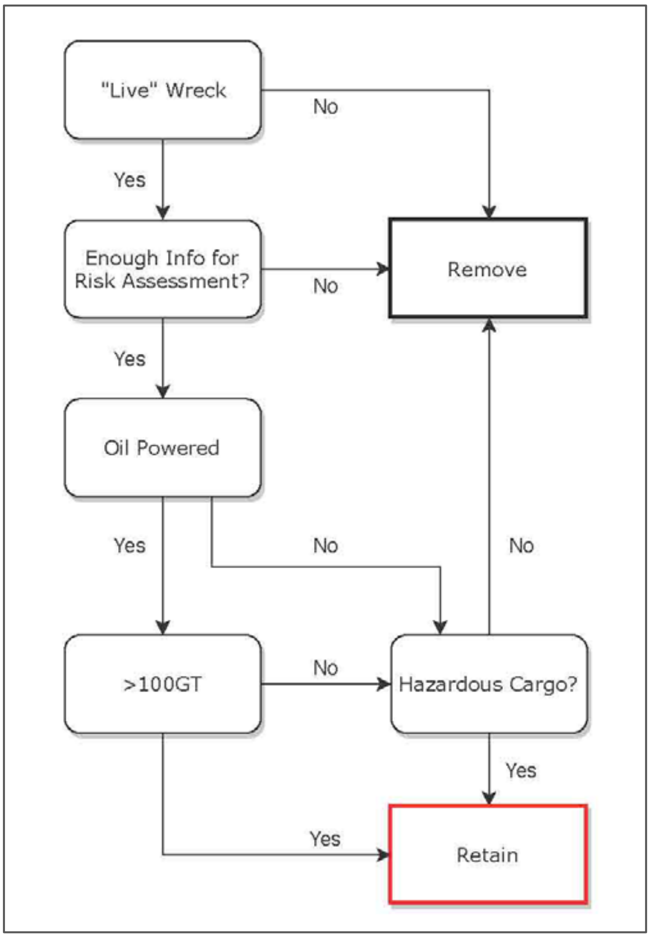

Figure 28 Flowchart of the PPW4 Database Refinement Process. (author's own image).**Refined Database Analysis**

To conduct further analysis on the data the vocabulary in the dataset needed to be homogenised. Rather than apply this to the whole dataset which would have been incredibly time consuming, the decision was made to only undertake this work on the wrecks within the UK CPZ that had undergone the refining process. As previously discussed, the Forum on Information Sharing in Heritage (FISH) provides several vocabularies that include vessel type, vessel destinations, cargo description and manner of loss terminology for use in building databases (Forum on Information Standards in Heritage, 2019f), these were applied to the 953 wrecks of the refined dataset.

In addition to the information discussed in the following subsections the wrecks were analysed on their fuel type. 225 of the wrecks had no data regarding their fuelling, although the majority of these were identified as submarines in the database so were likely have had diesel-electric motors. 275 of the wrecks are recorded as being steam driven. The remaining 453 wrecks were powered by a variety of means including diesel, oil and petrol, these wrecks are likely therefore to have a polluting potential from their propulsion method in addition to any prospective polluting cargo they may contain.

There are 338 recorded military wrecks in the dataset, these vessels have an increased potential for munitions related pollutants. It is likely that a number of the wrecks that sank in WWI and WWII were also defensively armed (Rowbotham, 1947), information in the database identifies that at least 156 of the wrecks in the dataset were known to be armed or to have a cargo of munitions. This number includes those wrecks related to munitions dumping post WWII.

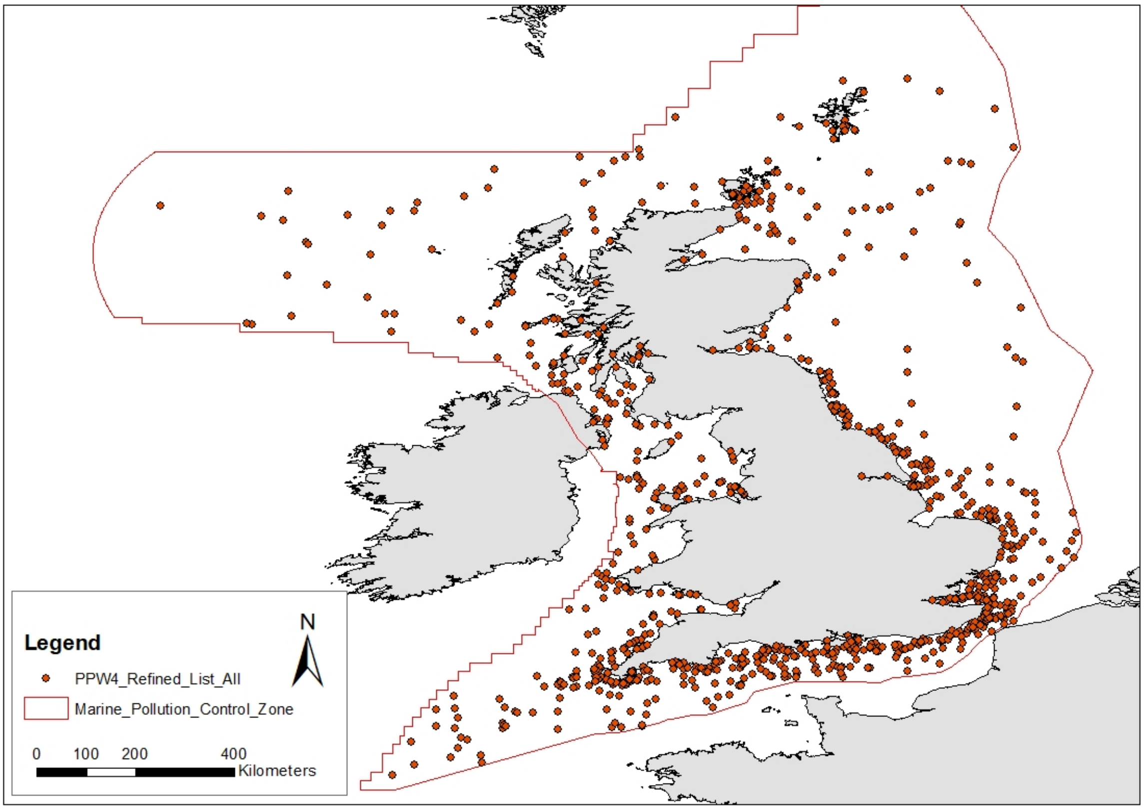

Figure 29 Location of Refined PPWD4 Shipwrecks. (author's own image).

4.3.1.1 Vessel Tonnage

The vessel tonnage statistics of the refined database follow a similar pattern to those of the overarching PPWD4 dataset for the UK, with frequency of vessel increasing to 400GT and then decreasing with increasing vessel tonnage (Figure 30). Of the 953 refined wrecks, 45 had no information on their tonnage (4.7% of the dataset). 459 of the wrecks were under 1000GT (48%) (Figure 31). The majority of vessels under 100GT have been removed from the database, only 14 remain that contain hazardous cargoes. The mean vessel tonnage across the refined dataset is 2,626GT.

When compared to the tonnage of vessels that have previously caused oil spills in UK waters (e.g. the *Torrey Canyon* – 61,263 GT or HMS *Royal Oak* – 29,000GT) the majority of the vessels in the dataset are relatively small. However, the majority of the wrecks are located in relatively shallow waters (>200m) with 64% of the wrecks located in 50m of water or less. Therefore even as relatively small vessels any pollution resulting from these wrecks may be a cause for considerable concern as they are close to the shore and more likely to have an impact on the coastline, and have a greater social and political impact than those in deeper waters. 435 (46%) of the wrecks are within 30m water depths and therefore accessible by sports divers. As mentioned previously (section 4.2.6.1) the ability for divers to reach these wrecks can have both advantages and disadvantages, this is further discussed in section 5.3.5.2.

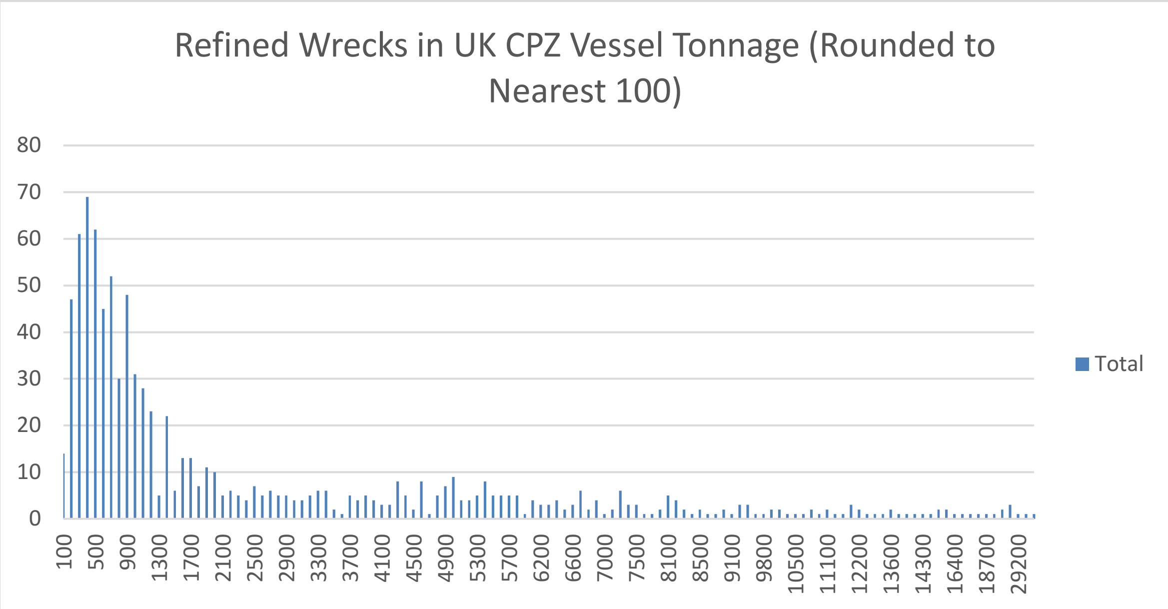

Figure 30 Refined database UK CPZ Vessel Tonnage to nearest 100GT. (author's own image).

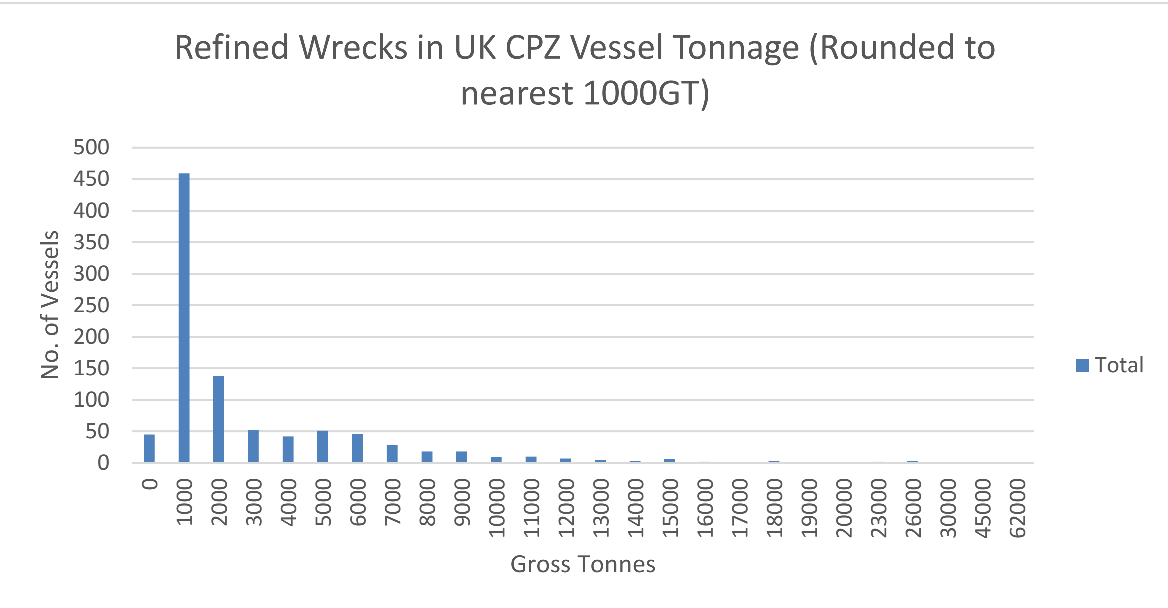

Figure 31 Refined database UK CPZ Vessel Tonnage to nearest 1000GT. (author's own image).

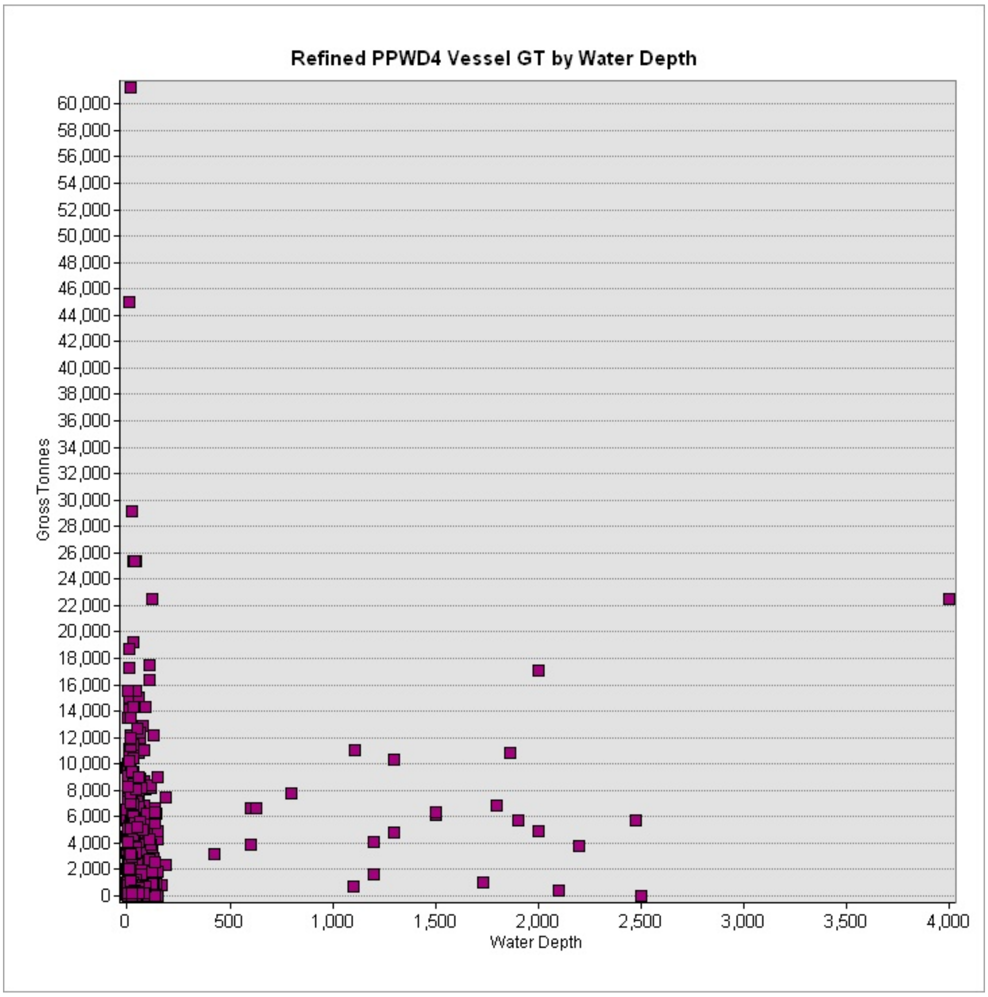

Figure 32 Refined PPWD4 Vessel GT by Water Depth (author's own image).

4.3.1.2 Vessels by Year of Loss

While the overarching trend for the refined database is similar to that of the overarching PPWD4 and shows peaks in vessel loss for WWI and WWII there are some key differences. Of the 953 wrecks in the refined list, 10 vessels contained no information on the year of loss. From the information displayed in Figure 33 we can see that unlike the overarching database which contains a greater number of vessels lost in WWI than WWII, here we have a higher number of potentially polluting vessels sunk during WWII than in WWI, this makes logical sense, as during WWI the majority of vessels were still steam powered rather than oil or diesel fuelled, and therefore less likely to pollute than vessels from WWII so will have been removed during the refinement process. The number of wrecks that are considered potentially polluting and were sunk prior to WWI is much lower than the number of wrecks sunk during this period in the overarching database, this is likely due to either a lack of information on cargo from this period, or again, the fact that the majority of these vessels were steam powered.

Vessels lost post-WWII see a gradual increase from the 1950's until the late 1970's/early 1980's. This is likely due to increased shipping during this period as the invention of the shipping container by Malcom McLean in the 1950's resulted in greater efficiency in transport of cargo by sea and an increase in maritime trade (Levinson, 2006). The adoption of increasingly larger container ships from the 1970's onwards means that these vessels have a far higher probability of being polluting not only due to their cargo, but also due to the amount of fuel carried in order to run the vessels themselves. The number of potentially polluting wrecks decreases from the late 1980's, this is possibly as a result of the stringent environmental legislation and liability schemes being introduced (previously discussed in Chapter 3), and the introduction of digital navigation aids. Vessels that sank from the introduction of the legislation should have been subject to immediate remediation and salvage by the vessel owner, therefore there are fewer wrecks from this period that pose a polluting threat.

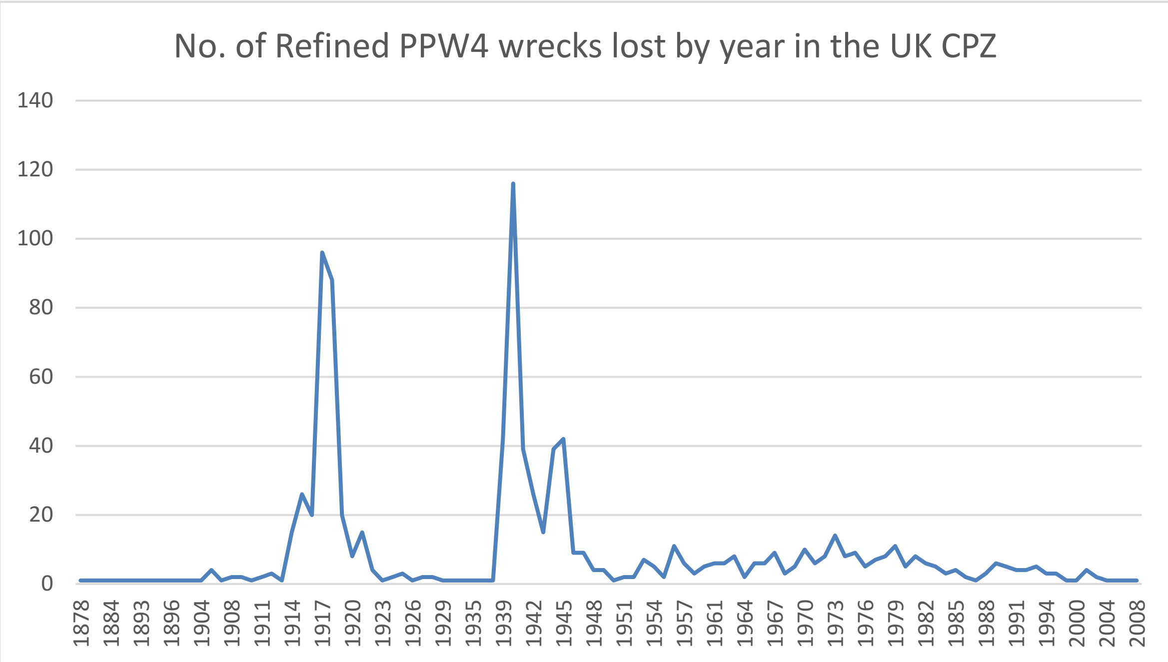

Figure 33 Refined PPWD4 Vessels by Year Lost (author's own image).

4.3.1.3 Vessels by Type

An assessment of the vessels by Vessel type identifies cargo vessels form the greatest proportion of potentially polluting vessels within the UK CPZ making up 27.4% of the dataset (261 vessels). Where possible the FISH vocabulary was used to identify the type of vessels. However, naming conventions for some of these vessels is complex, for example, the FISH vocabulary differentiates between "screw steamer" or "paddle steamer" but there was limited information in the existing database to identify which of these the vessels were, therefore the overarching term of "steamship" was utilised for ease. Steamships make up 18.2% (173 vessels) of the database. In reality it is likely that the majority of vessels recorded as steamships in the PPWD4 database are also cargo vessels so the percentage of cargo vessels in the database could be as high as 45.6% of the dataset (434 vessels), although some steamships may also fall within the “tanker” category. Submarines form 16.7 % of the dataset (173 vessels), while tankers make up 9.3% of the dataset (89 vessels) and Destroyers 6.5% (62 vessels). A full breakdown of the percentages and number of vessels per vessel type is provided at Appendix D. Some vessels could be recorded under other categories or are named as a subset of a larger category so while the values are helpful for an overarching estimate of the numbers of wreck per vessel type it these can change depending on how vessels are classified. Where the vessel category was uncertain it has been classed under the generic term “maritime craft” (41 wrecks, or 4.3%).

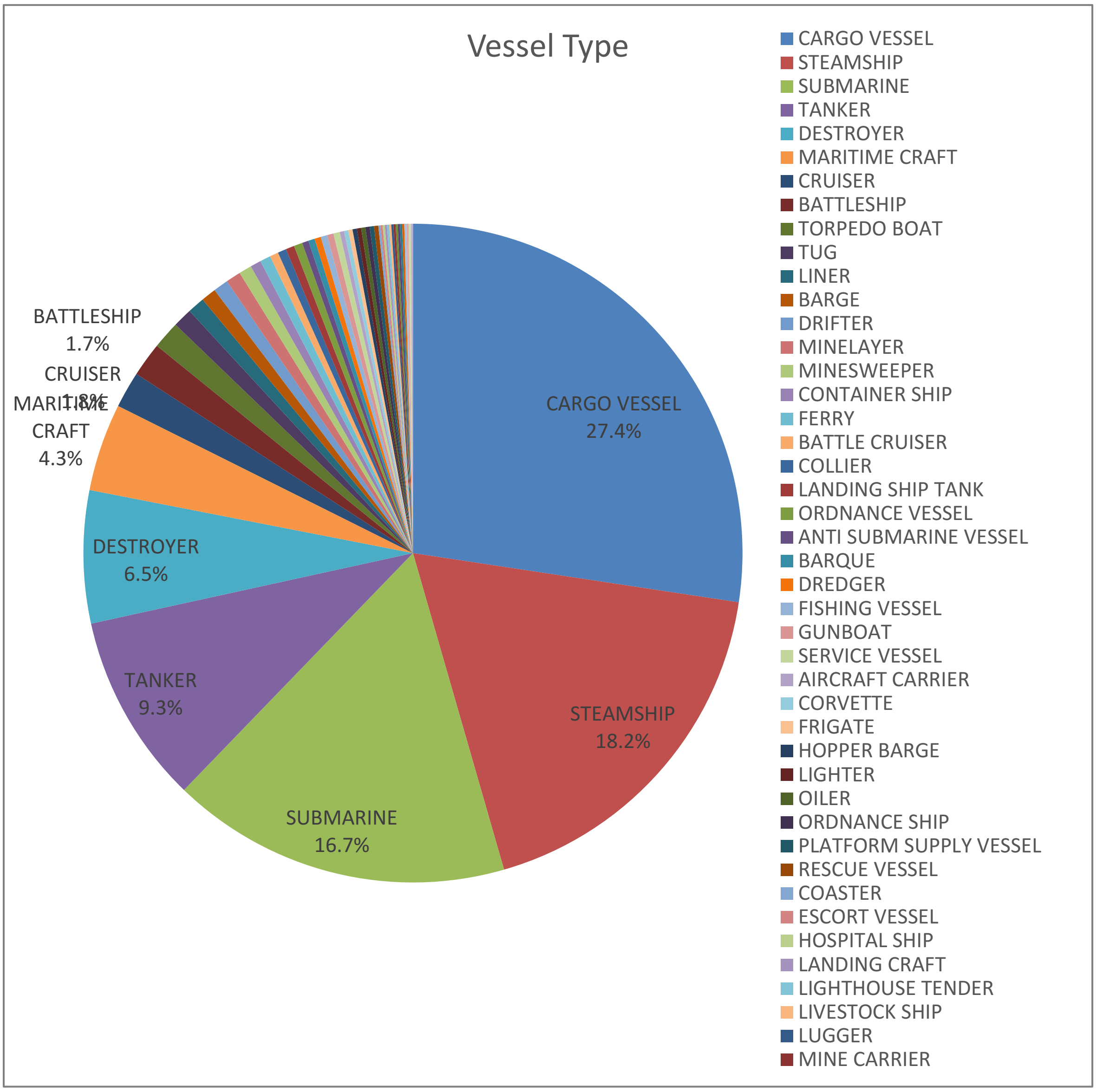

Figure 34 Vessel Types in Refined PPWD4 UK CPZ (author’s own image).

4.3.1.4 Vessels by Nationality

As might be expected, the majority of wrecks found within UK waters are British wrecks. The refined PPWD4 list contains 500 wrecks that are identified as British (52.5%), followed by 177 German vessels (18.6%), 54 Dutch vessels (5.7%) and 43 Norwegian vessels (4.5%) (Figure 35 and Figure 36) .Full details and percentages of other states vessels are given in Appendix D). Of the 177 German vessels, 151 are known to be military wrecks, and 126 of these are submarines.

Roughly 47.5% of the vessels in the dataset are non-British flagged vessels, therefore any intervention relating to pollution from these wrecks would need to be undertaken with knowledge and permission from the relevant flag state. Additionally, while the greatest proportion of the vessels in the database (British, German, Dutch and Norwegian) are attributed to flag states that have not signed the 2001 UNESCO Convention there are 59 vessels (6.1%) that have flag states that are signatories to the convention. Therefore, depending on their date of loss, vessels of over 100 years old may be considered to be UCH by their flag states and they may wish to see them protected and managed in line with the 2001 Convention, regardless of their polluting potential. Even those countries that have not ratified the convention are likely to have their own legislation and criteria for what they consider to be UCH.

It is potentially the responsibility of the flag state to remediate pollution from wrecks located in others waters where the owner cannot be found, however, in practice remediation of legacy wrecks in a nation states waters have been carried out with permission of the flag state, but without approaching the flag state for financial restitution (e.g. Norway and Sweden's remediation of British and German wrecks in their waters, (Ndungu *et al.*, 2017; Amir-Heidari *et al.*, 2019). This is fortunate for Britain as we have wrecks located across the globe, and significant numbers of wrecks within other European states waters. Given the current practice of states remediating wrecks within their waters regardless of the flag state of the vessel it would be wise for the British Government to take responsibility for remediating any wrecks within its waters regardless of their nationality, and even though these form 47.5% of the wrecks in British waters.

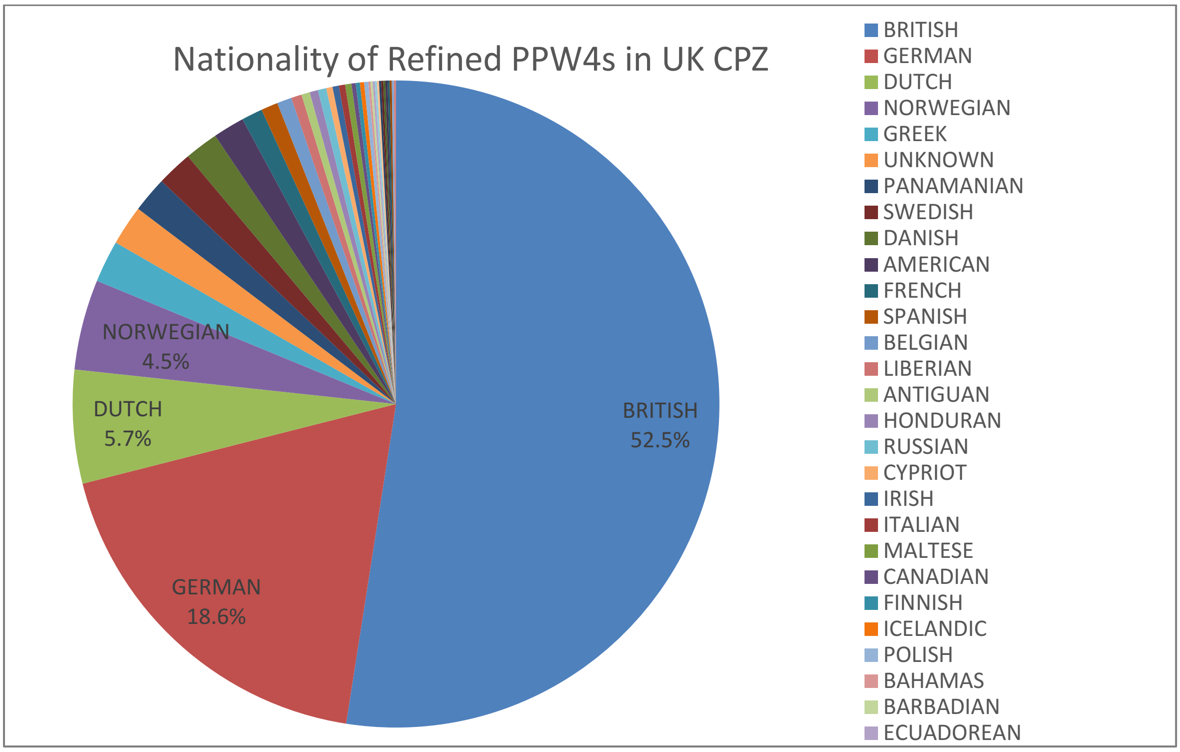

Figure 35 Nationality of Wrecks in Refined PPWD4 UK CPZ (author's own image).

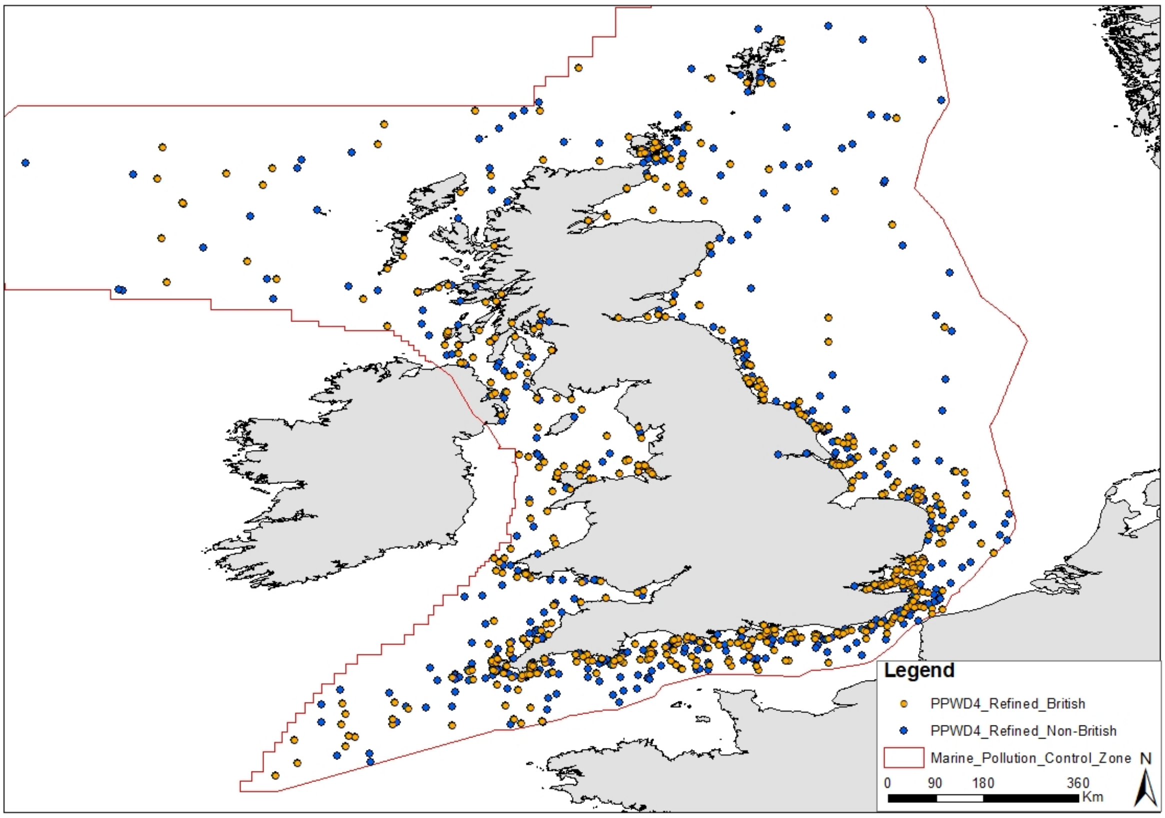

Figure 36 British and non-British wrecks in UK waters (author's own image).

4.4 Reducing Uncertainty

4.4.1 Historical Research

The risk assessments discussed previously are based on records that have not been fully populated with data. 25% of the dataset requires additional information about propulsion method and cargo which form the basic information required to determine whether a wreck has the potential to be polluting. It is therefore clear that additional research on these wrecks is required in order to remove these particular epistemic uncertainties.

The MoD has contracted Wessex Archaeology to undertake detailed assessments of wrecks that have been identified as high priority in the current risk assessments, however, this will take time and not all wrecks will be subject to the same level of scrutiny. Additionally, the MoD are naturally mainly concerned with MoD owned wrecks and not with other potentially polluting wrecks.

Additional research is therefore required across the wider dataset to take into account the 25% of wrecks that do not have cargo or propulsion details, and to undertake detailed background research on wrecks that are owned by other government departments or civilian owners.

The issue here is one of a lack of capacity in the market place to undertake such research. A study conducted in 2016 commissioned by Historic England (Hook *et al.*, 2016) identified that the archaeology sector has been operating at or near to capacity and that there were at the time a number of skills shortages across the wider archaeological sector. The report looked forward to 2033 in relation to large infrastructure projects and the skills required to provide adequate archaeological resources to these projects. It was determined that there would be significant issues meeting demand unless additional training and retention of archaeological staff and skills was undertaken. The fact that the archaeology sector was at capacity is likely to have an impact on the availability and capacity for the above research to be under taken. The research skills required to undertake detailed wreck assessments are currently provided by the archaeological sector, and while the report does not specifically examine the maritime archaeology sector as a subset of the wider archaeological sector it is likely that the findings also apply in maritime archaeology.

A report produced on the state of the archaeological market in 2018 (Aitchison, 2019) for the Chartered Institute for Archaeology (CIFA) recorded 4,908 people working in commercial archaeology in 2017-2018, unfortunately there is no breakdown into specific archaeological sectors. 8 out of 25 respondents to the survey stated that they believed there were skills shortages across desk-based assessments in archaeology. 3 out of 13 respondents reported a loss in skills relating to desk-based assessment in 2018, and the same number reported that they were in fact having to buy in external expertise in order to produce desk-based assessments. It is not known if these are the same three companies.

A search on the CIFA website (https://www.archaeologists.net/)*(Chartered Institute for Archaeologists*, no date) for companies with maritime archaeology capacity identified 40 organisations with a maritime archaeology function, however, the majority of these organisations are predominantly terrestrially focused and 20 of these were buying expertise in as it was not retained in house. The majority of the companies with in house expertise have relatively small maritime departments and these are likely to be in high demand for other offshore commercial project work.

An understanding of the nature of the wrecks requires historical and archival research to be undertaken, at present this work has largely been undertaken by the archaeological community, however, there is a capacity issue in moving this work forward at the pace and scale required to accurately assess the risk from potentially polluting wrecks. To improve upon the existing risk assessments and to ensure a base level of information will require a long term project or additional skills and training being brought in by a competent contractor. Without this additional research the epistemic uncertainties regarding potential for a wreck to be polluting will remain, resulting in unreliable risk assessment outcomes.

4.4.2 Survey Data

As previously stated the risk assessments that have been conducted in the UK are primarily rely on UKHO data to locate vessels, and information such as age of vessel, date of sinking and survey notes from previous UKHO surveys to determine potential condition of the wreck. This information then feeds into the probability calculations for when a wreck might break down and therefore release its pollutants. However, it is incredibly difficult to determine when a wreck might break down based on this limited information alone (M. L. Overfield, 2005; Medlin *et al.*, 2014; Moore, 2015; Macleod, 2016). A better method for determining the condition of the wreck would be to use existing bathymetric data to identify wrecks and give certainty as to their condition.

4.4.2.1 Vessels with CHP Coverage

In order to see whether it was possible to identify the location and condition of wrecks in bathymetric data a review of the Civil Hydrography Programme (CHP) bathymetric coverage of the wreck database was undertaken. Of the 953 wrecks in the refined PPWD4 dataset 690 wrecks are located within UKHO and Civil CHP surveyed areas (approximately 72.5% of the dataset). This is the same percentage of wrecks covered by CHP data in the overarching PPWD4 database before refinement. As has been discussed previously at sections 4.1 and 4.2.6.3, a proportion of the wrecks that are considered polluting are not covered by survey data and, where the data is available, often the data is of poor resolution so cannot be utilised to determine the location or status of the wreck. It was not possible to use GIS to automatically correlate shipwreck location with depressions or protuberance in the bathymetry which would potentially confirm the presence of a shipwreck at that location due to the transformation issues in the database.

To manually review the bathymetry of the 690 wrecks with CHP data was beyond the scope of the PhD, however, it was decided that an assessment of some of the wrecks would be worthwhile in order to determine if the CHP bathymetric data could be utilised to understand changes at a wreck site, and where possible, give a better confidence in the location and condition of the wreck which could then feed back into the risk assessment process. A provisional list of 89 wrecks that had more than one CHP dataset was created. Unfortunately, few of these had suitable resolution for using to assess the wreck in detail, and as such the majority of the CHP data is therefore not sufficient to provide better assessment of the condition of wrecks. However, it may be suitable for locating and identifying specific wrecks depending on the resolution of the data and when examined in conjunction with wreck construction and historical records. CHP datasets are constantly being collected and modern datasets are significantly higher resolution and include wreck reports for wrecks identified during the course of the survey. It is likely therefore that these datasets will become more useful in the future as coverage and resolution increases.

In her Master's thesis Kelsie Levin examined four wrecks which had two or more datasets available at a suitable resolution to determine if the CHP data was capable of identifying changes in the wreck structure and whether conclusions could be drawn regarding environmental effects at each wreck site and their potential for pollution dispersion (Levin, 2019). Levin identified that wrecks in dynamic seafloor environments showed a greater structural response than those in stable environments, however, site specific conditions influenced whether or not they were likely to have a potential for pollution dispersal.

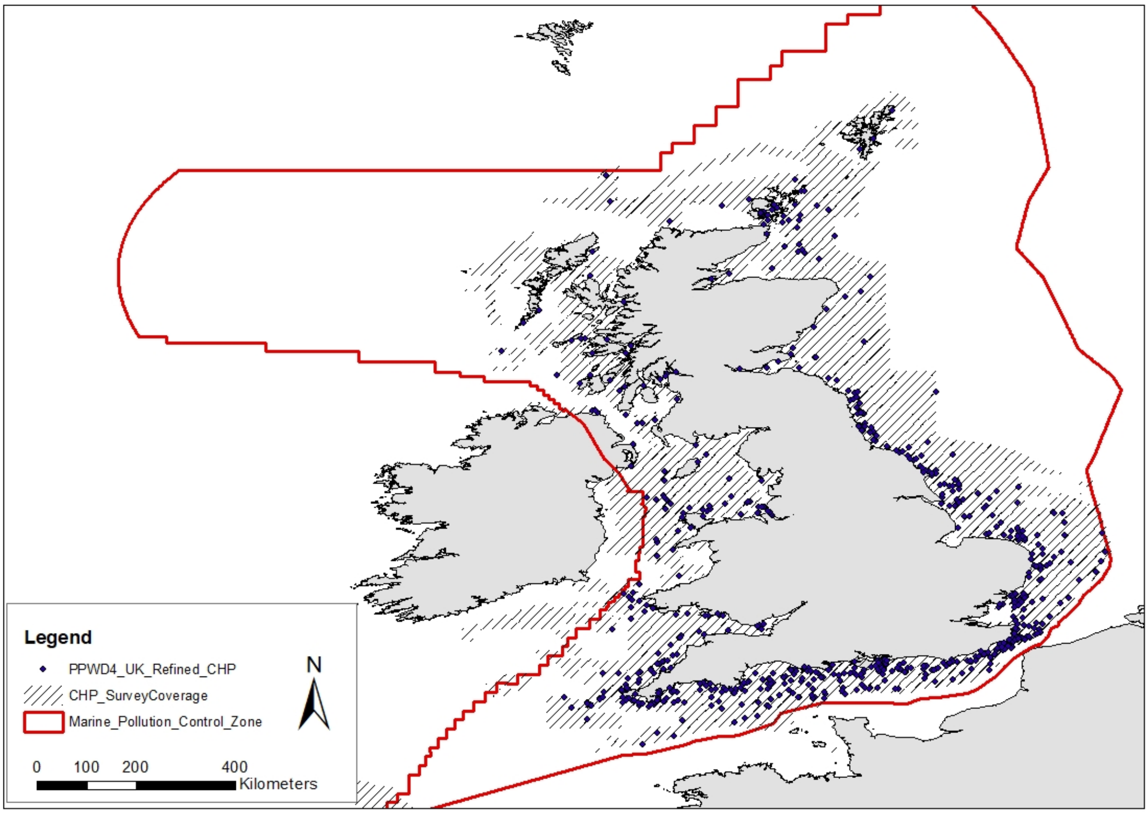

Figure 37 PPWD4 Shipwrecks with CHP survey coverage. (author's own image).

Given the poor coverage of the CHP data and the resolution of the datasets there is a distinct need for high resolution survey data to be collected to determine the location of shipwrecks and for this information to be cross-referenced with historical records to more comprehensively identify shipwrecks, and to understand the condition of these wrecks. Further survey may then be required to for shipwrecks identified as potentially polluting, where their rate of degradation and condition warrants further investigation.

There is future scope for machine learning to help identify the location of shipwrecks in bathymetric data, as has been demonstrated by recent work locating previously unknown wrecks in Jamaica Bay (Singh and Viswambharan, 2020). This still requires adequate survey data coverage and at a suitable resolution, but in the future it may be able to help locate the final resting place of potentially polluting wrecks for those where their exact location is currently unknown. .

4.4.2.2 Other Bathymetric Data

In addition to the UKHO and CHP survey data examined in the production of this thesis there are other projects in the UK which have undertaken survey in specific areas or for specific wrecks. An example of this is the U-Boat Project which aimed to identify WWI wrecks in Welsh waters. The project identified one of the potentially polluting wrecks that is included in the MoD's risk assessments discussed previously, and is noted as being relatively high risk. The *Derbent* was an

RFA vessel that was torpedoed and sunk in 1917 by U 96 whilst en route from Liverpool to Queenstown while carrying 3860 tons of fuel oil. The U-Boat Project has surveyed the vessel and built a 3D model which can be viewed on the project website (U-Boat Project (Royal Commission on the Ancient and Historic Monuments of Wales, 2018)). The vessel appears to be largely intact and is therefore highly likely to represent a future pollution risk. Data gathered from projects such as this one can be used to further inform the existing risk assessments and may help with understanding the risks posed by specific wrecks.

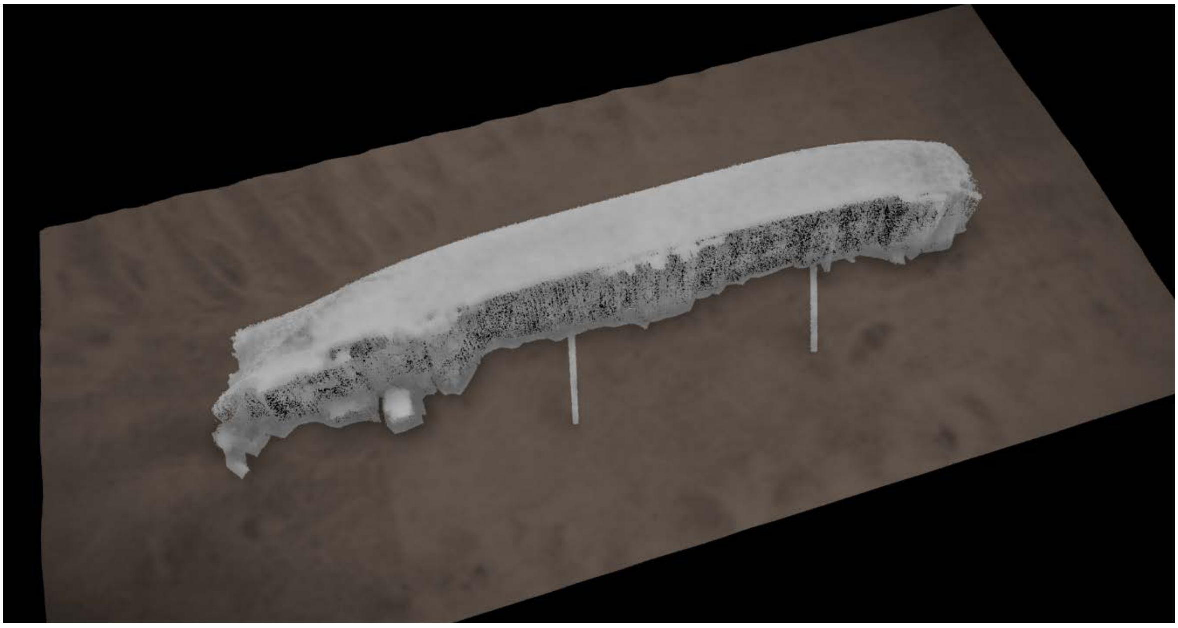

Figure 38 RFA *Derbent* (image screenshot from 3D model available at U-Boat Project Derbent)

4.4.3 Pollution Data

There are other data sets that can provide additional certainty about whether a wreck is or is not polluting and may be used to determine the accuracy of existing risk assessments. The European Maritime Safety Agency's (EMSA) CleanSeaNet is a satellite based oil spill monitoring and vessel detection service which provides locations of visible sheens and spills on the sea surface. The service is only available to participating states (including the UK) and the MCA has the relevant licence to utilise the data. Unfortunately lay persons cannot access the data and therefore it was not possible to examine the utility of the service in relation to legacy shipwrecks as part of this thesis. However, when combined with the UKHO database the service may aid in identifying wrecks that correlate with regular oil spills and would allow us to confirm the presence of a polluting wreck. This is particularly of use for UK Government owned wrecks as they may be able to request access to the EMSA data through the MCA.

4.5 Summary

It has been demonstrated that quantification of polluting wrecks is complicated due to the lack of capacity to undertake the necessary research into wreck histories. In the UK, the UKHO's shipwreck dataset, which is the baseline dataset for the subsequent shipwreck databases held by the MoD relies on relatively coarse hydrographic data, and is limited to mainly nearshore waters. The shipwreck database is a by-product of survey for navigational safety. While useful it has its limitations, and shipwreck information in the database has varying levels of confidence in terms of positional accuracy and identification of shipwrecks. A vast proportion of UK waters remain under or un-surveyed and therefore there is the potential for a greater number of wrecks within these areas than is currently recorded in the datasets.

Current MoD risk assessments & databases contain all wrecks polluting or otherwise. Refining the databases to only those wrecks with a polluting potential (minus <100GT) results in 953 wrecks in total within UK waters that might have a polluting potential. Meanwhile despite being removed from most risk assessments, vessels of <100GT may pose an aggregated polluting problem.

An assessment of the existing data on potentially polluting wrecks in the UK demonstrates that the majority of the wrecks in the PPWD4 database relate to WWI & WWII, with over half of the wrecks in the PPW4D refined database being British, and cargo vessels forming the highest percentage of vessels type in the database. The pattern of numbers of potentially polluting wrecks in the data can be seen to follow trends in changes to shipping technology and introduction of environmental legislation.

The potential to pollute does not necessarily mean that these wrecks will in fact be a source of pollution. A key factor in understanding whether a wreck is likely to pollute is the condition of the wreck and whether or not any pollutants remain within the vessel or if these are likely to have already been dispersed, either at the time of sinking, or during the intervening period. Bathymetric data is key to understanding a vessels condition on the seabed. As has been demonstrated in this chapter, a significant proportion of wrecks in UK waters are unlikely to have sufficient survey coverage or survey resolution to allow their condition to be determined. 72% of the wrecks in the PPWD4 database are within CHP survey areas. However, in many cases the data is of poor resolution and it is not possible to determine if a wreck is in fact present let alone its prospective condition. This impacts on not only our understanding of whether a wreck has the potential to pollute but also impacts on our ability to accurately quantify the number of wrecks on the seabed and therefore the number that might pose a pollution threat. There remain uncertainties around:

a) The location of wrecks
b) Lack of positive identification of wrecks
c) The condition of the majority of the wrecks in our waters.

Without this information risk assessments are essentially based on probabilities and estimation and expert guesses rather than quantifiable data. Researchers interested in wrecks have stated the need for verification of the data stored in shipwreck databases, and called for dedicated shipwreck surveys, as well as better environmental and ecological datasets (Ventikos *et al.*, 2016; Evans and Davison, 2019)

The recent risk assessment conducted by CEFAS is a step forward in that it allows for better quantification of risk using high resolution oil spill mapping and socio-environmental datasets, as well as bathymetric data. However it has some limitations (as discussed at section 4.2.4) and therefore is likely to be best suited to analysis of wrecks identified as being high risk once further assessment work has been conducted by refining the PPW4 database, or once a wreck has already been identified as leaking.

Further examination of socio-economic and ethical aspects of potentially polluting wreck risk assessment and management are required as this informs the use and adaptation of existing risk assessments, as well as the potential future requirements for any updated risk assessments or potentially polluting wreck databases.

Chapter 5 Stakeholder & Socio-Economic Assessment

In Chapter 2 it was identified that the majority of risk assessments that examine polluting wrecks fail to take into account stakeholder interests. They ignore the socio-economic impacts of wreck pollution or how socio-economic factors impact on wrecks. However, we also know from previous case studies of HMS *Royal Oak* and the USS *Arizona* that political and social pressure is one of the greatest influences on potentially polluting wreck management strategies, regardless of what the risk assessment and scientific evidence may state. It is therefore necessary to understand who the stakeholders are with an interest in polluting wrecks, and what socio-economic factors impact risk decision making and wreck management.

This chapter aims to demonstrate that inclusion of socio-economic data analysis in the risk assessment and strategic decision making process can add substantial value and improve the risk management process. Analysis of the socio-economic data can resolve some of the uncertainties that exist in current risk assessments (identified in Chapter 2 and Chapter 4) around the potential impact and consequences of a pollutant release from a potentially polluting wreck. Understanding what infrastructure, communities and economic activities might be affected by a pollutant release, allows us to strategically target future investigative work and additional data collection which will then feed back into the risk assessment process, and aids in future decision making.

The assessment presented in this chapter goes beyond the simple assessment by proximity to protected sites and key infrastructure which is has been included in previous studies and includes an examination of social and economic use of marine and coastal space in the UK. A variety of data commonly utilised for marine spatial planning and environmental protection have been analysed against the potentially polluting wreck data, the results indicate areas of potential impact and conflict between activities in the marine and coastal environment and potentially polluting wrecks.

This chapter also includes a discussion about stakeholder perspectives on wreck for stakeholders where spatial socio-economic data is not available. These stakeholders have perspectives and attitudes towards shipwrecks that may be ethically or politically contentious, and which might impact on their risk tolerance and their acceptance of certain management strategies in respect of polluting wrecks.

5.1 Stakeholders

In addition to wreck owners and the managing bodies previously described in Chapter 3 there are a variety of stakeholders that might also have an interest in how potentially polluting wrecks are managed. In the report *Managing Shipwrecks* Antony Firth (2018) identifies ten categories of stakeholders with interest in wreck that are interlinked through a complex web of relationships and effectively summarises the complex and often competing interests in wreck and the challenges of wreck management in the UK. The ten categories are:

- Navigation safety and wreck removal
- Nature Conservation
- Fishing
- Sea-use
- Recreation
- International Interests
- Ownership and recovery of wrecks
- Heritage
- Commemoration
- Public and Environmental Risk

As Andersson *et al.* (2016) state, what constitutes an environmental problem is not simply a change in an environment by an input or stimulus (e.g. pollution) but the societal agreement that such a change is unwanted. Environmental problems are therefore a social construction. As a result the deciding factor on what constitutes an environmental problem and the acceptable means of dealing with it ultimately come down to stakeholder perspectives and priorities. It is therefore critical to understand how potentially polluting wrecks will impact on stakeholders, and what their views are regarding these shipwrecks.

Marine spatial planning has been adopted as a method that allows for stakeholder data to be analysed together to de-conflict competing priorities between stakeholders and ensure marine activities can go ahead with minimum disruption (Lindgren, Andersson and Landquist, 2016). In relation to potentially polluting shipwrecks the same data used in marine spatial planning can help us understand which stakeholders might be affected by pollution from wreck, and what the impact might be. It can also give us an indication of how to minimise disruption to stakeholders during remediation and management of shipwrecks.

The stakeholder categories proposed by Firth have been loosely used as a framework to conduct an analysis on the available spatial datasets for each category of stakeholder. Where applicable datasets have been identified they have been analysed under the categories above using spatial analysis in GIS. However, there are some aspects that have not been included in the spatial analysis; ownership and international interest aspects have previously been covered in Chapter 3 and Chapter 4, and wreck removal, recovery of wrecks, aspects of heritage, and commemoration do not have available spatial datasets and are therefore addressed in a separate assessment at section 5.4. Public and environmental risk is the overarching theme for this research as a whole, however, where specific datasets have been identified for public risk these they are presented at section 5.3.6.

5.2 Methodology and Data Sources

Originally the aim of this research had been to develop a GIS based risk assessment that improved upon the existing PPW3 and PPW4 risk assessments. One that would take into account existing bathymetric data to inform the condition of the wreck and the environmental conditions at the sites. This would then feed into an ecological impact assessment, and finally a socio-economic assessment using readily available public datasets. However, as has been previously discussed the basic shipwreck dataset had various issues that would have required amendment in order to run the assessment, and the dataset had very little in the way of bathymetric survey coverage resulting in an inability to improve the database at a basic level. Alongside this CEFAS published their risk assessment methodology in 2019 and the level of ecological assessment that they present far exceeds the work that would have been undertaken as part of this project. In light of this the decision was made to focus on the socio-economic assessment of the refined PPW4 database as it demonstrates that a better understanding of socio-economic impacts of wrecks can be achieved using existing and open source data, and it can be incorporated with any existing or future risk assessments.

Specific methodologies for data assessment are described in each section as they were largely dependent on the type and format of the data available. Ultimately, where quantitative analysis of the datasets was possible the data has been appended to the PPWD4 Refined database's attribute table to inform future decisions regarding the wrecks in the database.

A number of publicly available data sets were used to spatially assess the social and economic impacts of potentially polluting wrecks in the UK. Much of the data comes from UK government departments and agencies and is made available under the Government Open Licence scheme. A significant proportion of the data came from the MMO, including navigational points, Automatic Identification System (AIS) data, and recreational models. Data on nature conservation sites and seabirds was accessed from DEFRA, Natural England (NE), Scottish Natural Heritage (SNH), Natural

Resources Wales (NRW), and Northern Ireland's Department of Agriculture, Environment and Rural Affairs (DAERA). The locations of offshore infrastructure was available from the Crown Estate, and through EMODnet. Information on the locations of critical national infrastructure was acquired from the DfT and the Department for Business, Energy and Industrial Strategy (BEIS). Additional data for navigational points, transport and industrial facilities was procured through Digimap's web service to which the University of Southampton subscribes.

The data utilised was designed to be used in marine spatial planning and not specifically for assessing polluting shipwrecks, however, it can give us insights into the spatial relationship of the wrecks with environmental and socio-economic aspects of the UK. Using secondary data does have its limitations, and at the time of assessment not all of the data was available for the whole of the UK. A review of socio-economic data for use in the marine environment conducted by EMU Ltd and The Marine Biological Association and Plymouth Marine Laboratory (2012) identified the various datasets available at that time. The resolution and availability of socio-economic datasets have significantly improved since 2012, however, some of the limitations and gaps they identified remain, such as lack of publicly visible economic data for several industries and the inability to map some social datasets across into the marine environment. The limitations of the various datasets used in this assessment are described in the sections below where applicable.

5.3 Spatial analysis of Socio-Economic Data

5.3.1 Navigational safety

Pollutant release from a wreck and the subsequent remediation operation is likely to have significant consequences for shipping and navigation. To understand the potential impact of a pollutant release from vessels in UK waters on shipping it is first necessary to determine the areas in the UK with the highest levels of marine traffic.

While not designed for research purposes, Automatic Identification System (AIS) data has been used in a variety of ways to assess marine traffic and other vessel related research (Svanberg *et al.*, 2019). To understand where potentially polluting wrecks are likely to have the greatest impact on shipping and navigation AIS data was analysed to identify areas of high vessel density. AIS data from the MMO is available online through the DEFRA data services platform for 2012-2015. Unfortunately, only the data for 2013 and 2014 was in a format suitable for use in GIS, therefore only these years have been analysed. The data was disaggregated and track lines for non-fishing vessels were separated from fishing vessels (further discussed in section 5.3.3). The data for 2013 and 2014 was combined and a line density analysis conducted on the data to create a density map for the density of shipping activity in the UK (Figure 39).

As might be expected the English Channel and the Dover Straits features the highest density of transits through the region. However, as demonstrated by Figure 40 and the heat map in Figure 42 a relatively high density of potentially polluting wreck's is also focused on the south coast and the Humber in particular. Figure 41 also shows the location of key navigational points and routes through UK waters in relation to the density of potentially polluting wrecks. In the Dover Straits in particular there is a high quantity of shipping that might be affected by a polluting incident from wreck, this area features key navigational routes and there is also a high density of potentially polluting wrecks in these areas so the probability of encountering pollution from wreck in this region is elevated.

The UK shipping industry is estimated to have contributed £13.9bn in business turnover, £4.3bn in GVA and 152, 600 jobs in 2015 (Cebr, 2017). An estimated 2.5 million Heavy Goods Vehicles travelled on the short sea routes through Dover in 2015 (UK Chamber of Shipping, no date) and approximately 9.2 million passengers travelled by sea between Dover and Calais in 2018 (Department for Transport, 2019). The cost of disruption to shipping and these routes from a pollution event is likely to be held in the millions or more. Given the transitory nature of navigation routes, the impact will be felt far wider than the UK as a significant proportion of vessels passing through the English Channel and Dover Straight are foreign vessels. The international socio-economic impacts of a pollutant release from potentially polluting wrecks in UK waters is not possible to quantify, however, it is of considerable concern.

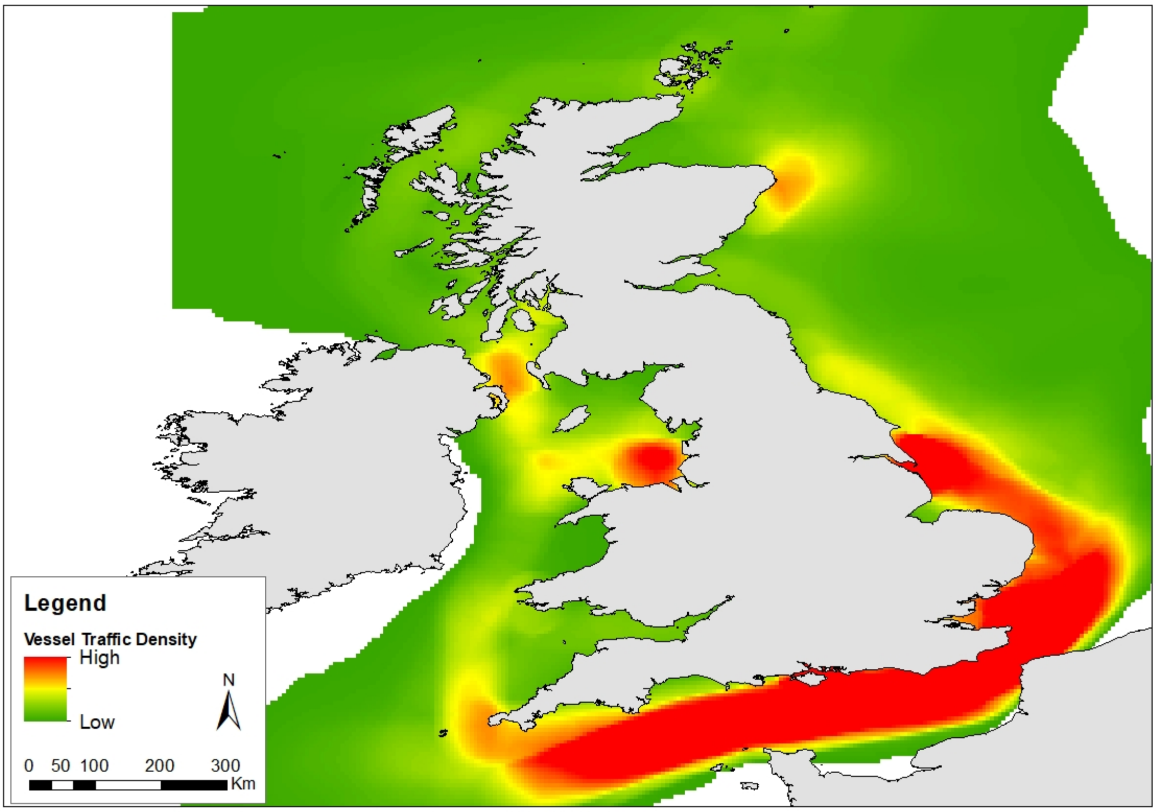

Figure 39 Density of non-fishing vessel activity 2013-2014. (author's own image).

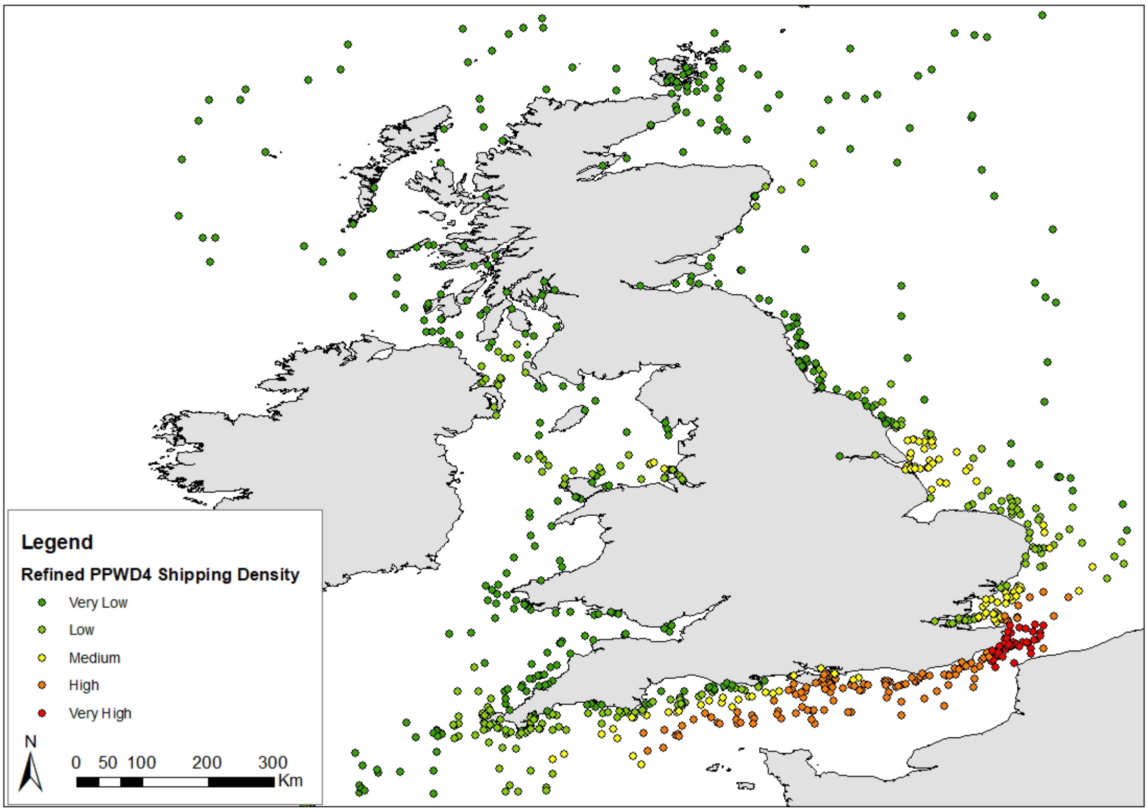

Figure 40 PPWD4 refined shipwrecks and the density of shipping at their location (author's own image).

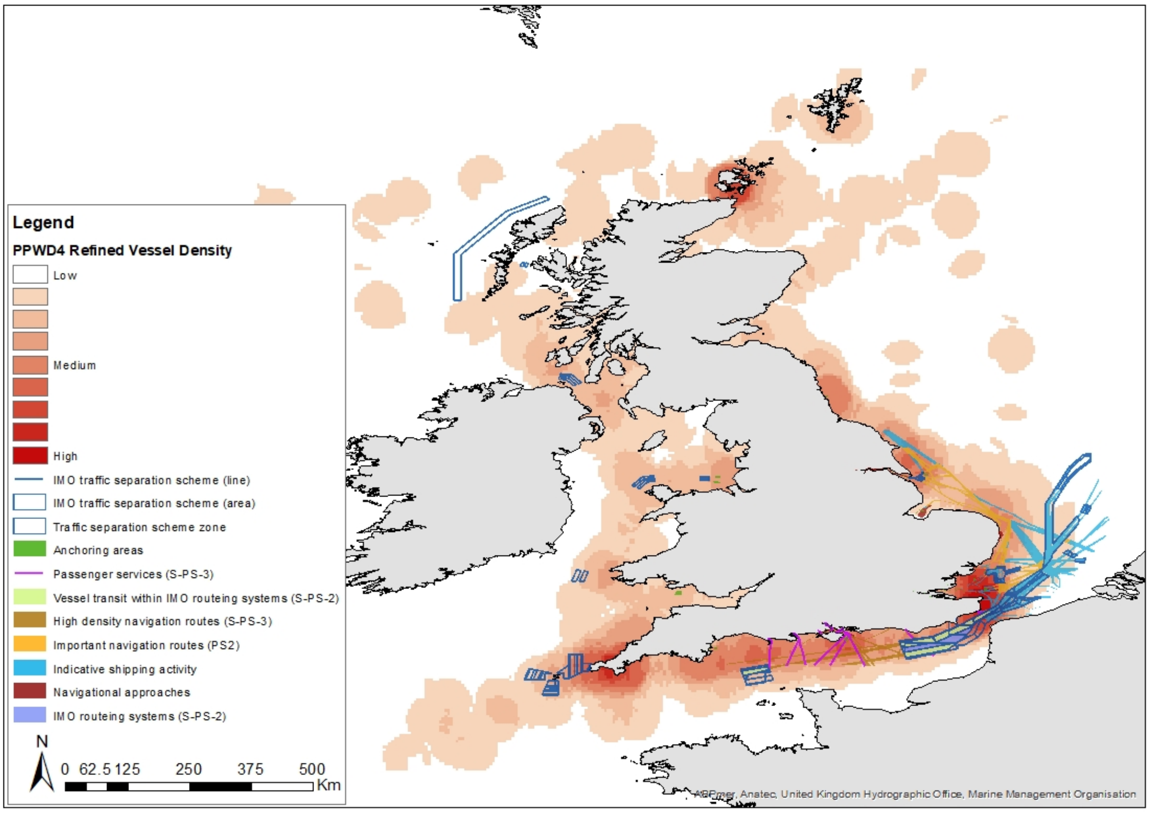

Figure 41 Density of Refined PPWD4 potentially polluting wrecks against key navigation points (author's own image).

5.3.2 Nature conservation

As previously discussed in section 793.3 there is requirement to protect certain habitats and species under the Environmental Liability Directive with regard to the prevention and remedying of environmental damage (2004). There are a number of areas in the UK that are designated as protected areas, these include sites of scientific interest (SSI's), marine conservation zones (MCZ's), special areas of conservation (SAC's), special protection areas (SPA's), protected wetlands (Ramsar) and nature reserves and trusts (Figure 42). In addition to conservation areas there are also landscape designations such as areas of outstanding natural beauty (AONB), national parks and heritage coasts which are likely to suffer in a pollution event.

Of the 953 wrecks in the refined database 387 are located within these conservation zones, protected areas and designated landscapes. Depending on the size and trajectory of any pollution leak the number of wrecks that might affect one of these areas is likely to be considerably higher. In order to help inform future decision making the distance of the wrecks to the nearest conservation zone, protected area etc. has been determined using the spatial join tool in ArcGIS and the values included in the attribute table of the PPWD4 Refined database. There is also a potential aggregated risk from vessels of less than 100GT within the special conservation area within the approaches to Liverpool, and the special areas of conservation off the coast of East Anglia, as these are the areas with the highest concentrations of vessels of this size (Figure 24).

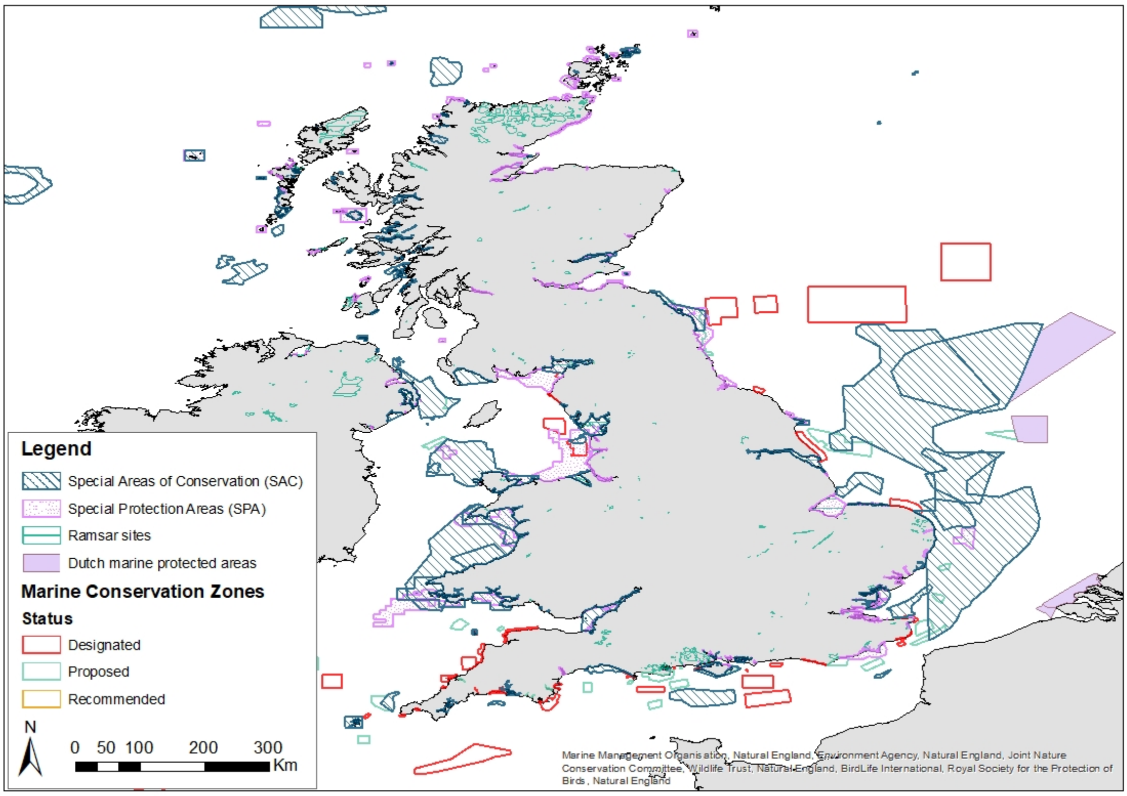

Figure 42 Marine Conservation Zones and Protected Areas (author's own image).

An additional consideration, particularly for vessels with an oil pollution potential within the database is the concentration of seabirds in the UK at different times. As discussed in section 2.1.1 seabirds are particularly at risk from oil pollution and therefore wrecks within areas with a high density of seabirds are likely to pose a higher risk than those outside of these areas. Data for the density of seabirds within English waters in winter and summer is shown in Figure 43 and Figure 44. Unfortunately seabird density data was not available for other parts of the UK. However, we can see just from the English data that there is a significantly increased risk to birds during the summer months, particularly from wrecks located on the north east coast of England and off East Anglia. In the winter the risk appears to be mainly in estuarine areas. The wreck and subsequent oil spill of the *Sea Empress* at Milford Haven in February 1996 demonstrated the relatively low environmental impact of an oil spill on birds during the winter months, a rapid clean-up effort, combined with the minimal number of birds in the region at the time reduced the impacts of the oil spill significantly (Edwards and White, 1999). However, the opposite would have been true during spring and summer. It is therefore difficult to accurately determine the impact that wrecks may have on birds as it is based on seasonal and environmental conditions. We can however, identify wrecks in areas where seabird densities are high at certain points of the year.

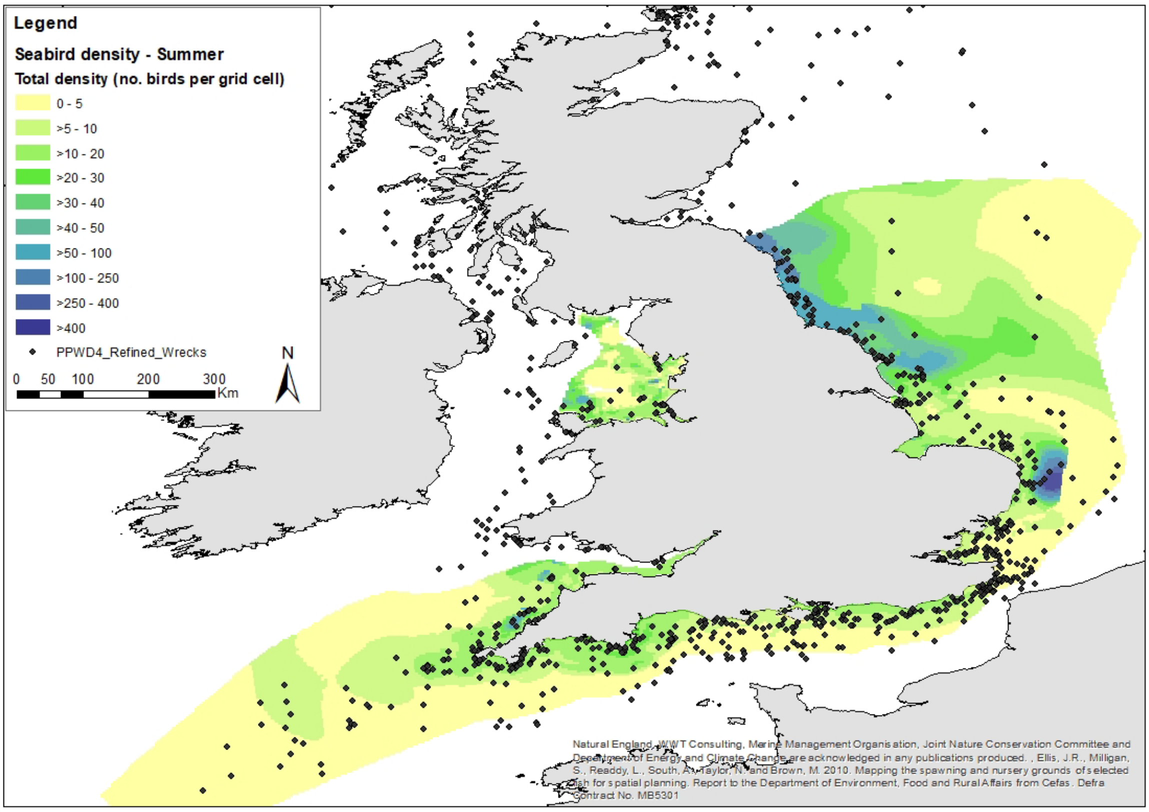

Figure 43 Summer seabird density in England (author’s own image).

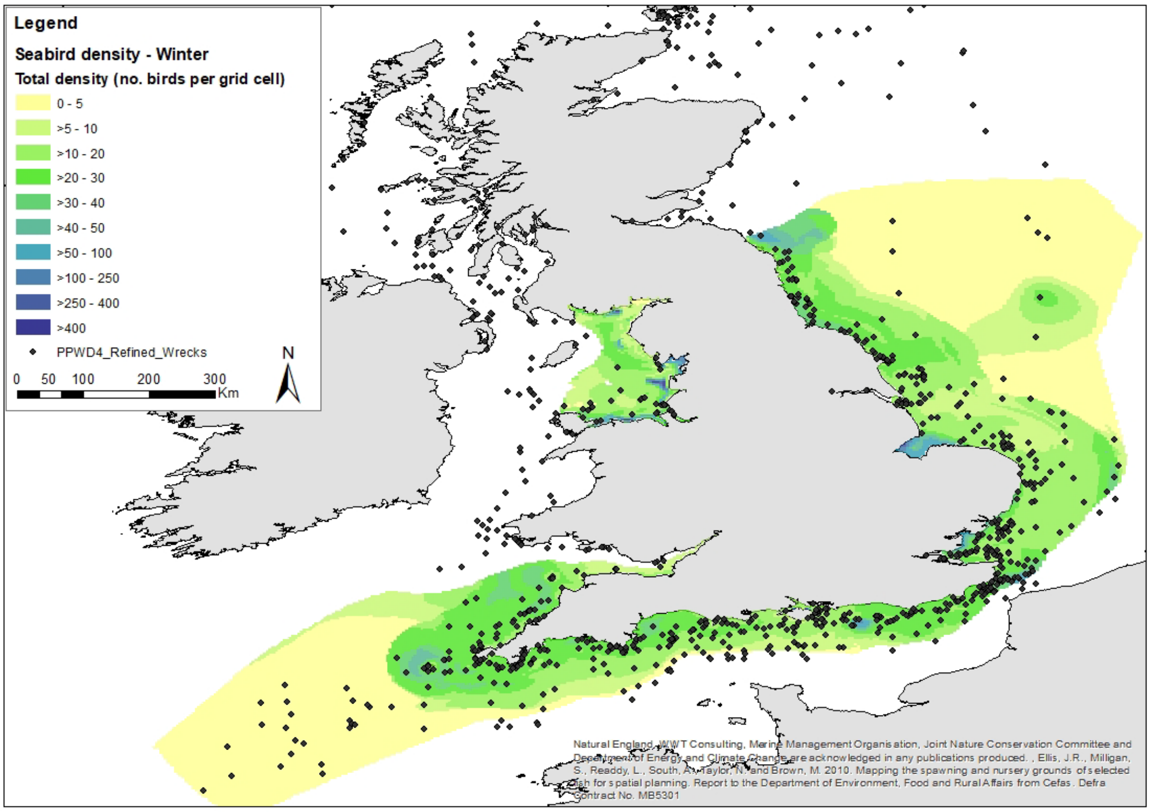

Figure 44 Winter seabird density in England (author’s own image).

The social and economic value of marine and coastal nature conservation areas has been assessed by a variety of marine social science scholars (Pike *et al.*, 2010; Jobstvogt, Watson and Kenter, 2014; Rees *et al.*, 2015; Brooker *et al.*, 2016; Kelly, 2018). A study by Christie and Rayment, (2012) suggests that the amount that the public are willing to pay for services and benefits delivered by SSSI conservation activities amount to £956 million annually. A separate study shows that divers and anglers alone estimated that protection of natural sites would be worth in the region of £730-1,310 million, with an annual recreational value of £1.87-3.39 billion for England, £69-122 million for Wales and £67-117 million in Scotland (Kenter *et al.*, 2013). It is also interesting to note that Jobstvogt, Watson and Kenter (2014) identified that divers and anglers were most willing to pay towards marine protection if the protected areas contained shipwrecks. The economic value of conservation and protected zones is often difficult to determine as the economic benefits are not necessarily directly attributable, however, it is clear that marine and coastal conservation areas generate economic value for the UK economy which might be threatened by a pollution event. It is also clear that the public feel strongly about the importance and benefits of protected areas, therefore any pollution event in these regions is likely to be seen as more problematic than in other parts of the UK.

This impact assessment is somewhat limited as it does not model pollution spill trajectories or detailed impacts on specific flora and fauna, however, it does give an indication of the wrecks that might pose the highest risk to nature conservation efforts. A detailed assessment of the ecological impacts needs to be conducted on a wreck by wreck basis and the existing CEFAS risk assessment provides a mechanism for this type of assessment. On the social and economic side though, it is clear that there is significant value attributed to marine and coastal protected areas in the UK, and that pollution events in these areas are likely to have a negative impact on social and economic wellbeing. In contrast however, the risk of pollutant release from potentially polluting wrecks in these areas is likely to be slightly lower than in un-protected areas as the wrecks are likely to encounter less fishing activity, and lower levels of human interference that promote wreck degradation.

5.3.3 Fishing Activity

Fishing activity in and around a wreck can have a significant impact on the condition of a wreck which in turn increases the likeliness of pollutant release from a vessel. Fishermen and anglers often target wreck locations as the wrecks form reef structures which are attractive to fish (Firth *et al.*, 2013). Many archaeological investigations into wrecks have noted the presence of “ghost nets” on wrecks, where fishing equipment is either caught on the wreck and abandoned, or is lost at sea and drifts on to the wreck. Work to clear nets from shipwrecks in the Baltic estimated that

150 to 450 tonnes of nets were deployed on shipwrecks in the Polish marine area (WWF, 2011) and a study in the mid-Atlantic Ocean found that 69% of the shipwrecks studied had 1-5 trawl nets or scallop dredges on the wreck site (Steinmetz, 2010). Nets have the potential to damage superstructure of wrecks and when caught put strain on the structure of the vessel. Trawling activity has been identified as a particular culprit in damaging historic and archaeological shipwrecks (Firth *et al.*, 2013; Brennan *et al.*, 2016). Additionally, any pollution resulting from wreck has the potential to heavily impact on the fishing industry when fisheries exclusion zones are implemented and fish stocks from the area are tainted, as was the case with the wreck of the MV *Braer* in Shetland in 1993 where financial compensation for fisheries disruption due to the exclusion zone was estimated at over £5 million, which is roughly £8.6 million today (Ritchie, 1995; Goodlad, 1996, p. 182).

In order to understand the potential impact of fishing on potentially polluting wrecks and vice versa it is necessary to understand where the highest concentration of fishing is undertaken in relation to the location of sensitive wrecks. An investigation of the effect of fishing on wrecks was undertaken by Firth *et al.*, (2013), in which they examined wrecks in relation to fishing effort in key study areas of the UK using Vessel Monitoring Systems (VMS).While it was able to give some indication of fishing interaction the level of detail and number of vessels using the system at the time was limited. However, since May 2014 it has been a requirement that all fishing vessels of over 15m must have automatic identification systems (AIS), a follow on from VMS. Various studies have used AIS data to assess fishing density in a similar fashion (Svanberg *et al.*, 2019). Although the activity of smaller fishing vessels is not captured in the dataset the AIS data does give an indication of the locations of larger fishing vessels which are most likely to be engaged in large scale trawling activities and are also the vessels most likely to generate the greatest contribution to the fishing economy (over 74% of the UK fleet were longer than 24m in 2017 (Marine Management Organisation, 2018)) and therefore likely to be most affected by pollution from wrecks.

As discussed in section 5.3 AIS data for 2013 and 2014 has been analysed. The data was disaggregated and track lines for fishing vessels and trawling vessels were separated from other vessels. The data for 2013 and 2014 was combined and a line density analysis conducted on the data to show "hot spots" where the greatest fishing activity appears to occur (Figure 45). Unfortunately, it was not possible to differentiate in the data between fishing vessels in transit and vessels engaged in fishing activity but it does provide some indication of fishing activity in UK waters.

The density map indicates areas of intensive fishing vessel activity in and around the southwest approaches, the waters of the English Channel (with the exception of the area around the Isle of White), off Peterhead, and North of the Shetland Islands. The density of fishing in the English Channel can be attributed to the fact that this area is relatively narrow and concentrates shipping and fishing activity into defined areas, thus increasing the density when compared to the North Sea where fishing can take place over a much wider area.

When compared against the refined PPWD4 we can see that a significant proportion of wrecks are located within the area of high intensity fishing on the south coast of the UK. Figure 46 shows these vessels colour-coded with their respective fishing density. As is apparent there are a significant number of vessels within the Channel that have a high or very high density of fishing associated with them. These are the wrecks that are most likely to be damaged by fishing equipment, but also the wrecks that will have the greatest impact on the fishing industry if they are found to be leaking.

In 2017 UK vessels landed 724,000 tonnes of sea fish amounting to a value of £980 million (Marine Management Organisation, 2018) of which 80% was landed in the UK. Peterhead had the highest UK fleet landings (151,000 tonnes) and Brixham had the highest quantity and value of UK fleet landings in England (15,000 tonnes) in 2017. It is therefore unsurprising to see high densities of fishing vessels in both these areas, it also means that pollution events in these regions could have a significant economic impact on the fishing industry. In addition to direct economic impact, the fishing industry employed approximately 11,700 fishermen in the UK in 2017, of which 2,000 were part time (Marine Management Organisation, 2018). In the event of pollution resulting in fishing bans then it is likely that some of these jobs might be temporarily lost, thus having a knock on effect on the economy, as well as having social repercussions.

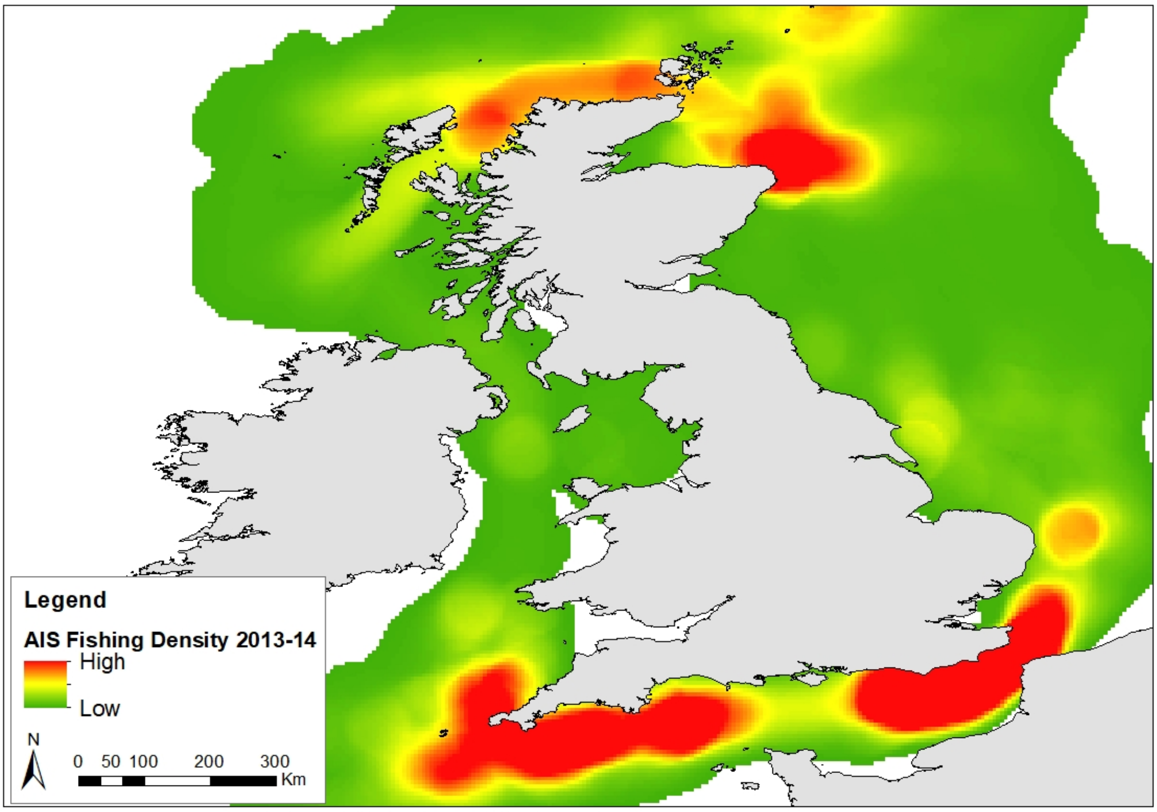

Figure 45 AIS Fishing and Trawling density 2013-2014. (author's own image).

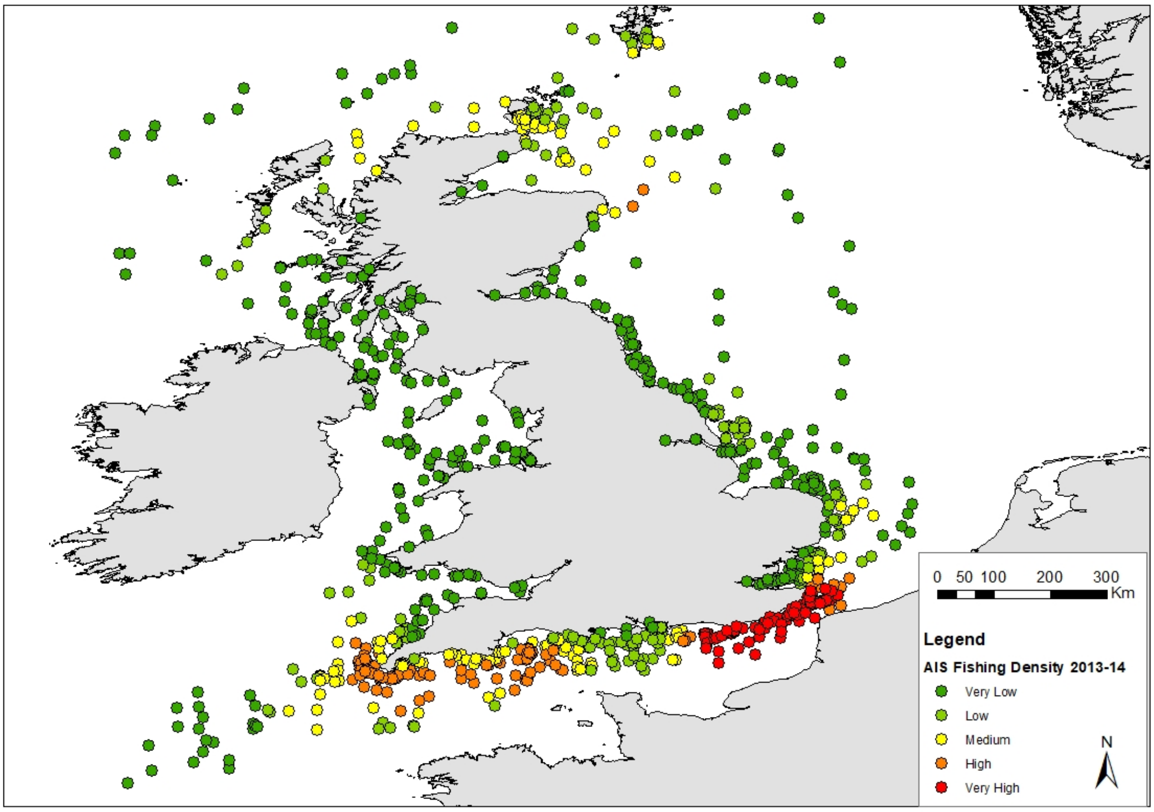

Figure 46 Refined PPWD4 wrecks showing fishing vessel density over the wreck. (author's own image).

5.3.4 Sea Use

5.3.4.1 Dredging

The total market in the UK for aggregates is approximately 251.8 metric tons (Mt), of which 19 Mt comes from marine sources (Mineral Products Association, 2018). Marine aggregates are required in many industries, but the greatest demand is for construction. The marine aggregates industry is estimated to be worth £253 million in 2017, with a direct GVA of £137 million (ABPmer and ICF, 2019, p. 37). In the UK 365 people were directly employed by marine aggregates companies in 2017 (Mineral Products Association, 2018). The wider economic contribution of the industry is likely to be significantly higher as the aggregates industry supports construction of economically contributing sites, and supports wider employment in logistics and transport companies etc. Social benefits from the aggregates industry include beach nourishment in tourist areas, resulting in higher quality beaches for public enjoyment, and supporting water sports and recreation activities (ABPmer and ICF, 2019). The industry also contributes to coastal defences, thus preventing flooding, erosion and other environmental impacts on coastal communities. The location of licenced aggregates dredging sites in the UK is shown in Figure 47.

Dredging for aggregates has the potential to impact on shipwrecks if they are located within the dredging area (Wessex Archaeology, 2003). Dredging could result in damage to the wreck resulting in a pollutant release, or can destabilise the environment around a wreck resulting in increased degradation of the wreck. Meanwhile pollution from wrecks might prevent dredging taking place, or cause contamination of sediments resulting in wasted resources. Spatial analysis of the wrecks using the select by location tool in ArcGIS identifies that, fortunately, only six of the PPWD4 refined wrecks are located within an aggregates extraction area, these are given in Table 7 and a column has been added to the PPWD4 refined shapefile attribute table noting their presence within aggregates zones. Of these however, RFA *War Mehtar* is known to be leaking small quantities of oil and has the potential to contaminate sediments in the region, resulting in a loss of aggregate resource.

The wrecks in the refined database only contain wrecks that are considered to be “live”, there may be a number of shipwrecks that are no longer present on the seabed or that are no longer considered to have a polluting potential based on their poor condition which are not included in the current risk assessment/database. These wrecks may have already collapsed and released their pollution into the seabed resulting in contamination of sediments. Further work may be required to identify shipwrecks that have previously collapsed and which might have had a cargo of fuel or hazardous substances and which are located within licenced aggregate areas, and to determine their potential risk to the aggregate extraction industry.

Reporting of wreck material and items found during dredging is undertaken through the Marine Aggregate Industry Protocol for the Reporting of finds of Archaeological Interest (Wessex Archaeology, 2018). Reporting of finds is currently forwarded to Historic England, the Crown Estate, the Receiver of Wreck and the National Record of the Historic Environment as well as the local Historic Environment Record (HER). Any that are considered to be from uncharted wrecks are forwarded to the UKHO, and any that might have a military connection are forwarded to the MoD. A review of these finds may help identify sites of interest in terms of their polluting potential. This may be of particular relevance where munitions are recovered from the seabed and might relate to wrecks containing further explosive items. Reported finds from 2017 included 11 ordnance related finds (Wessex Archaeology, 2018), and ordnance pollution risk is further discussed at section 5.3.6.3.

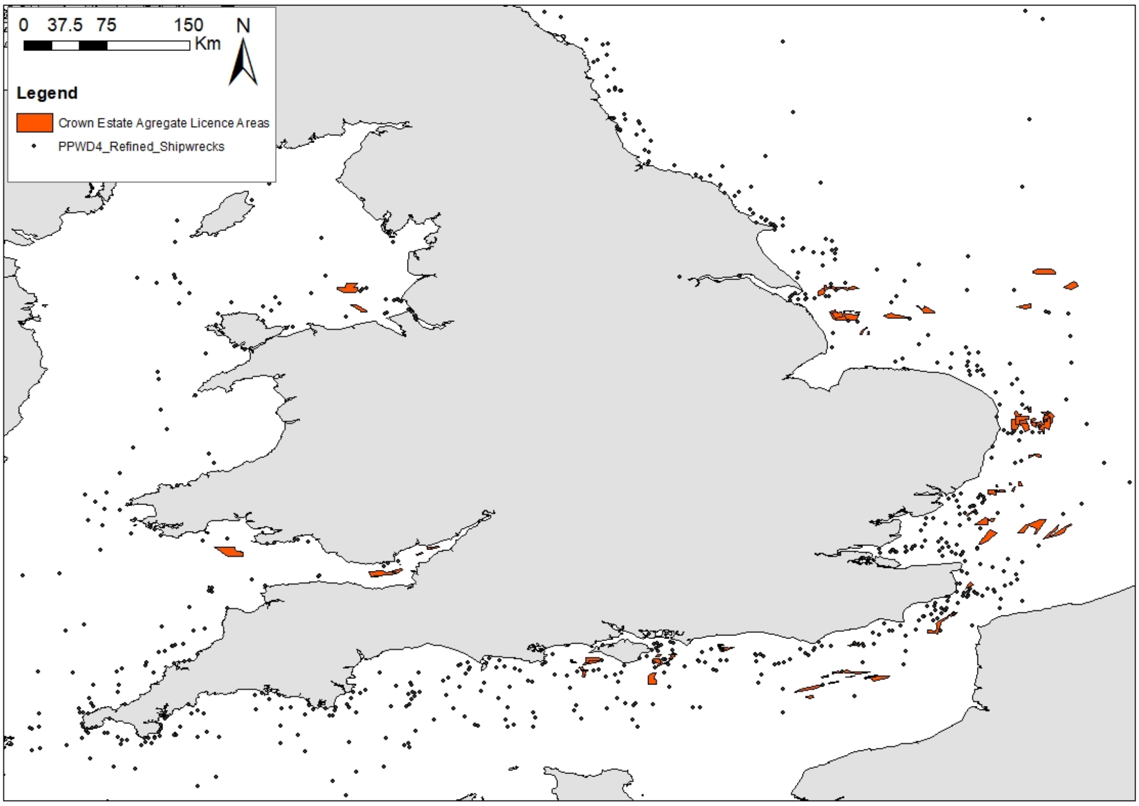

Figure 47 Licenced Aggregates Dredging Locations UK (author’s own image).

Table 7 PPWD4 Refined shipwrecks located in licenced dredging areas

UKHO	**Other ID**	**Vessel Name**	**Nationality**	**Year Lost**	**Fuel**	**Cargo**	**Latitude**	**Longitude**
20506	EH	*Gold Coin*	Greek	1972	Motor	2132 Mt Maize	50.73194	0.5797
12419		*Diana*	Dutch	1941	Motor	Coal	51.30716	-3.17015
11016	EH_912988	HMS *Exmoor* (Possibly)	British	1941		None	52.50403	2.0851
21141	EH_901760	*UB 56* (Possibly)	German	1917			50.97555	1.3868
20310		*U 671*	German	1944			50.39483	0.3182
11051	EH	RFA *War Mehtar*	British	1941		7000T Fuel Oil	52.60561	2.1503

5.3.4.2 Offshore Development

Offshore development in the UK and use of marine resources has grown significantly in the last decade. There are currently 37 operational offshore wind projects in the UK with an estimated GVA of £1,118 million, tidal and wave energy installations form a small part of the UK's offshore developments with a GVA of £64 million in 2016/2017 (ABPmer and ICF, 2019). Carbon capture storage is relatively nascent with three demonstration projects currently in the UK, the economic value of these developments is as yet unknown. A map of these sites is presented in Figure 48. These projects also require submarine cabling to shore, and there are a series of interconnector projects, telecoms cabling etc. linking the UK to Europe. Subsea electricity cabling is thought to add £2.8bn to the UK economy. There are also numerous oil and gas sites throughout UK waters (not shown on Figure 48). Approximately 36,000 people were employed in the oil and gas industry in 2017 (ABPmer and ICF, 2019, p. 30) and the overall GVA for the industry was estimated at £23.5bn in 2016 (ABPmer and ICF, 2019, p. 29).

Social benefits of offshore developments include high levels of employment in often remote locations, a demand for a skilled workforce has resulted in greater investment in training, and an increase in demand for service sectors relating to offshore development. Development of clean energy sources results in better environmental and social benefits including better public health as a result of cleaner energy production (ABPmer and ICF, 2019).

Increased development may adversely affect potentially polluting wrecks by directly impacting the wreck itself, or through changes to the environment in which the wreck is located. Given that all offshore developments require a marine licence, the likelihood of an accidental encounter with a potentially polluting wreck during installation and operation of offshore developments is relatively low.

Pollution from wreck will affect various development types differently, while oil and gas are used to dealing with pollution events, windfarms and tidal infrastructure may be adversely affected. Tidal energy generation is particularly likely to suffer in the event of oil pollution as the machinery sits at the surface where it is likely to be coated by oil. The presence of wind turbines in the vicinity of a wreck may complicate remediation work and hinder clean-up operations.

Spatial analysis of the wrecks using the select by location tool in ArcGIS identifies that there are eleven wrecks from the PPWD4 refined database located within offshore development lease areas for wind, tidal, carbon capture and gas storage. As offshore development increases, resulting in the collection of more survey data, it is likely that more wrecks will be identified that might have a polluting potential. These development sites can provide valuable data for further analysis of wrecks within their development areas as many of these will have conducted in depth surveys and will have examined potential ecological and social impacts in the area. If the data can be obtained from the developer the 11 wrecks located within existing development areas can be further examined to give better indication of the likelihood of pollutant release from these vessels based on their condition and the environmental conditions at the site. A column was added to the PPWD4 refined database attribute table noting their presence within development licence areas for future reference, these wrecks are also presented in Table 14 at Appendix E.

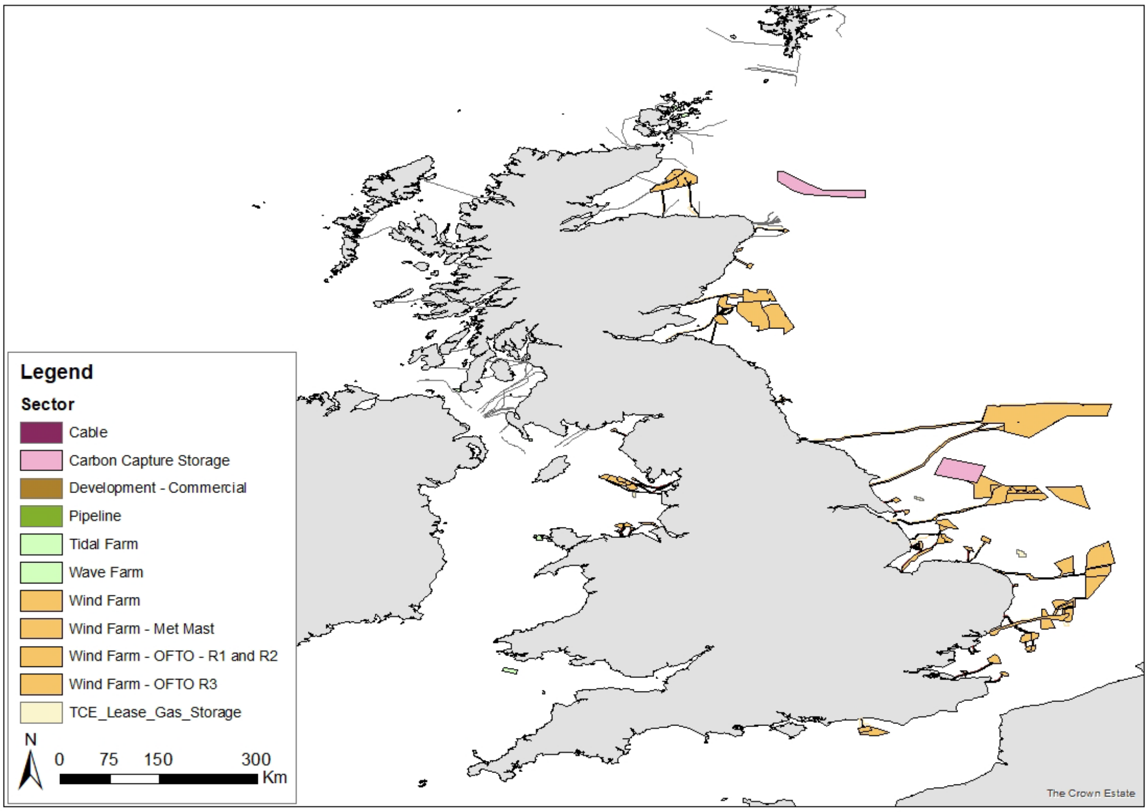

Figure 48 Offshore renewable development sites in the UK (author's own image).

5.3.4.3 Aquaculture

Aquaculture (or fish farming) in the UK is primarily focused in Scotland and mainly produces salmon, which accounts for 95% of the finfish production by volume in Scotland (Highlands and Islands Enterprise and Marine Scotland, 2017). Aquaculture in England and Wales is predominantly centred on shellfish production in inter-tidal areas. The UK produces over £35 million in shellfish each year (Adamson, Syvret and Woolmer, 2017) The value of the sector is in excess of £590 million to the UK economy, with the majority of fish being exported abroad (Black and Hughes, 2017).

Many have noted the social benefits afforded to often remote communities from aquaculture, primarily due to increased employment in these regions, but also increased tourism and economic sustainability (Frankic and Hershner, 2003; Shumway *et al.*, 2003; Highlands and Islands Enterprise and Marine Scotland, 2017). Aquaculture brings in younger people with families to areas with often aging populations, and encourages the growth of service industries to maintain their lifestyles, ultimately establishing more sustainable communities.

Loss of aquaculture from previous wreck events gives some idea of the potential impact of pollution events from legacy wreck. Estimates from the *Amoco Cadiz* oil spill suggest that the destruction of 6400 tons of oysters as a result of the spill came in at a loss of 26 million Francs (Whitmarsh and Palmieri, 2008). Aquaculture losses due to oil pollution from the *Prestige* wreck are estimated at 31,000 tons and 56 million Euros (Garza-Gil, Prada-Blanco and Vázquez-Rodríguez, 2006). In the UK the spill from the MV *Braer* resulted in 11 salmon farms within the exclusion zone being affected (roughly 25% of Shetland's production) with 5,399 tonnes of salmon being destroyed (Goodlad, 1996, p. 130). The subsequent media storm resulted in low consumer confidence in Shetland fish and a reduction in sales (Goodlad, 1996, p. 131). Pollution affecting any of the sites identified in the UK is likely to have an economic impact not only on the aquaculture industry itself, but also on the service industries that it supports. Pollution events could lead to destabilisation of communities in rural areas that are reliant on aquaculture as their primary economy and result in loss of social and cultural benefits that aquaculture affords.

Figure 49 shows the locations of aquaculture sites in the UK against the density of wrecks in the refined database. It is clear from this image that the sites at key risk from potentially polluting wrecks are mainly located in southern England and are shellfish production sites. While the majority of fin fish sites are located at some distance from dense areas of vessels in the refined database, with the exception of the Orkneys, vessels of less than 100GT may pose a risk to fin fish sites on the west coast of Scotland (Figure 50). Given the intensive nature of fish farming, these sites are likely to be severely affected by a polluting incident from even small amounts of pollution, whereas shellfish sites may be more resilient, as they are located on the seabed rather than in the water column or surface where oil pollution in particular is more likely to be found. Additionally, as many of the sites in England are located in areas which are not solely financially dependent on aquaculture, but have diverse economies they are less likely to be impacted than those communities reliant on fin fish sites in rural Scotland.

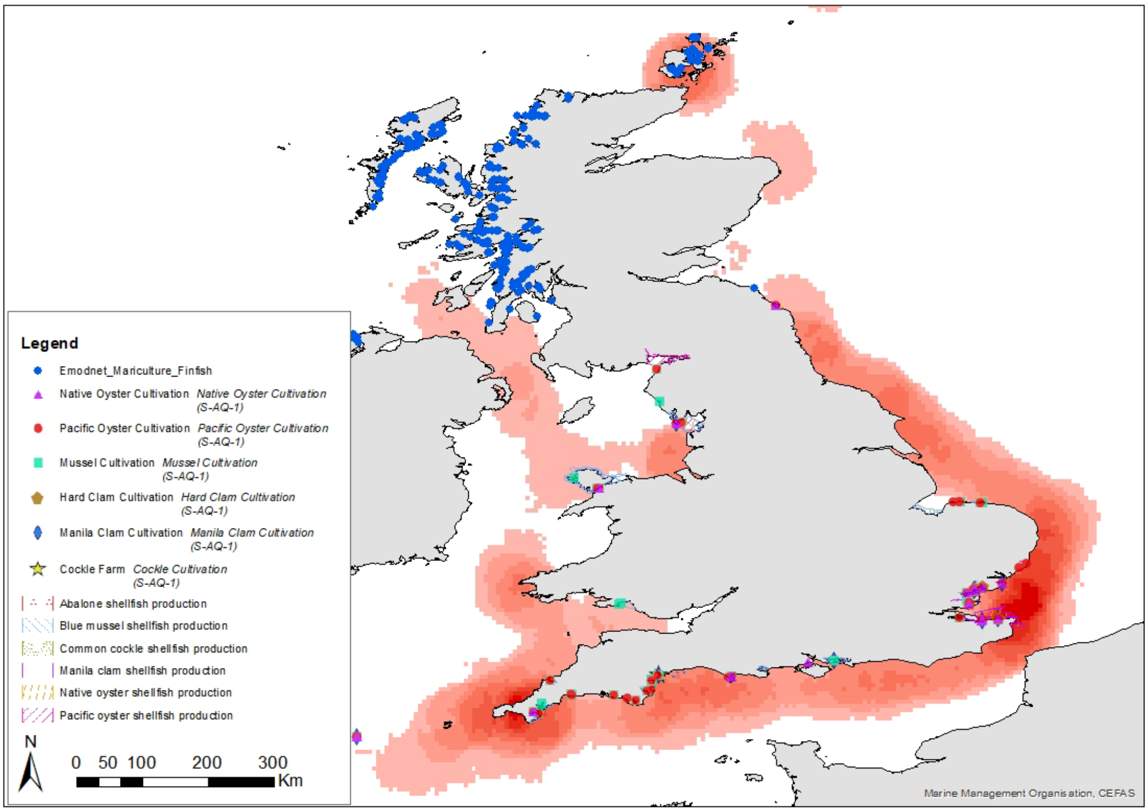

Figure 49 Aquaculture sites in the UK against density of vessels >100GT (author's own image).

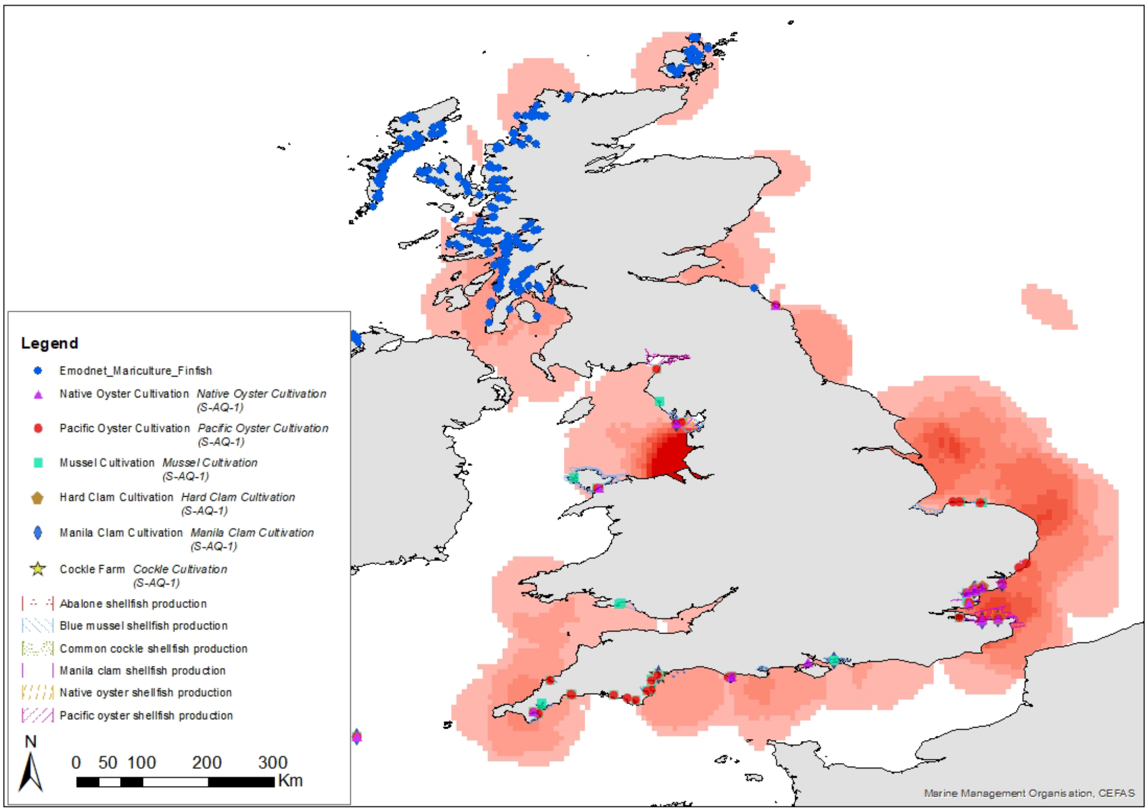

Figure 50 Aquaculture sites in the UK against density of vessels <100GT (author's own image).

5.3.5 Recreation

The impact of wreck pollution on recreational activities that take place on the UK coast is difficult to quantify as there is little quantifiable data regarding recreational use of coastal resources. Activities that are not formally organised or economically tracked are rarely quantified and activities such as swimming, coastal walking and beach use are rarely recorded. The number of visitors to beaches in the UK has been minimally studied, with the exception of localised studies in East Anglia (Coombes et al., 2008), although interest in this area of study is growing as new technology makes conducting these studies easier, for example, drones have been successfully used in Australia to conduct surveys of beach visitor numbers (Guillén et al., 2008; Provost et al., 2019). There is a growing literature supporting the beneficial impact of recreational use of the coast and sea for mental and physical health (White et al., 2016; McKinley and Acott, 2018), however, again, the value of this both socially and economically to the UK as a whole is difficult to quantify. The socio-economic impact of wreck pollution is therefore likely to have a greater impact than described in this section once these un-quantified activities and effects are taken into account.

5.3.5.1 Boating & Water Sports

The marine leisure industry has a total economic contribution of £2.75 billion in the UK (RYA, 2019). Data from the Royal Yachting Association (RYA) estimates that they have 110,000 members and that there are approximately 500,000 boat owners nationally (RYA, 2019). The total economic contribution from leisure boats is estimated at £1,508 million in 2017 (ABPmer and ICF, 2019). Approximately four million UK adults took part in a boating activity in 2017 with 49% being coastal rather than inland, an estimated 16.3 million taking part in a water sport activity of which 95% was coastal rather than inland based (Arkenford, 2018). In terms of social benefit, water sports clubs have an important social function in bringing communities together, and the industry promotes health and wellbeing, attracts tourism, and increases employment levels and skills development (ABPmer and ICF, 2019).

The MMO has created recreation models for water sport and boating activities in England (Marine Management Organisation, 2014) based on areas most likely to afford best conditions for each activity, and using data and feedback from relevant stakeholders. Unfortunately this data was not available for the rest of the UK.

In order to assess which wrecks are within areas of high density of water sports (excluding the beach activity and diving activity models (discussed in the subsequent sections)) the values for each of the recreation model raster at each shipwreck location were extracted using the ‘Extract

Values to Points' tool in ArcGIS. The values for each wreck from the recreation models were then added together to give the total value of activity for water sports as a whole at each location.

Of the 953 wrecks in the database only 624 fell within the MMO model areas, additionally some activities had values that were only calculated for a nearshore area (e.g. for shore angling and paddle sports) so wrecks outside these areas have a lower density of water sport activity. Figure 51 shows the wrecks with their respective water sport density. Those highlighted as being in high density areas are most likely to have a significant impact on the water sports industry and have a negative impact on the social aspects of water sports in those areas. Ideally, with further data, this analysis could be extended to wrecks in Welsh, Scottish and Northern Irish waters to give a holistic view of the impact of potentially polluting wrecks in Britain on recreational water sports.

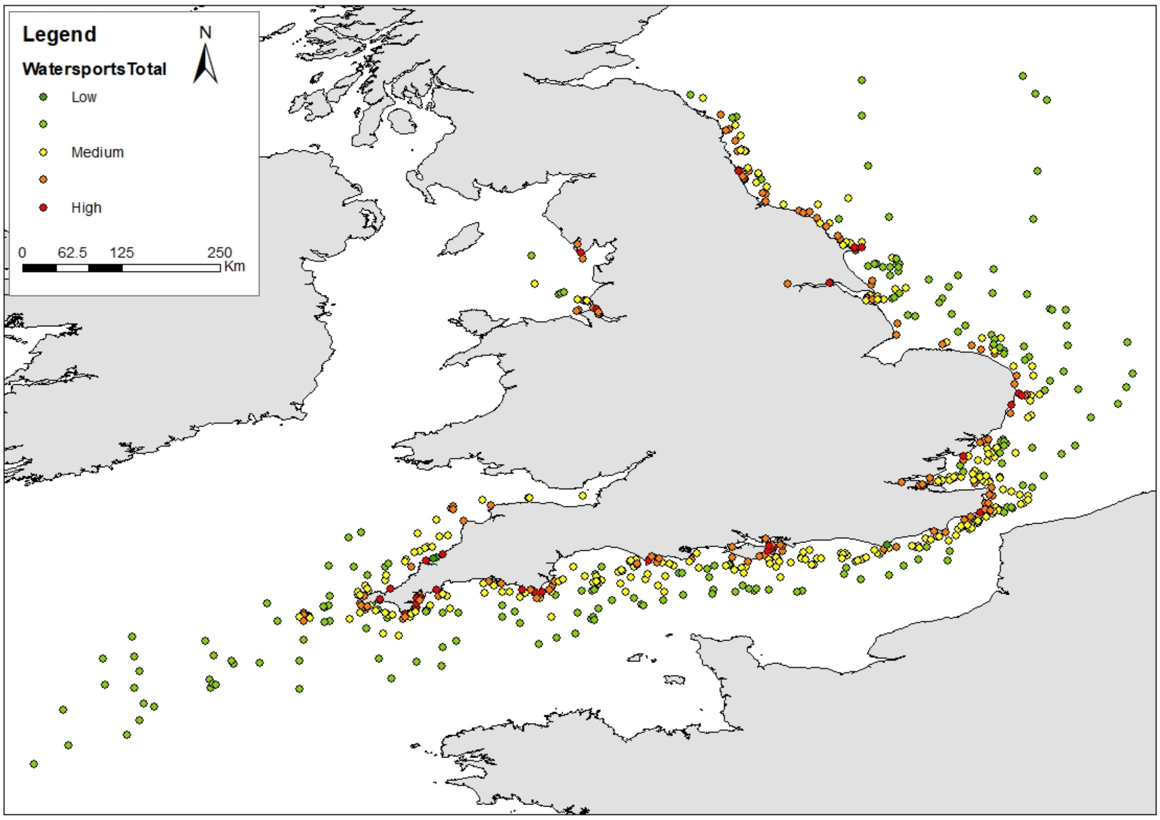

Figure 51 Density of water sports at shipwreck locations in England (author's own image).

5.3.5.2 Diving

One specific water sport that is likely to have the most impact on shipwrecks is diving. Divers interacting with wrecks might cause the wreck to deteriorate and release pollution. The impact of pollution from a wreck is also likely to have a severe impact on the economic and social benefits of recreational diving. It was not possible to find data for an estimated number of recreational divers in the UK so the risk from divers to wrecks is difficult to quantify, as is the economic value of diving in the UK. However, in their study of the cultural ecosystem service value of marine protected areas in the UK Jobstvogt, Watson and Kenter (2014) identified that divers were willing to pay £18.98 on average to travel to dive on shipwrecks, compared with £8.83 by anglers. The majority of divers also have an awareness of the importance of a "look don't touch policy" promoted as part of the "respect our wrecks" campaign conducted by dive training organisations (BSAC, 2019) so even if numbers of divers were available, this would not necessarily equate to the level of interference expected at a wreck.

As previously discussed at section 4.2.6.1 (and shown in Figure 23) the majority of vessels of less than 100GT are located within 30m water depth. Within the refined database, 435 vessels of greater than 100GT were in 30m of water or less (45.6% of the dataset). 30m is the limit to which most recreational divers are certified and trained, although experienced technical divers will be able to access wrecks at greater depths the 30m limit has been used as an indication of accessibility to wrecks it applies to the greatest number of divers.

The MMO diving model for English waters is shown in Figure 52 and wrecks most likely to be affected are in the areas of high intensity diving are shown in Figure 53. Given that these wrecks are in areas of high diving intensity and therefore likely to be well monitored by divers already, it may be possible to engage divers in "citizen science" activities to officially monitor and record the wrecks to determine their risk of pollution, thus freeing resources for use on other sites. Engaging local communities with wrecks may prevent unwanted damage to the wreck from irresponsible diving.

Unfortunately, as we do not know the number of we also do not know how many may be impacted by a potential pollutant release. In addition to oil and chemical pollutant release from these wrecks impacting on divers ability to access and enjoy diving, the risk from ERW to divers is of considerable concern, this is further discussed at section 5.3.6.3.

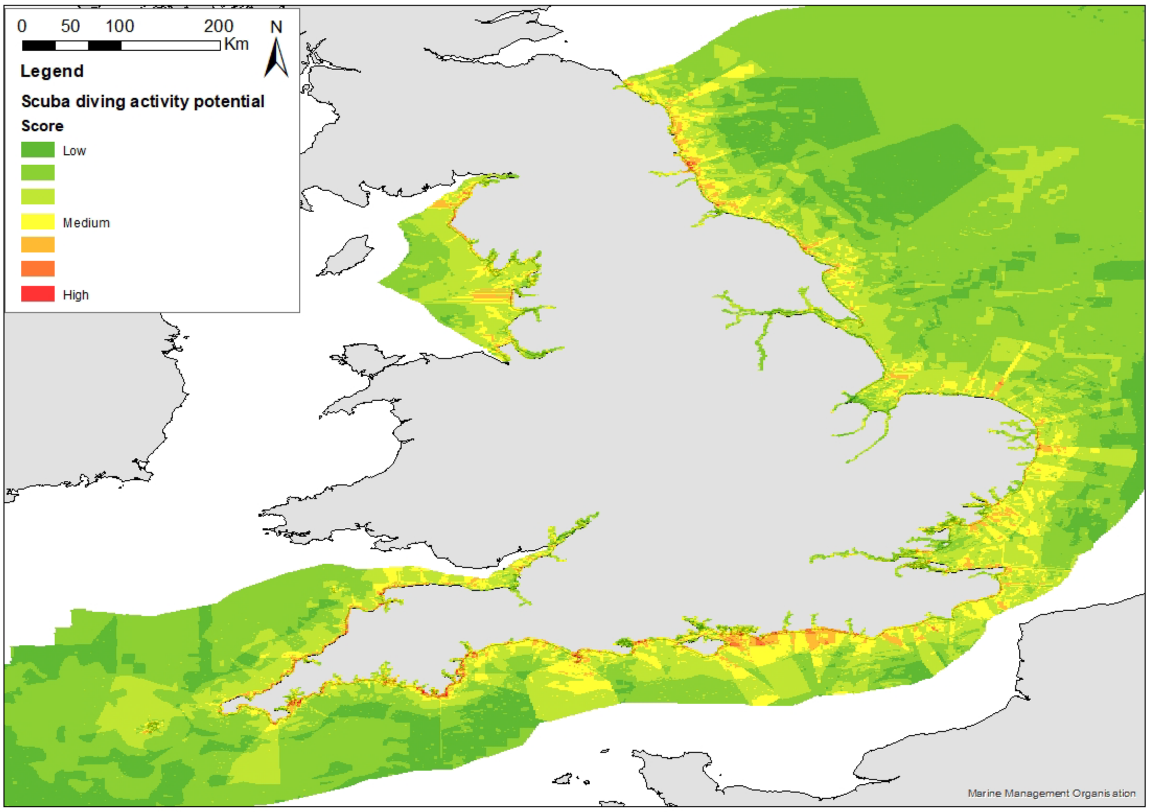

Figure 52 Scuba Diving Activity Potential Model from the MMO (author's own image).

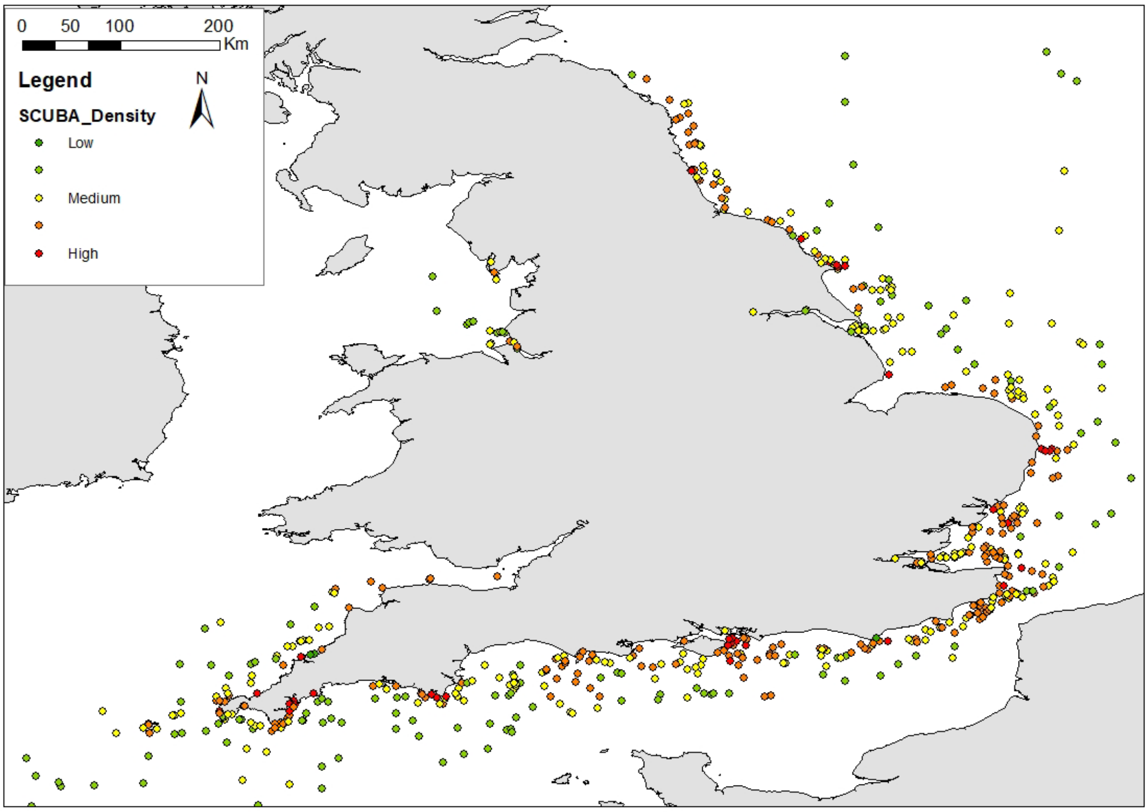

Figure 53 PPWD4 refined database colour coded by density of SCUBA activity (author's own image).

5.3.5.3 Beach Activities

While data on beach activities are largely unquantified, the MMO's water use models includes a beach activities model calculated using data on bathing water sites and blue flag beaches, as well as information from beach related stakeholders. Figure 54, Figure 55 and Figure 56 demonstrate the results of the beach activity model for England. The model limits are relatively close to shore so spatial analysis of the model against the database is not possible without also modelling pollution release from wreck and its trajectory. If combined with oil spill modelling for shipwrecks such as in the CEFAS risk assessment the beach activity model may give a better indication of the potential impact of wreck pollution at coastal beach sites. Areas with a likelihood for a high density of beach activities are the most likely to be severely impacted both economically and socially by wreck pollution. Again, expanding this beach model to the rest of the UK would result in better capacity to assess wreck pollution across the whole of the UK.

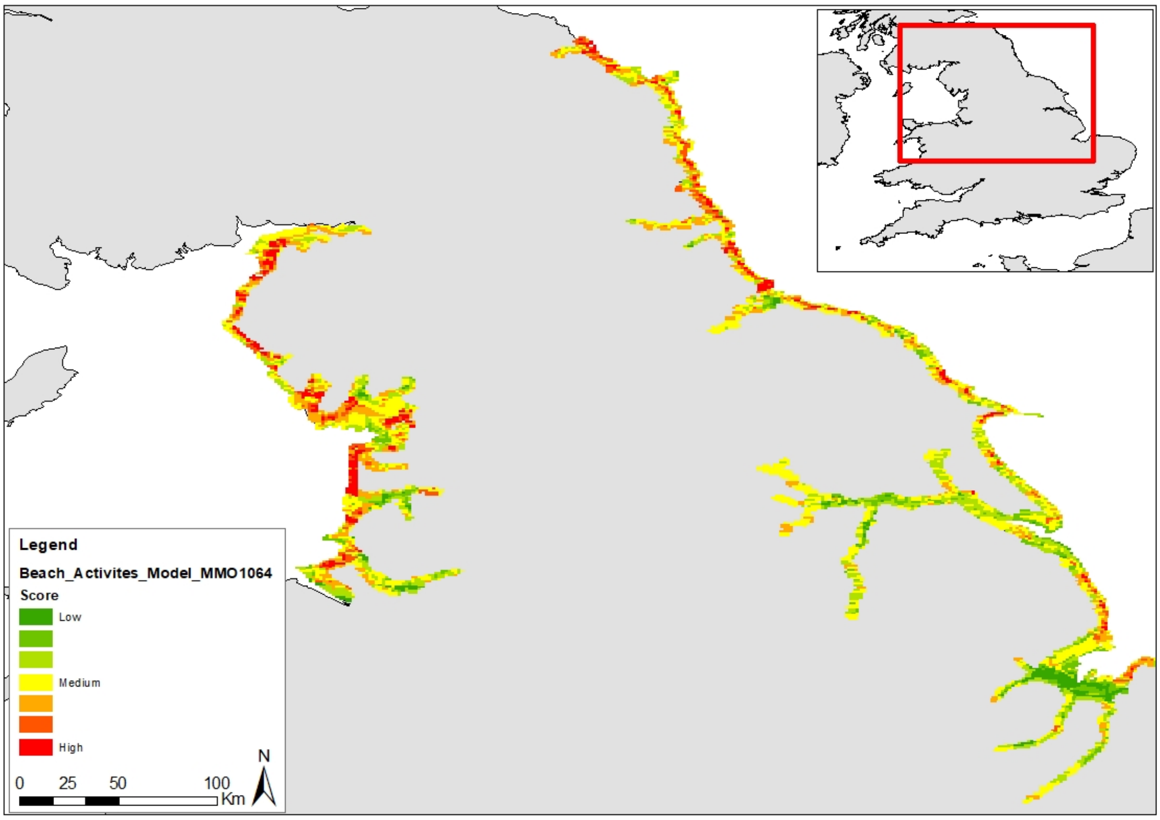

Figure 54 Beach Activities Density North of England (author's own image).

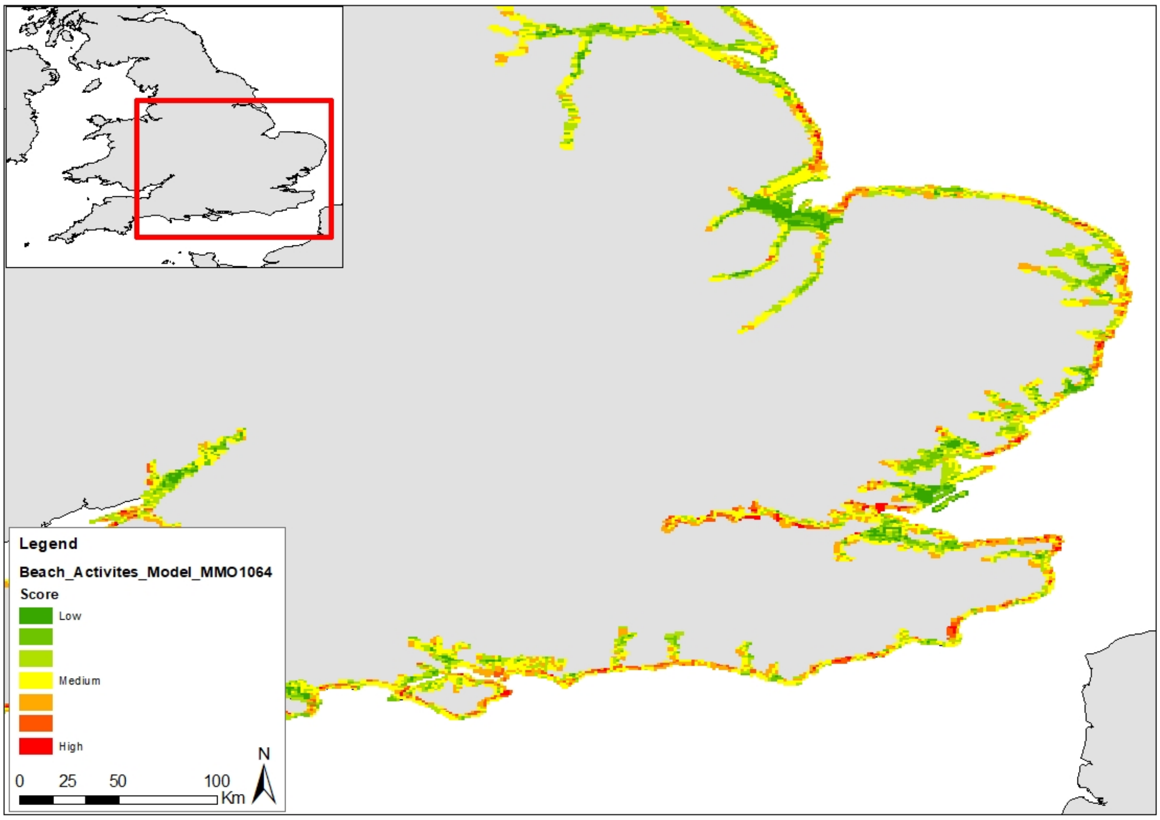

Figure 55 Beach Activities Density East of England (author’s own image).

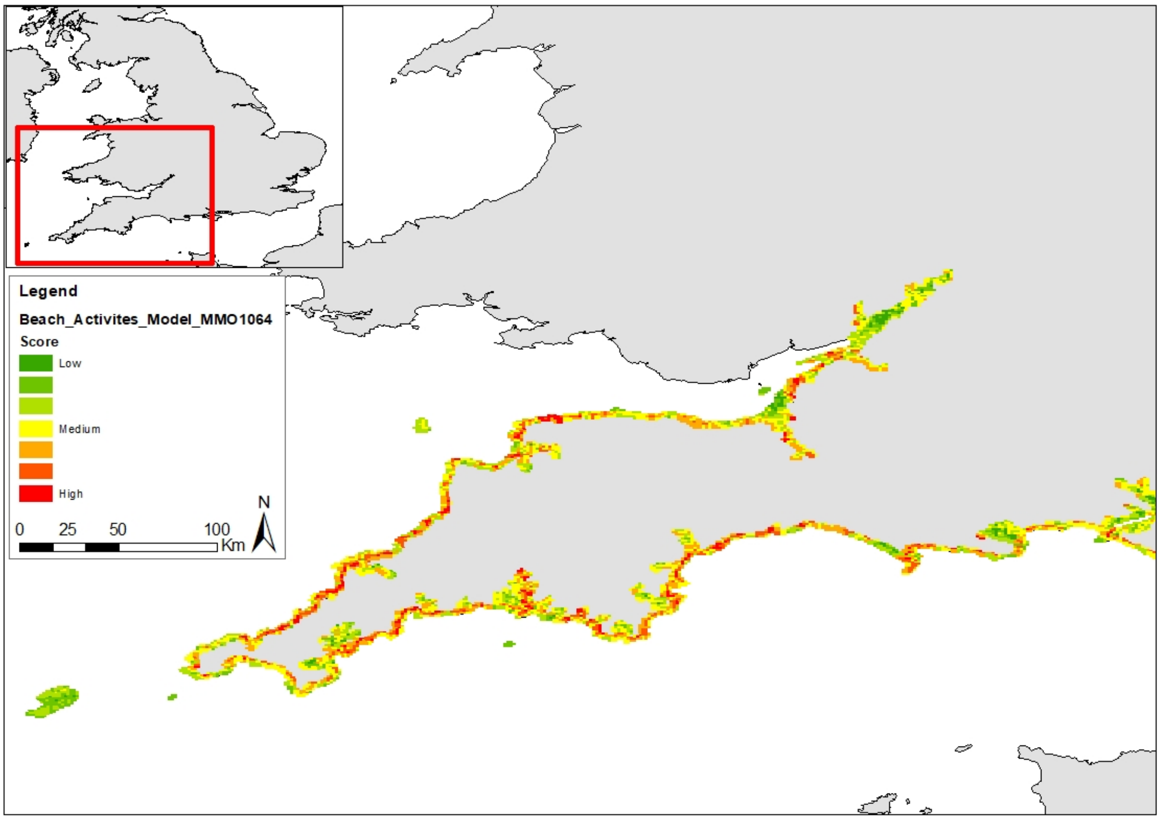

Figure 56 Beach activities density in the southwest of England (author’s own image).

5.3.5.4 Tourism

Shipwreck pollution events have been known to have a significant impact on the tourism industry. The *Erika* wreck and oil spill resulted in the estimated loss of 500 million Euros to the French tourism industry (Bonnieux and Rainelli, 2004), the *Exxon Valdez* spill in 1989 resulted in a loss of U.S.$5.5million for the tourism industry (Cheong, 2012), and the *Prestige* incident resulted in a 210.4 million Euros loss in tourism income (Garza *et al.*, 2009). Losses in the tourism industry often extend beyond the point where the region has recovered from a polluting incident as tourists remain cautious and uncertain about the regions affected (Cheong, 2012), thus resulting in further long term economic impacts in the region.

Coastal tourism in the UK employed 336,786 people in 2006 (ECORYS, 2013), with approximately 210,000 jobs in England and Wales in 2014 (National Coastal Tourism Academy, 2017), and is valued at approximately £8bn in England for domestic tourism (National Coastal Tourism Academy, 2016a). Peak visitor times occur in May, July and August, coinciding with the May Bank holidays and school summer holidays (National Coastal Tourism Academy, 2016b, p. 6). The South West of England is the most popular destination accounting for 43% of trips (National Coastal Tourism Academy, 2016b, p. 3), unfortunately this is also a region that has been identified as having a high density of potentially polluting wrecks and is more likely to experience pollution as a result. The data presented in this section includes visitor numbers to marine and maritime cultural heritage sites (possibly including wreck sites), which might be particularly adversely affected by marine pollution from wrecks. A discussion on the value of shipwrecks as cultural heritage is discussed separately in section 5.4.3.

In order to assess the impact of potentially polluting wrecks in the UK on tourism statistical data regarding visitor numbers and expenditure in the UK for 2018 was analysed. Statistical data was obtained from the Visit Britain website for England, and data for Northern Ireland from the Northern Ireland Statistics and Research Agency (NISRA). Unfortunately data separated by region was not available for Wales and Scotland, however, overarching data was obtained for both countries (The Welsh Government, 2019; Visit Scotland, 2019). The data was assigned to regions based on the Nomenclature of Territorial Units for Statistics (NUTS) 2018 Level 2 regions across the UK (European Union, 2018). Where the data for Scotland and Wales could not be regionalised it was allocated for the country as a whole, this may therefore give a false impression of the distribution of tourism within Wales and Scotland but is useful as a country based comparison. The data was then mapped against the density of potentially polluting wrecks in the UK shows which regions may face the greatest impact from decline in tourism as a result of a polluting incident in their vicinity. A caveat is that the data is provided at a regional level and may be distorted by inland tourist destinations where density of tourism is high, while the coastal areas we are interested in may have relatively low visitor numbers. Therefore the assessment presented here is relatively coarse. While data is available for local council areas in England these do not correspond with NUTS regions and were therefore not used for statistical analysis. Additionally, the disparity between local administrative areas in England and the country-wide data for Scotland and Wales would have made the assessment difficult to analyse. However, the data could be used for a more refined assessment of potentially polluting wreck effects on tourism in England in future research.

The coastal areas with the highest visitor numbers are East Anglia and Sussex, with the Kent, south west and Welsh coastlines have a medium level of tourism (as demonstrated in Figure 57). The East Anglian, Sussex, Kent, and southern part of England are also in an area of high density of potentially polluting wrecks, and therefore most likely to encounter pollution from this source. The impact on tourism numbers in these areas could be severe. Additionally, pollution in these areas is likely to have a significant impact on the overarching contribution of UK tourism to the economy as these are the areas where the greatest tourism expenditure takes place (as shown in Figure 58). The North of Wales and Pembrokeshire also stands to be impacted relatively heavily in the event of pollution from wreck, and while pollution in this area is likely to have a localised economic impact, the impact on the overarching UK tourism economic contribution is likely to be minimal as there is less expenditure in this region than the rest of the UK. While high density areas of potentially polluting wrecks are also located on the North East coast of the UK and in Orkney, these areas have significantly less visitors than southern and eastern England so the impact of pollution on tourism, both in terms of visitor numbers and economically, is likely to be much less.

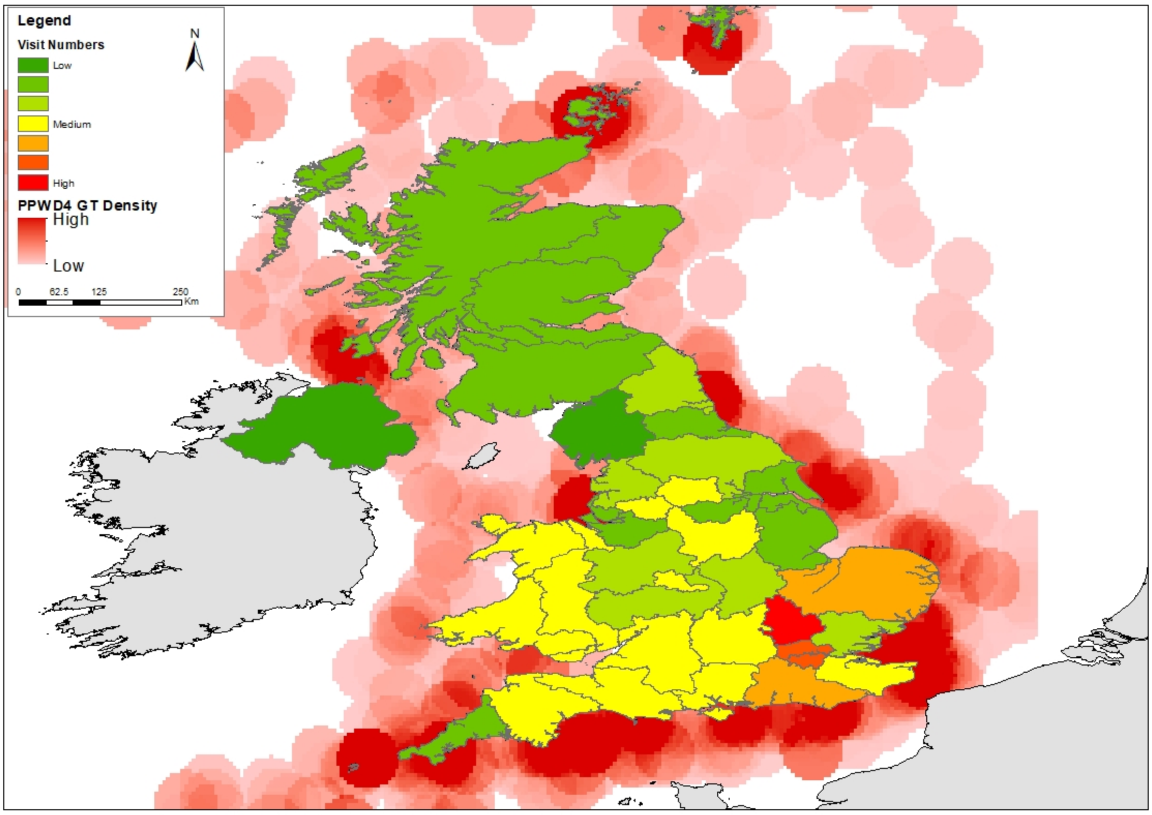

Figure 57 Tourist visits by region and density of refined shipwrecks (author's own image).

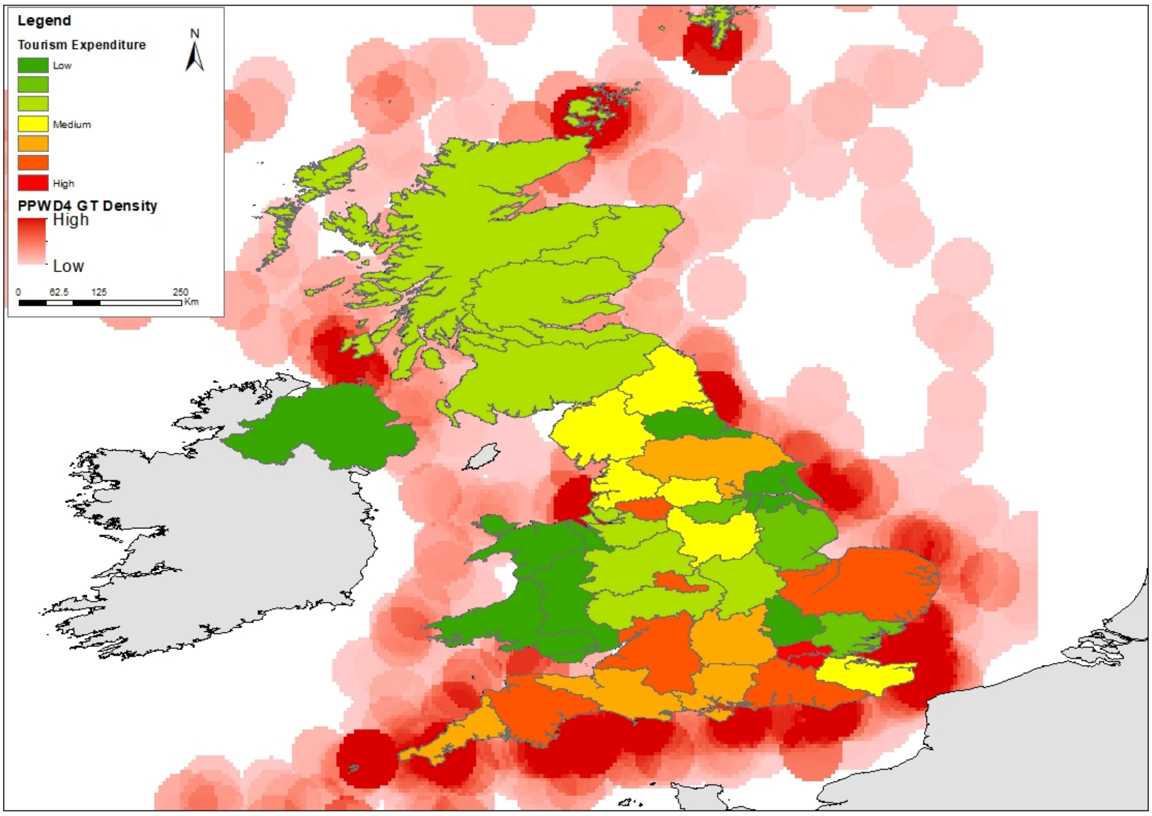

Figure 58 Tourist expenditure by region and refined vessel density (author's own image).

Wreck pollution that has a severe environmental impact tends to be the main focus of potentially polluting wreck studies, resulting in the focus on wrecks of over 100GT or 150GT depending on the risk assessment. There is evidence that in respect of economic and social damage to the tourist industry even small amounts of pollution can have a severe impact, despite having a relatively low environmental impact. A relatively minor oil spill of approximately 20 tonnes in total of fuel oil, diesel oil and lubricants from the wreck of the Don Pedro, in 2007 in Ibiza resulted in compensation claims from tourism firms of 1,504,423 Euros, with the final compensation and salvage costs amounting to approximately 7.5 million Euros (Cirer-Costa, 2015). Hotels estimated their loss of income was at around 50%, and with the beach closed the estimated loss of earnings for smaller businesses is estimated at approximately 2,387,000 Euros per day (Cirer-Costa, 2015, p. 70). Therefore it is not sufficient to omit smaller wrecks from potentially polluting wreck risk assessments, as they may in fact have a significant economic and social impact within the tourism industry, even if their environmental impact is relatively low.

Figure 59 shows visitor numbers by region in relation to the density of vessels of less than 100GT. The density of smaller vessels against the tourism patterns seems to largely agree with the findings from the density of the refined database, however, the south coast is less likely to suffer from aggregated pollution from smaller vessels based on their density. East Anglia and Kent remain a concern both in terms of visitor numbers and potential economic impact (expenditure by tourists against the density of vessels of less than 100GT is shown in Figure 60).

Many seaside towns and resorts in the UK suffer from low employment and education rates as well as a host of other socio-economic problems, partly due to the seasonal nature of the tourism industry, upon which they are reliant (Agarwal *et al.*, 2018). Impacts of loss of tourism as a result of a polluting incident will hit these communities hard, causing increased unemployment and contributing to wider social problems. The resilience of various coastal communities to pollution incidents is further discussed in the next section.

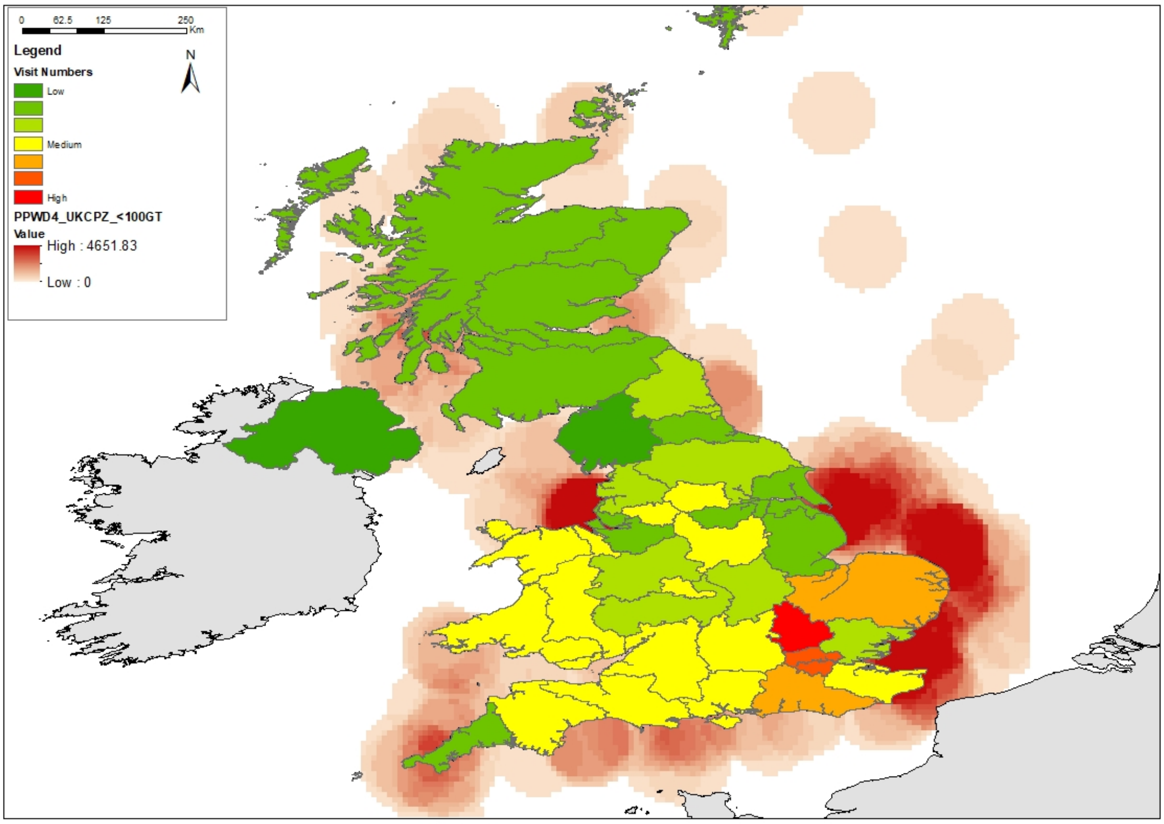

Figure 59 Tourism visits by region and density of vessels of <100GT (author's own image).

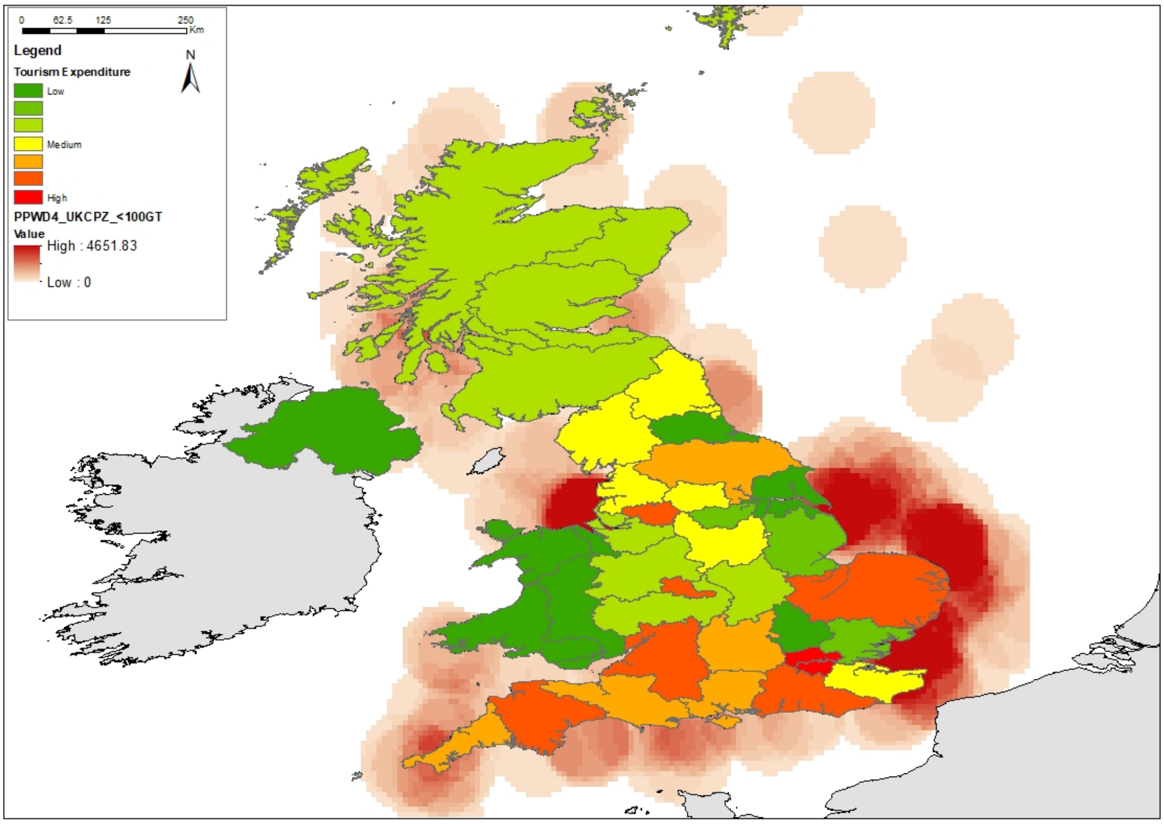

Figure 60 Tourism expenditure by region and density of vessels of <100GT (author's own image).

5.3.6 Public Risk

5.3.6.1 Coastal Communities

Coastal communities in the UK are the most likely to be affected by wreck pollution, many of these communities benefit economically and socially from their proximity to the sea. Many are economically reliant on the marine and coastal environment, through employment at harbours and ports, in recreational water sport industries, and from coastal and marine tourism. 85% of coastal local authorities had mean pay levels below average for Britain in 2016 (Corfe, 2017). Socially, educational qualifications tend to be lower in coastal communities, and health problems are more prevalent, although this may be as a result of the attraction of coastal sites for retirees who experience greater health complaints (MMO, 2011; Corfe, 2017). Other studies indicate that coastal communities are healthier and happier than those living inland due to the perceived benefits of coastal living (White *et al.*, 2016). Pollution impacts can exacerbate social issues, particularly where they restrict access to the benefits that the coast provides for these communities, e.g. improvement to physical health through exercise potential from water sports, or the economic benefits of tourism, both of which will be negatively impacted in a pollution event.

An indication of the potential impact of potentially polluting wreck pollution on coastal communities might be provided by the research conducted by the MMO into the socio-economic nature of coastal communities in England (MMO, 2011). Similar research has been undertaken in Wales but the data behind the report is not publicly available (OCSI, 2014), and no data of this kind was identified for Scotland. An analysis of the data for England was undertaken, and a summary of the data is presented in Table 15 at Appendix F.

The highest proportion of coastal communities in England are classed in category D2 (16%) (Figure 61). While dependent on ports these communities are likely to be relatively resilient against pollution based incidents as they have stable populations, non-maritime related revenue streams and a strong economy. 15 % of English coastal communities fall within category D1, these are likely to be the most resilient communities in the event of a pollution affecting the coast as they have greater affluence, and low dependence on coastal infrastructure. The least resilient communities are likely to be those in categories B1 (9% of the UK), B3 (12%), and C1 (6% of the UK) as these have the most fragile economies and their communities are far more reliant on the marine environment. Table 8 gives a full breakdown of the categories, their description and their resilience in the face of marine pollution.

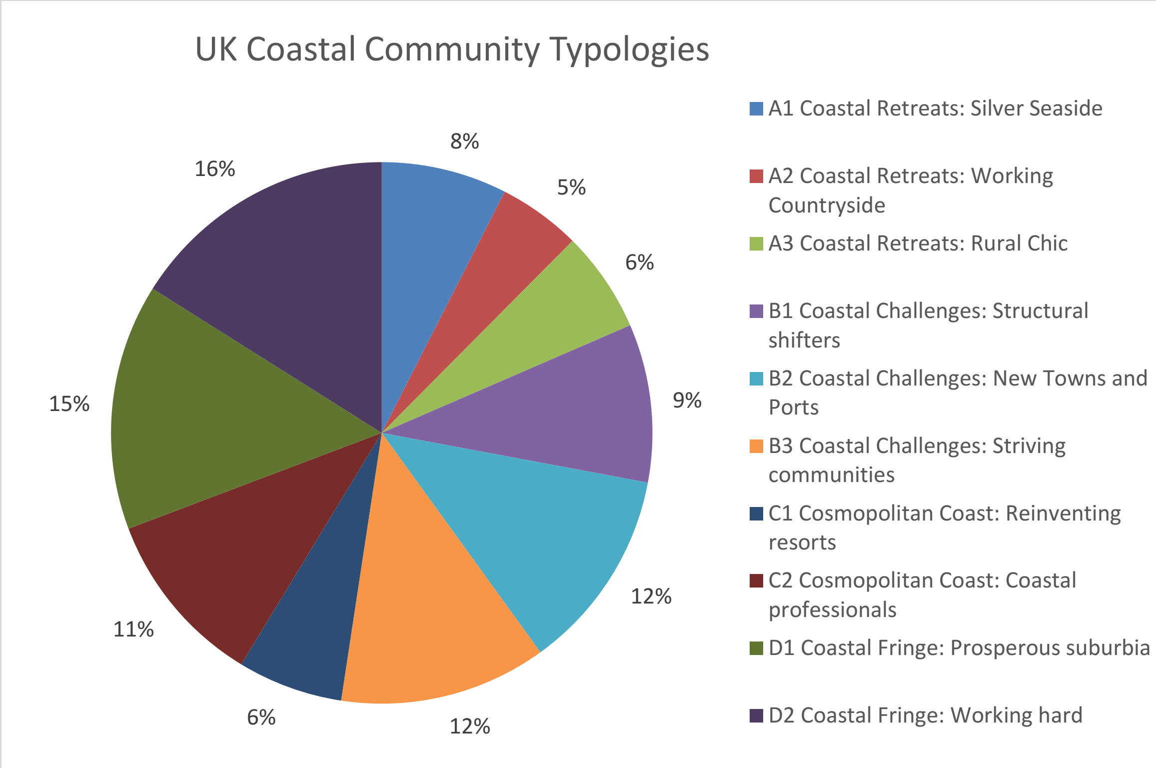

Figure 61 English Coastal Community Typologies (author's own image).

Table 8 Coastal community categories and their resilience in the face of pollution

(Category information taken from MMO, (2011))

Category	**Description**	**Pollution resilience**
A1 Coastal Retreats: Silver seaside	Retirement areas primarily located in smaller, less developed resorts	Medium
A2 Coastal retreats: Working Countryside	Predominantly rural areas, sparsely populated or in smaller settlements, with people employed in lower skill occupations	Medium
A3 Coastal retreats: Rural chic	Predominantly rural areas, sparsely populated or in smaller settlements, with a well-qualified population	High
B1 Coastal Challenges: Structural Shifters	Towns and cities which have lost their primary markets and are facing the challenge to find new ones. This group includes a range of single industry coastal towns, including seaside resorts, mining areas, industrial heartlands and former agricultural centres	Low

Category	Description	Pollution resilience
B2 Coastal Challenges: New towns and ports	Challenges relating to poor skills and high levels of worklessness, but counterbalanced by relatively strong economy and often located close to areas of economic growth	Medium
B3 Coastal Challenges: Striving communities	High levels of deprivation across all indicators and a very high proportion of people living in social rented accommodation	Low
C1 Cosmopolitan coast: Reinventing resorts	Primary tourist economies with high levels of deprivation, but diversifying to attract a more highly skilled population	Low
C2 Cosmopolitan coast: Coastal professionals	City and market town service centres with highly skilled populations and dynamic economies	High
D1 Coastal fringe: prosperous suburbia	Affluent areas predominantly on the edge of towns and in satellite towns around larger coastal cities	High
D2 Coastal fringe: Working hard	Towns characterised by high levels of employment typically in industrial sectors, and a stable population	High

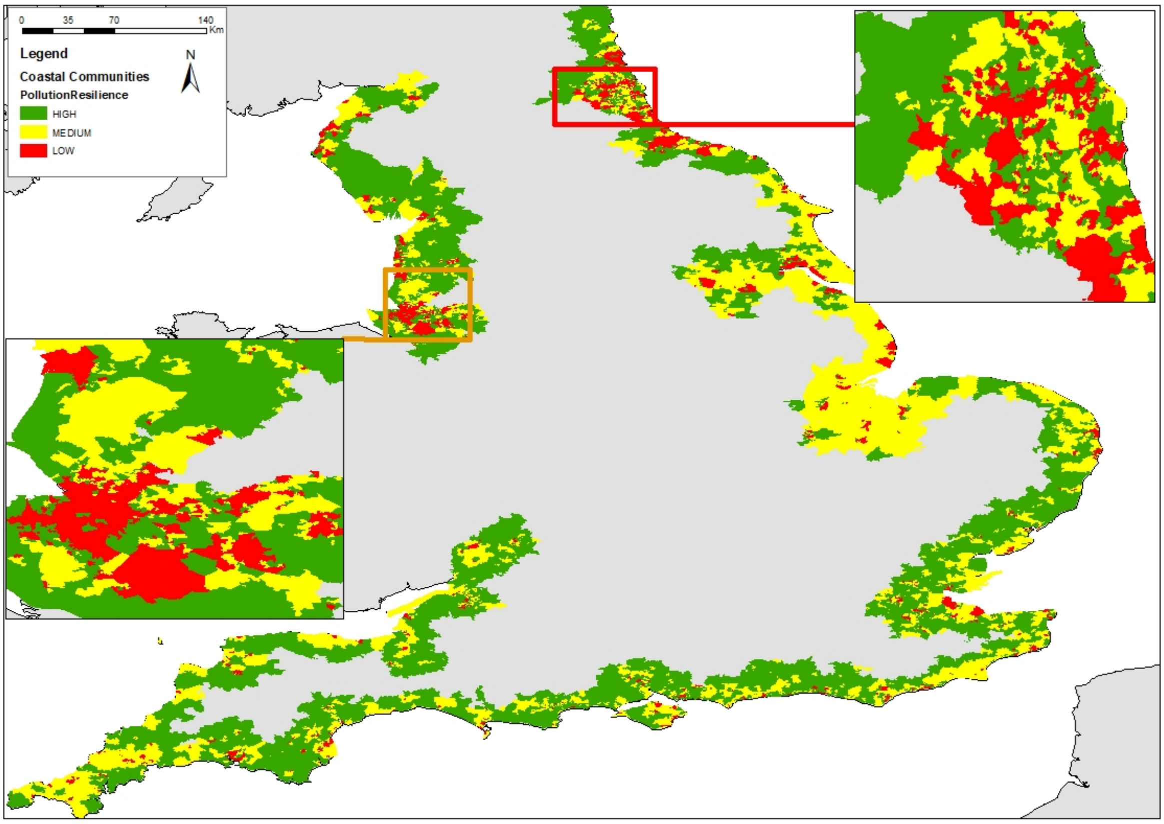

Figure 62 Coastal Communities in England and their resilience to marine pollution (author's own image).

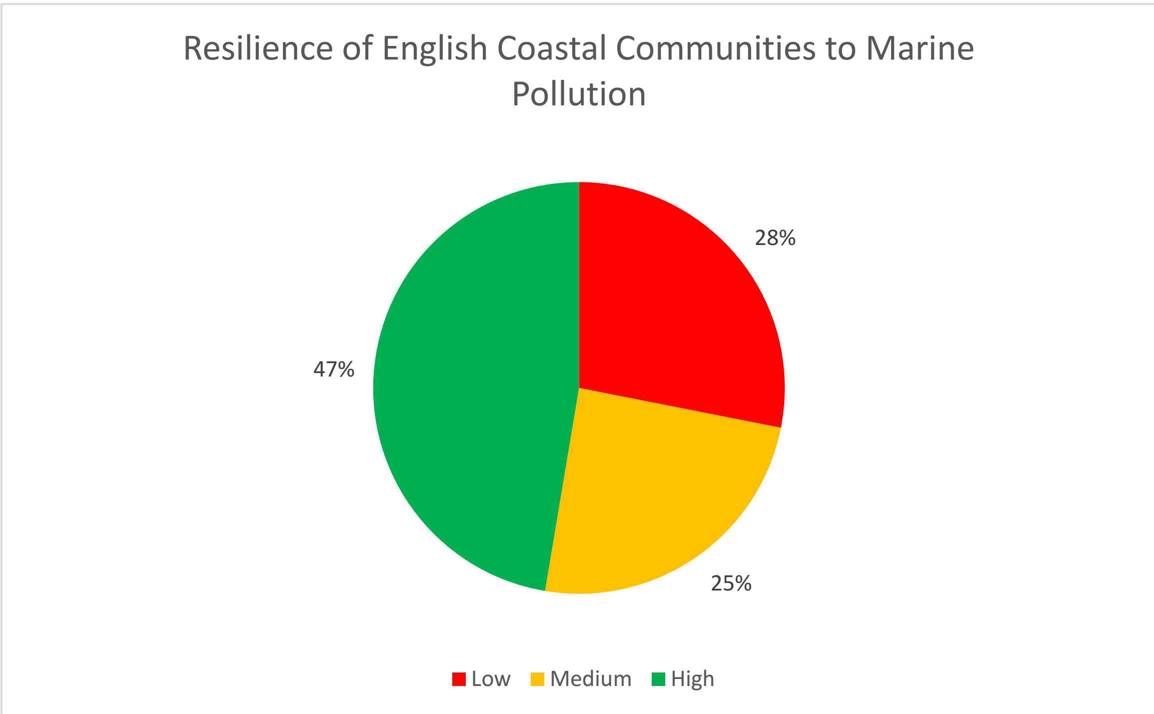

Figure 63 Resilience percentages for English Coastal Communities in England (author's own image).

Figure 62 shows English coastal communities and their respective resilience to pollution events. The majority of English coastal communities are relatively resilient to marine pollution events. 47% of communities are likely to be highly resilient in the face of marine pollution (green in Figure 62 and Figure 63), while 25% are likely to be moderately resilient (orange) and 28% have a low resilience to marine pollution (red). Certain cities that rely on ports for their economy are likely to be highly affected, these include Plymouth, Liverpool, Newcastle and Hull.

This is a relatively coarse assessment, and those communities located on the coast itself are likely to face greater disruption in the event of pollution than those further inland, however, it is helpful to assess regions where wreck pollution may have the greatest impact. An analysis of the coastal communities within each region of the UK, based on the NUTS Level 1 classifcation of the 9 statistical regions of England (European Union, 2018), was undertaken. Figure 64 shows the number of communities with each level of resilience by region. It is clear that the North East of England, and Yorkshire and Humber are the least resilient regions, while the South East, South West, East of England and London are the most resilient regions. The North West of England is likely to be somewhere in the middle as while it has a high proportion of highly resilient communities, it also has a high number of low resilience communities.

At county level, the east coast of England from Kings Lynn in Norfolk, to Whitby in Yorkshire is likely to be particularly vulnerable due the lack of high resilience communities nearby (Figure 62). While the majority of coastal communities in this area are classed as having a medium resilience, they would struggle to recover in the event of a polluting incident as there are no very resilient communities nearby to help support them. Similarly large parts of Kent, Devon and Cornwall are also likely to suffer more greatly than other parts of England where the medium and low resilience communities are surrounded by high resilience communities or a more varied mix of communities within each county.

It is not possible to determine which potentially polluting wrecks might impact on individual communities as this will depend on environmental factors governing pollution spill trajectories (wind direction, currents, etc.) at the time of the pollution event. However, a general idea of the impact and vulnerable communities can be ascertained from comparison with the vessel density heat map (Figure 65). It is clear that communities in Cornwall, the regions around the Humber and Newcastle are vulnerable and also have a relatively high likelihood of being impacted by pollution from wreck (Figure 65). While the highest density of polluting vessels is off the Essex and Kent coasts, these regions are more likely to be resilient in the event of a pollution incident so the economic and social risk from vessels to communities in this area is lower.

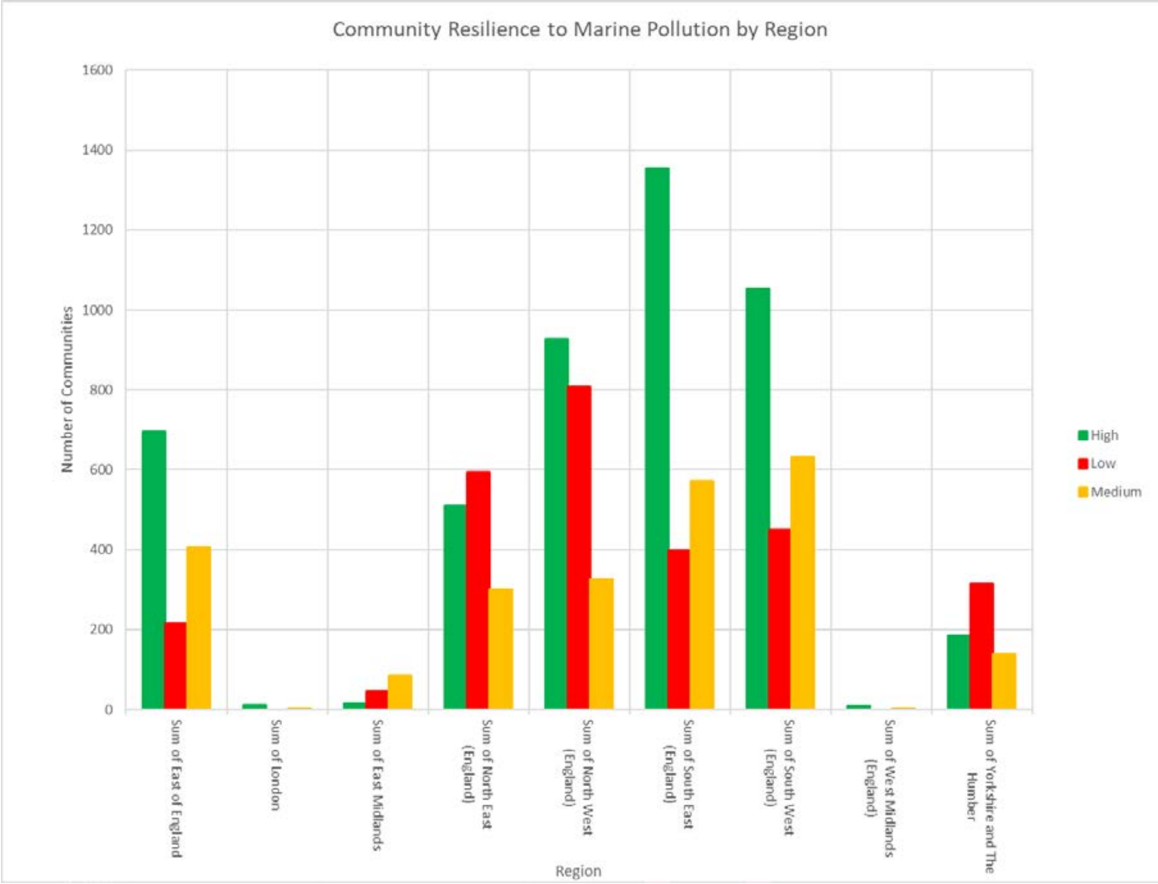

Figure 64 Resilience of Communities per Region of England (author's own image).

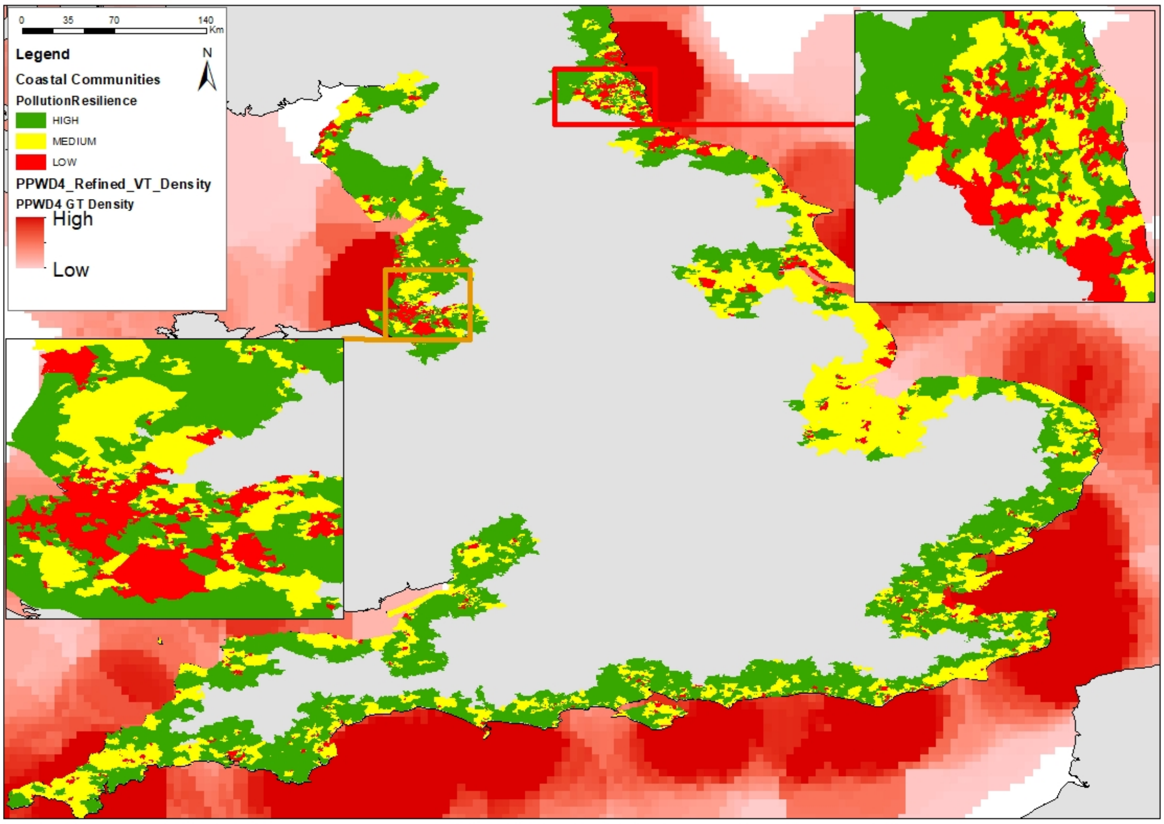

Figure 65 PPWD4 Vessel heat map and location of coastal communities (author's own image).

5.3.6.2 Critical National Infrastructure

Critical national infrastructure (CNI) are the facilities, sites etc. that are necessary for a country to function and therefore are critical to public life. According to the Centre for the Protection of National Infrastructure (CPNI, 2019) the UK has 13 national infrastructure sectors: chemicals, civil nuclear, communications, defence, emergency services, energy, finance, food, government, health, space, transport and water. The impact of wreck pollution on food, marine space, public health and some aspects of transport have been discussed previously in this chapter. It is unlikely that pollution from wreck will have significant impact on the ability of the chemicals, communications, defence, emergency services, and finance or government sectors to function in their required capacity, although the coastguard and specific government departments responsible for pollution response may be stretched in the event of an incident

Aspects of CNI that have yet to be assessed include power generation sties (both gas and nuclear), electricity substations, ports, railway stations, airports and to a lesser extent coach stops. Data for these sites was collected from the National Grid, from the National Public Transport Access Node (NaPTAN) and from EMODnet. Locations of rail, coach, airport, substation and gas sites were clipped to only include assets that are within 500m of the coastline or river system. Ports, ferries and nuclear power stations were included in the dataset without being clipped to distance to coastline as these all have facilities that are located in the marine environment.

The locations of CNI in relation to the density heat map of potentially polluting wrecks in the refined database is presented in Figure 66. As previously noted the highest density of wrecks is in the south of the UK and it is the CNI in the south and East of the UK that is therefore most likely to encounter a pollution event from wreck. Ports are most likely to be affected given their large numbers (365 in total). Ferry facilities also have a high likelihood of pollution encounter (302 sites). Terrestrial transport sites such as airports, railway stations and coach points are much less likely to be affected by marine pollution, as are terrestrial gas and electrical energy sites. There are only 6 active nuclear power station sites in the UK, however, these are likely to suffer from any pollution arising from wreck as they use seawater in order to cool the reactors. Of the nuclear sites, two are situated in areas identified as having a high density of refined PPWD4 wrecks, namely Hartlepool and Dungeness B Power stations.

A proximity analysis of CNI sites was undertaken using the select by location tool in ArcGIS. There are 12 wrecks within 1,000m of a site of critical national infrastructure. Fortunately none of these are within 1,000m of a nuclear site, airport, gas site or electrical substation. Five are in proximity to ports, eight in proximity to ferry locations and one in proximity to a coach location. The 1,000m distance is somewhat arbitrary as we know that depending on the severity of a pollution event, type of pollution, weather conditions etc. pollution could affect sites many kilometres from the point of origin. However, it is a useful measure to see which wrecks might pose an immediate problem based on their proximity, or where smaller levels of pollution released from a wreck might have an effect on CNI. A second assessment of the data was undertaken to find out the location of the nearest shipwreck to each point of CNI using the spatial join tool in ArcGIS. The distances of the nearest shipwreck to CNI and vice-versa were appended to the attribute table of both shapefiles, and which could easily feed into future risk assessment processes.

Wrecks of less than 100GT are most likely to primarily affect ports and ferry locations based on the areas of high density of these vessels (Figure 67). Areas of high density are not located in proximity to nuclear sites and terrestrial sites are less likely to be affected by pollution from these vessels. The risk from vessels of less than 100GT is therefore greatest to ports and ferry locations in the Liverpool region, in East Anglia and the Thames. Economic impacts of reduced port access and ferry travel have already been discussed at section 5.3.1.

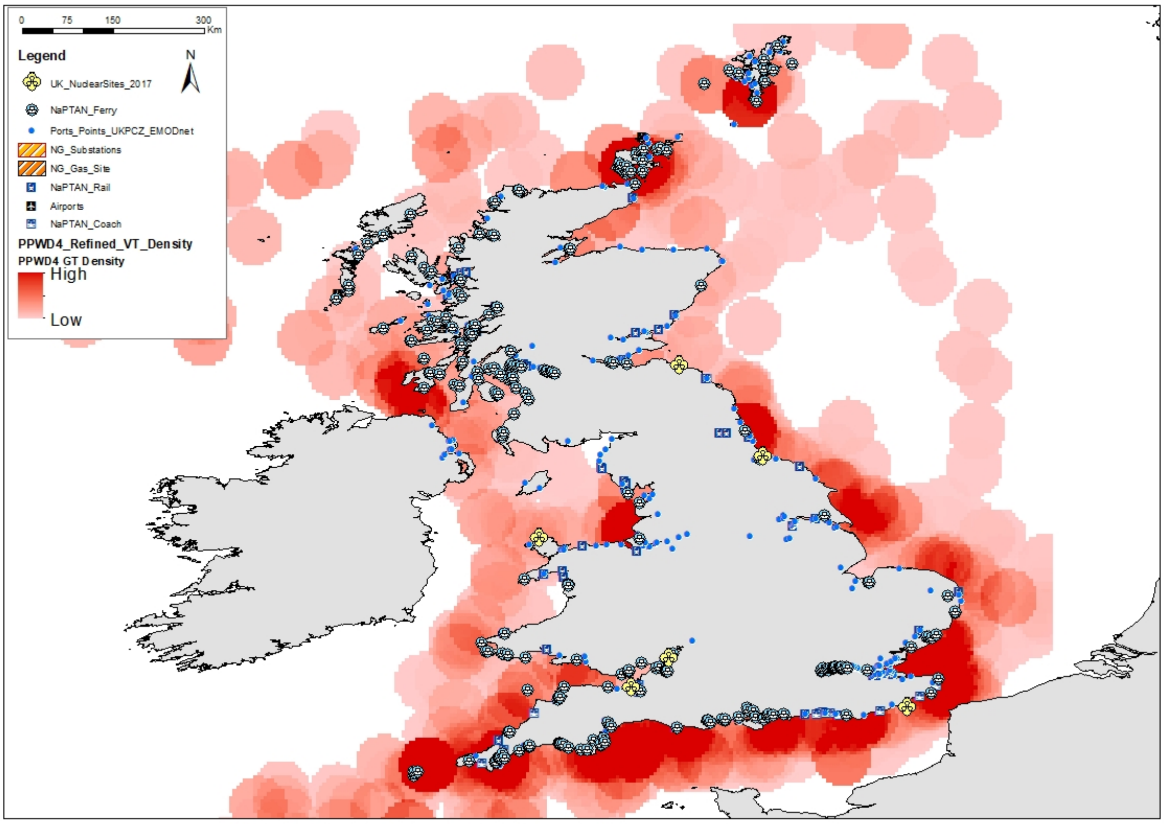

Figure 66 CNI and PPWD4 refined vessel density (author’s own image).

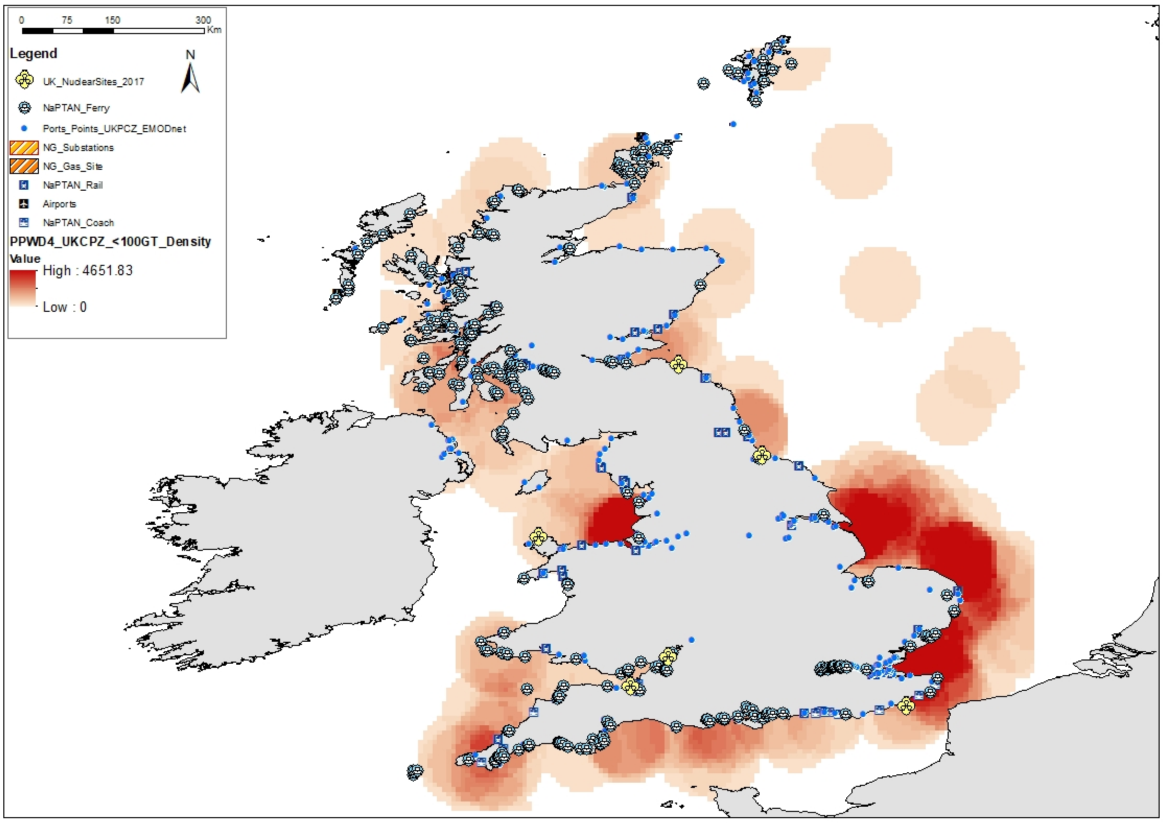

Figure 67 CNI and vessel density of <100GT. (author's own image).

5.3.6.3 Public Health

While there are clear public health concerns regarding oil and HNS pollution from wreck (Antizar-Ladislao, 2008; Aguilera *et al.*, 2010; Farrington, 2014; Laffon *et al.*, 2016), there is little data available that would allow for a spatial assessment of the level of damage to public health likely to be experienced due to oil or HNS pollution from wrecks in the database. The severity of impact would depend on the severity of pollution release, the trajectory of travel of the pollution, underlying medical conditions, and the density of population and beach use among other factors. Some data on these factors can be inferred from discussions in this chapter but a complete picture of the impacts is impossible to assess without trajectory modelling due to the relative mobility of oil and HNS pollutants once they have been released. It is possible that this could form an additional assessment using trajectory modelling results of the existing CEFAS risk assessment. The assessment would also need to take into account the removal of positive benefits of coastal living on public health, for which there is currently limited data (as discussed in sections 5.3.5 and 5.3.6).

However, an area of growing concern in relation to risks to public health, and one are for which there is some available data, is the presence of munitions and ERW related pollution in and around certain wrecks. As has been discussed previously at section 2.1.4, many of the wrecks in the database have an ERW risk associated with them, additionally there are a number of shipwrecks that were used in munitions dumping operations post-WWII. Figure 68 shows the location of wrecks within the database that are known to either be armed, to have been carrying munitions as cargo or which have been used in munitions dumping operations. The wrecks have been mapped against other munitions dumping locations to differentiate between wrecks used as specific dumping locations, and those that were not.

Those wrecks highlighted in Figure 69 in red show the vessels with an ERW risk that are within 30m of water depth and therefore most accessible by recreational divers. The risks from ERW to divers is incredibly high, even items with a small net explosive quantity (NEQ) are likely to be fatal if initiated while diving.

The majority of the wrecks that have an ERW risk are military vessels, or were hired by the MoD, with the exception of those used in dumping operations. However, at present the munitions are only considered to fall under the remit of the MoD SALMO group while they are enclosed within the wreck (A. Liddell 2019 pers. comm.). As these wrecks degrade munitions may be left on the seabed which do not fall within their responsibility. Two additional munitions wrecks are administered by the Receiver of Wreck for the DfT under Section 2 of the Protection of wrecks Act 1973. These are the SS *Richard Montgomery* (discussed at section 2.1.4) and the SS *Castilian* near Anglesey. It is clear that there needs to be further discussion about wrecks that contain munitions and the future of remediation of these wrecks. The public is increasingly aware of the risk that these wrecks may pose both in terms of public safety and environmentally.

Despite the perceived risk from ERW, encounters of munitions from wreck are difficult to quantify. Under the OSPAR convention records of encounters of munitions in the UK have been reported to the OSPAR commission since 1999. The location of these encounters between 1999 and 2017 is presented in Figure 68 , unfortunately the OSPAR data for 2001, 2008 and 2012 was missing from the OSPAR website so the data for those years is not included in this analysis. 35 of the munitions encountered were chemical, 1,215 were conventional and 130 were unknown. The south and east coast of England have the highest density of munitions finds, this correlates with both the high density of wrecks in these areas, but also with the density of sea mining, aerial bombing and naval activity in these areas during both World Wars.

Only two of the munitions encounters occurred within 200m of a shipwreck, however, recording of the locations of the munitions is problematic as often their location of destruction or landing ashore was recorded but not the location found at sea. While data on the type of encounter is missing for much of the data, Table 9 shows those where data was recorded. Of the recorded encounters the majority were found on shore, with entanglement in nets being the next most common. Only two encounters were resulted from diving. While this data is interesting, as the vast majority of finds have unrecorded information and location recording inaccuracies the data fails to help determine whether these munitions were encountered on or near shipwrecks. There are a number of munitions dumping sites in the UK that might also account for these munitions. This is particularly apparent for the finds of chemical munitions which appear to originate from the Beaufort's Dyke munitions dump, clustered as they are on Scotland's west coast.

Table 9 Munitions Encounters in UK waters 1999-2017

Type of Encounter	**No. of Munitions**
Diving	2
Dredging	4
Entanglement in nets	11
Found on shore	32
Mine hunting	1
Others	8
Unrecorded	1322

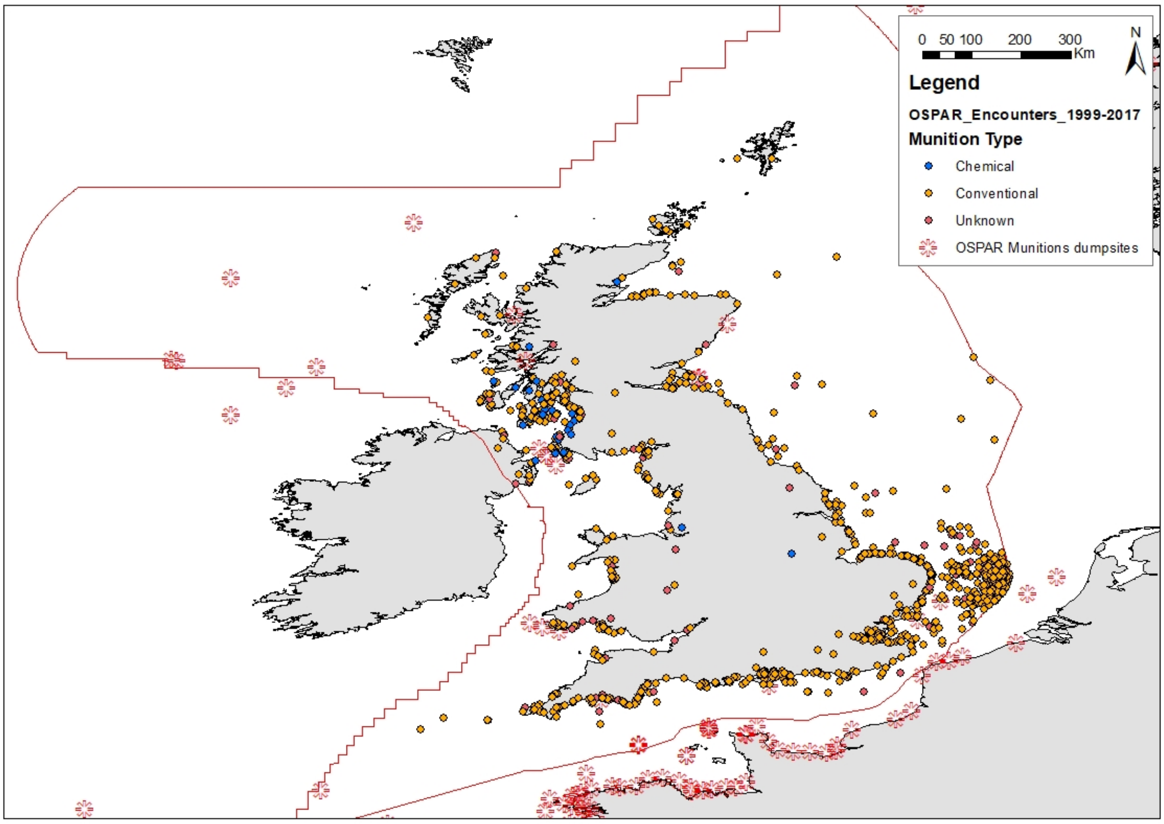

Figure 68 Munitions Dumping and Encounters in UK waters (author's own image).

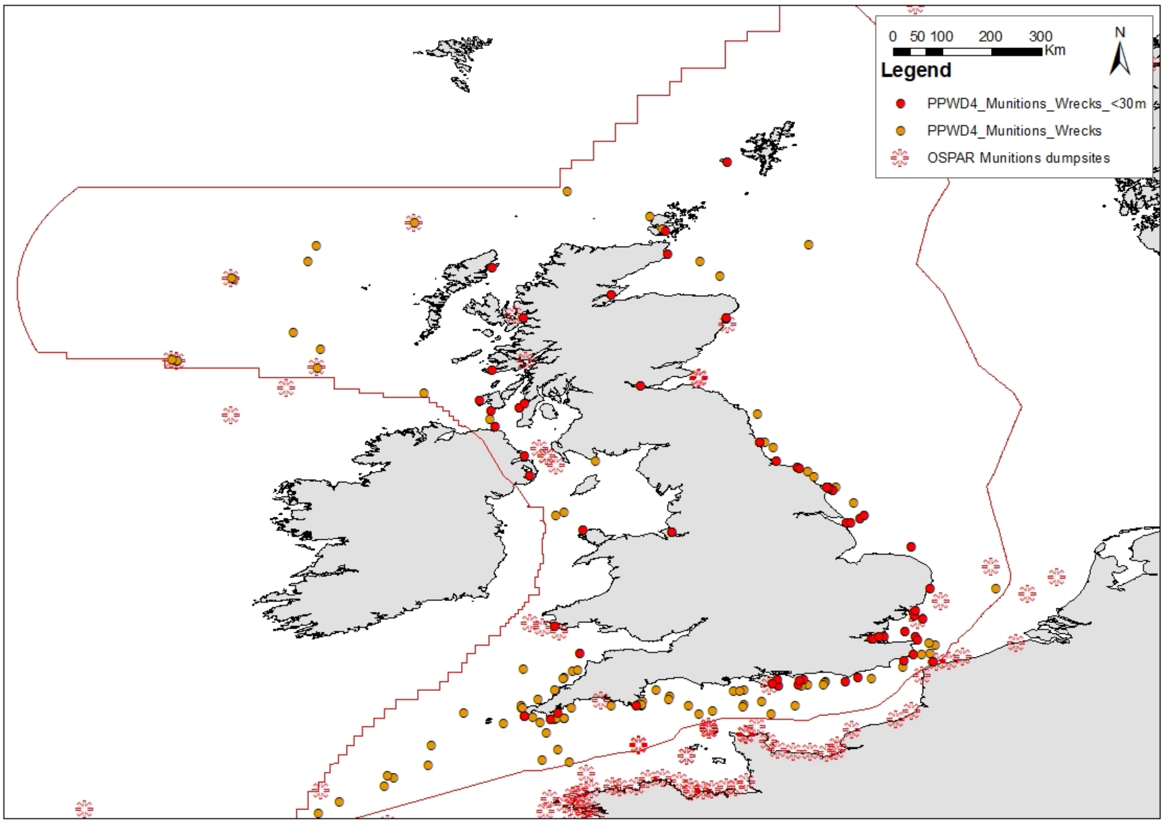

Figure 69 Location of armed or munitions related wrecks and their diver accessibility (author's own image).

5.4 Unquantifiable Aspects

In addition to the various stakeholders and datasets that have been spatially assessed in the preceding sections, there are several unquantifiable social and cultural factors that feed into management of shipwrecks, and which have in the past had a significant impact on how shipwrecks are managed. These elements cannot be assessed in a spatial manner and require alternative methods of assessment. It is beyond the scope of this thesis to fully explore these in depth or to conduct the surveys required to fully study these factors, however, an overarching discussion of heritage, commemoration, and wreck removal and salvage are presented in this section of the thesis with the aim of demonstrating their potential impact and influence on polluting wreck management.

5.4.1 Wreck Removal and Recovery of Wrecks

Owners of wreck can contract to undertake wreck removal and salvage of their property provided they are granted a marine licence for the work and that the wreck is not designated. The salvage convention also applies (under the Merchant Shipping Act 1995) to the recovery of shipwrecks that are not protected by heritage legislation in the UK. It is therefore legal to voluntarily salvage wrecks to return property to their owner, in return for a salvage award. Additionally, as previously discussed at section 3.3.2 under the Wreck Removal Convention various authorities have the power to remove wrecks that are deemed a hazard.

Spatial analysis of salvage activity in the UK is not possible as there are no accessible datasets for this activity. There is however, both commercial and non-commercial salvage activity occurring in the UK, whether this affects the potentially polluting wrecks is difficult to determine without spatial data. Given the lack of spatial data, we must instead look at the social and political aspects that might influence polluting wreck remediation.

Public attitudes towards wreck salvage or recovery vary significantly and are dependent on a number of complex factors. These varied perspectives on wreck removal and recovery are likely to have an impact on any management strategies that require partial or entire salvage of vessels. Commercial salvors are likely to be in favour of intrusive and wide ranging wreck remediation practices, as they will benefit from the work that this provides. They have experience in remediation of modern polluting wrecks and are therefore less likely to see problems with remediation practices. However, they may also view legacy wrecks as being higher risk than they are based on their experience with modern wrecks.

As previously identified the majority of wrecks in the UK that pose a polluting potential date to the World Wars. Following WWII many wrecks were removed, destroyed or dispersed (often using explosives) as they posed a navigational hazard (Booth, 2007). Other wrecks were sold on to salvage companies and salvaging of wrecks from the World Wars continued into the late 1970’s (Booth, 2007). More recently, alongside a growth in commemoration of War anniversaries, the idea that a wreck from the World Wars be salvaged has become anathema. With outcry at the salvage of vessels demonstrated in numerous news articles and professional papers (Browne, 2014, 2018; Holmes, Ulmanu and Roberts, 2017; Williams, 2017).

An example of how this has affected wreck management where wrecks were owned for salvage are SMS *Markgraf*, SMS *Konig*, SMS *Kronprinz Wilhelm*, and SMS *Karlsruhe.* The wrecks were originally brought in order to be salvaged and salvage of parts of the wrecks has been undertaken in the past. However, the wrecks were subsequently designated as Scheduled Ancient Monuments under the Ancient Monuments and Archaeological Areas Act 1979, thus effectively preventing any further salvage from taking place. Following their designation various ceremonies, memorials and other activities have been undertaken at Scapa Flow. The wrecks were put up for sale by the owner on eBay in 2019 with an asking price of £840,000 but sold for £85,000 (BBC News, 2019). Three went to a foreign owner, and the *Karlsruhe* to a buyer from the UK. The wrecks were sold on the basis of their heritage rather than their salvage value. The new owners may not have considered that they are now liable for any UXO pollution resulting from these wrecks as they breakdown. Owners who have a liability for pollution will wish to remediate their wrecks regardless of any heritage considerations.

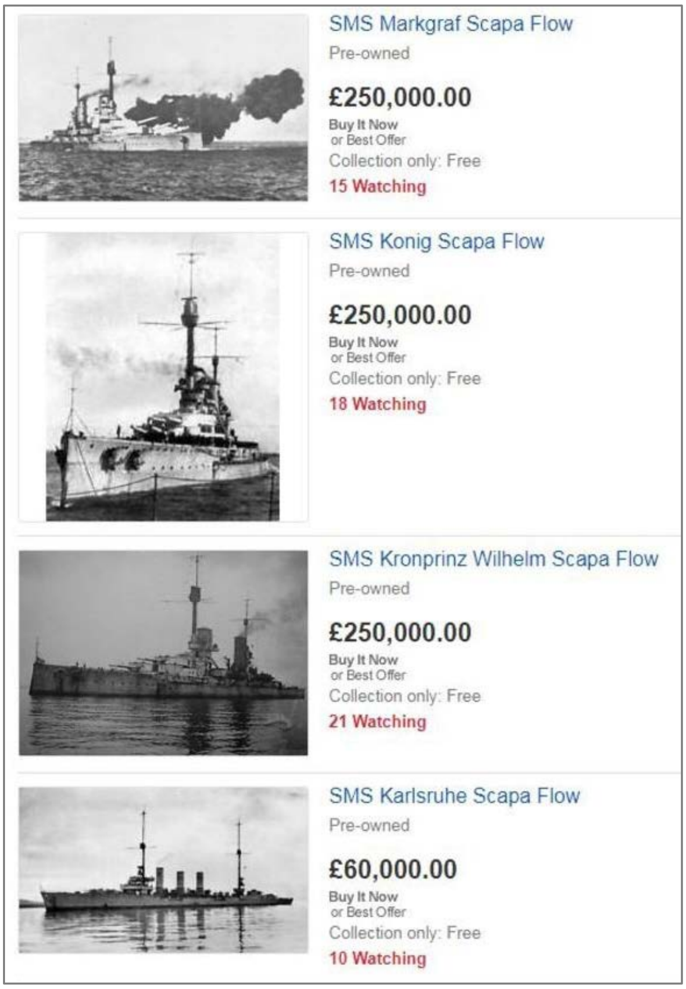

Figure 70 Screenshot taken from eBay of the Scapa Flow wreck listings.

While wholesale salvage of wrecks in the UK is rare, and the majority of salvage focuses on cargo or smaller items from wrecks, elsewhere in the world we do see WWI and WWII wrecks being salvaged in their entirety, often accompanied by pollutant release (Browne, 2018). Recent examples of this include the British wrecks of HMS *Repulse* and HMS *Prince of Wales* (Kubale, 2016) and wrecks from the Battle of Jutland (McCartney, 2017). The steel of these battleships is sought after as it is one of the few sources of low-background steel, which is steel that was produced prior to the background radiation increase that was caused by the use of the Atomic bomb (The Strait Times, 2018). Military wrecks are favoured in salvage efforts because they were constructed out of thick steel which is more likely to have survived over time in the marine environment than other wrecks with low-background steel. Low-background steel has a number of uses in space exploration equipment, medical equipment and scientific equipment (Holmes, Ulmanu and Roberts, 2017). While many are understandably horrified at the salvage of these wrecks, there are those that suggest that they are a resource like any other and provide benefit to mankind through their salvage and reuse. Comments on a Guardian article (Holmes, Ulmanu and Roberts, 2017) on this topic ranged from:

> "These salvagers have got living people problems to worry about. Why would they prioritise the long-dead victims of a long-ago war? The rational thing to do is recycle the metal. They can't hurt those soldiers." **rdoubled**

To:

> "In addition to being war graves for all the brave men who fought to give us the free world we live in today, they are also habitats for numerous aquatic life, it's down to the respective governments to ensure these sites are not desecrated." **CitizenWise**

Interestingly many comments also drew comparison with post-war clearances of battlefields and cities, and modern archaeological practices around the world, as well as the perceived classist and colonialist viewpoint that these wrecks should be protected while the British Museum was full of "looted" artefacts from other graves. Other comments suggested that if the British Government wished to preserve the sanctity of the wreck as graves then they should themselves have salvaged the wreck and repatriated the bodies. There is in itself a thesis that could be written on the ethical issues surrounding salvage of potentially polluting shipwrecks, and the public perception of military wrecks located in other States or international waters on which we claim Sovereign Immunity. However, this is out of scope of this thesis.

In the UK the MMO has a policy of not issuing salvage licences for wrecks of over 100 years old, which will include for salvage of potentially polluting wrecks from the First World War, and will soon include those from the Second World War. This policy has been implemented in accordance with the UK government's agreement to follow the rules of the UNESCO Convention on UCH. While this applies to generic salvage, it is not clear whether the same rules would apply in the event of a potentially polluting wreck. It is likely that this rule would be waived in order to prevent the ecological damage that might occur from a potentially polluting wreck, and which will most likely outweigh the potential heritage value of the wreck.

It is clear that there is a distinct conflict between how heritage bodies and those individuals or companies involved in wreck recovery and salvage view historic wrecks. There are numerous archaeologists and maritime lawyers who have written on this conflict (Varmer, 1998; McQuown, 2000; Forrest, 2003, 2009; Gregson, Crang and Watkins, 2011; Huang, 2013; McCartney, 2017; Browne, 2018; Hosty, Hunter and Adhityatama, 2018; Juvelier, 2018) and it is not within the scope of this thesis to revisit this topic in detail. This argument is likely to be polarised by issues of potential pollution with heritage bodies promoting protection of the wrecks to prevent interference and reduce the likelihood of pollutant release, and salvagers stating that the wrecks need to be removed.

In contrast to legacy wreck salvage, there are fewer disputes involved in salvaging modern wrecks that may present a pollution risk. The conflict between ownership and heritage is less problematic in these cases, although it may meet resistance if there have been fatalities during the sinking. This largely depends on whether the wreck is considered to be an underwater grave, and the level of commemoration that has already taken place around the wreck (see section 6.3).

What this means for remediation of potentially polluting wrecks is that any remediation that requires significant intrusive intervention and/or salvage is likely to have different acceptability levels with commercial salvors, recreational divers and heritage bodies and will depend on the age and history of the wreck. It is clear that attitudes towards salvage of legacy wrecks vary wildly and that the idea of salvage is tied in with people's concepts of heritage, commemoration, social standing and use or availability of resources. Risk tolerance in relation to managing their polluting potential is also likely to differ based on these factors. Early communication of the remediation strategies for potentially polluting wrecks is recommended so that stakeholders can have an input into the remediation and solutions can be designed to best fit with stakeholder expectations.

5.4.2 Commemoration

As has been discussed above many of the polluting vessels that require further attention are considered to be "war graves" even though this is not a legal term that applies to wrecks. In light of this many believe these wrecks need to be treated in a manner that warrants their preservation as graves and memorials to the dead. Survivors associations are likely to have strong feelings about disturbance of potentially polluting wrecks where there has been loss of life.

There are a few studies that examine the phenomenon of monumentalisation of wrecks and commemoration of loss of life at sea in relation to polluting wrecks. A key study is the work by undertaken by William Jeffery, (2004, 2007) in examining the post-colonial aspects of commemoration and conflicts between commemorative practices of the WWII shipwrecks in Chuuk Lagoon, where there is also a significant polluting threat from these vessels. His research identified that commemorative practices in the west were in direct conflict with those of the Japanese, who favour repatriation of their dead (Trefalt, 2017) over preservation of the vessels as grave sites, and that there needed to be a more inclusive discussion about the ongoing management and monumentalisation of the wrecks. Studies by McKinnon (2015) and Edney (2018) have identified ongoing changes in engagement and interaction with underwater cultural heritage memorial sites by divers at the Northern Mariana Islands and Chuuck Lagoon, including activities such as graffiti, artefact and bone piling, collection of souvenirs, and other actions that are discouraged by those managing the sites, but which link to the way in which individuals view and engage in commemoration and memorialisation practices.

In the geographical region of this thesis, Barbara Tomlinson (2015) has provided an in-depth study into the memorialisation of seafarers through terrestrial monuments, and while it does not comment on memorialisation practices at shipwreck sites, her work does provide insight into changes in memorialisation and commemoration more generally. Tomlinson states that WWI fundamentally changed memorialisation practices, for the first time memorials included all those lost, and were no longer limited to those willing to pay for a family memorial. WWI memorials were primarily seaside located and were local memorials, whereas those erected in WWII were centralised and formed a central part of the national identity, reinforcing concepts of national unity and crusade (p112). Her research identified that memorialisation and commemorative activity is increasing while the Navy is shrinking in size (p118), and she suggests that as surviving WWII veterans are dwindling in number the public search for national identity is contributing to this memorialisation movement. There are relatively few memorials to modern seaborne trade, and the few that exist are low profile. The vast majority of maritime commemoration is nostalgic and the loss of passengers and yacht sailors tends to attract greater attention than the loss of fishing or merchant crew members (p233). This once again highlights the complex ethical questions that exist around the discrepancies between how military vessels, passenger vessels and working vessels are treated both in terms of memorialisation but also protection and designation.

The example of HMS *Royal Oak* discussed previously at section 2.1.1 demonstrates the important influence that commemoration can have on managing potentially polluting wrecks. The vessel is entrenched in local and national memorial practices. When remediation was required at the wreck the social significance of the vessel had to be taken into account to ensure that the management strategy followed was socially acceptable, as well as effective to reduce the risk of oil pollution from the vessel. The USS *Arizona* discussed at section 2.1.1 also shows how memorialisation impacts on the management of pollution from the vessel. In this particular instance the vessel is actively polluting the surrounding environment, however, to remediate the vessel would potentially harm the vessel, which would result in significant social and political backlash.

Many of the most iconic wrecks that are considered to be war graves in UK waters have been designated under in order to protect them from salvage, diver interference and other threats. More widely the principle of preservation in situ has been promoted by many archaeologists dealing with underwater cultural heritage and shipwrecks, which in turn feeds into the commemoration and memorialisation narrative. However, this preservationist principle is only one of many options available for managing UCH, and there are many examples in archaeological practice to support alternative management strategies. Sites on land such as WWI battlefields and mass graves from the Spanish Civil War are being excavated and the remains identified where possible and, where applicable, repatriated (Cornish and Saunders, 2013).

Shipwreck sites that relate to earlier periods of history or civilian vessels lost during the wars do not usually suffer from the same "war grave" treatment as those from WWI and WWII. Wrecks such as the London and the Mary Rose have been excavated despite human remains being located within or on the wreck sites (MacLeod, 2008). Archaeologists tend to find it easier to justify excavating and removing human remains on land than we do underwater, although both are equally technologically possible.

Civilian vessels are usually not subject to the same scrutiny and therefore the ethical concerns associated with these are largely ignored. However, we must consider the ethical appropriateness of promoting one form of management strategy over another. We advocate for certain protection and memorialsiation practices of military wrecks, then the same protection and commemoration should be afforded to civilian and working vessels.

As has previously been discussed many military wrecks (which would be considered war graves today) were salvaged several years after they sank (in the 1960's and 1970's) but this is now unacceptable to many in the present. Practices of monumentalisation and commemoration are subject to significant change over time and are likely to continue to change in the future. It is therefore necessary to engage with these changing practices to ensure that management of wrecks is appropriate both now and in the future.

5.4.3 Heritage

As has been demonstrated above the heritage value of wrecks is a key socio-economic factor that must be taken into account when risk-assessing potentially polluting wrecks. Shipwrecks are considered to be highly valuable culturally as underwater cultural heritage (UCH) because they capture a snapshot of life at the time of their sinking and act as a 'time capsule'(McKee, 1982). Wrecks can provide an insight into society at the time of sinking as they contain goods and materials from widespread backgrounds and links to different areas and communities. The cultural value of shipwrecks has therefore been widely studied by archaeologists and heritage professionals. However, as EMU Ltd, The Marine Biological Association and Plymouth Marine Laboratory (2012) identified in their review of socio-economic data for the marine environment, the value of the maritime historic environment (shipwrecks) is largely unknown both in terms of economic value and social value (EMU Ltd, The Marine Biological Association and Plymouth Marine Laboratory, 2012, p. 29). Ethical concerns have been raised around assessing cultural artefacts in economic terms, however, with the increasing trend to use ecosystem services for marine spatial planning and other decision and policy making processes, there is growing evidence that suggests that without valuing heritage in this manner we risk it being omitted entirely from these assessments. We must therefore demonstrate the value of UCH in order to enable protection and suitable management of the resource in the future (Firth, 2015). The same point stands for potentially polluting wrecks, if we do not know the value of the wreck and the socio-economic benefits it affords, how can we then determine the best management strategy for any prospective pollution arising from it? Suggested tools for valuing maritime cultural heritage have been proposed by Claesson (2011) however, little has been done to progress this and there are few studies that examine the economic value of underwater cultural heritage.

One study that aimed understand the value of the designated wreck Coronation to the local Plymouth economy estimated that the total annual spend by divers was between £20,328 and £77,000, with a total income benefit to the local economy of between £53,900 and £19,823 (Beattie-Edwards, 2013). These are relatively large sums of money for the wreck given that only those licenced to dive on the wreck can visit it, and as they state in the study many of the divers live locally so their expenditure is less than they might be elsewhere. As this focuses on a specific wreck it is not known if this value is comparable across other wreck or protected wreck sites, however, it does provide some indication of the prospective value of a shipwreck and wreck diving.

The number of people that can visit shipwreck sites is limited both by the requirement to be able to dive and through legislative restrictions. Information on diver visits and diver spend is not currently gathered from dive operators who run wreck diving trips, beyond the example presented above for the Coronation there has been no further work done to capture this data.

While the economic value of wrecks to some extent remains a mystery, there have been attempts to understand the social value of wrecks. In his 2015 thesis, Christopher Underwood surveyed professional and non-professional groups with interests in UCH. His research identified a number of concerns regarding management of wrecks and lack of public awareness of the cultural heritage value of wrecks. The social valuation of wrecks was shown to differ between views of professionals and those of recreational divers. Where in-situ protection and management of wrecks was not possible, recreational divers preferring wreck to fall under salvage legislation with material being sold on and having an economic value, while professionals disagreed wholeheartedly with this as a management option, preferring for material to be held in museums for the wider public and not fall to individual's collections (Underwood, 2015, p. 284). Underwood also examined public perception of wrecks through a review of television shows, and BBC articles relating to wrecks. Public interest was mainly focused on key well known, and designated sites (Underwood, 2015, p. 287).

Historic England have commissioned 9 virtual dive trails of protected wreck sites accessible from the Historic England website (James, 2018). A review of the usage statistics of the sites was undertaken in 2018, for the seven sites that were active at that time. 15,025 virtual dives took place between August 2016 and February 2018, with the U8 submarine proving to be the most popular with over 7,000 visits during that time (James, 2018, para. 5.3). The popularity of the U8 dive trail is likely due to the fact that it was promoted by the main historic England twitter and Facebook accounts, and the contractor for the site paid for Facebook advertising outside the scope of the project (James, 2018, para. 5.4). People from at least 88 countries visited the sites through the virtual dive trail, with the majority being from the UK (9,090) and the USA (1,079)(James, 2018, para. 5.6). While these numbers demonstrate clear advantages for engaging remote audiences with shipwrecks, the numbers are still relatively low in terms of gauging interest in wreck beyond the narrow field of maritime archaeology. There are issues associated with accessibility of the online resource as it requires access to the internet, a good level of digital competence and the ability to visually navigate the website (James, 2018), thus the numbers may not accurately reflect the number of people who would wish to engage with or have an interest in shipwrecks. The success of Facebook and twitter advertising for the dive trails, and of news articles in the Google Trends data for the Black Sea project (see section 5.4.4) suggest that the general public do not necessarily have an inherent interest in wreck, and do not actively seek these stories out, however, once their attention has been drawn to shipwrecks it is a subject with which they are happy to engage further. Interest in wreck is therefore likely to be fleeting for the general public, but something that can be raised when needed by groups that do have an inherent interest in wreck to promote specific ideas about wreck when desired.

Another source of quantification of a heritage interest in wreck is the free Shipwrecks and Submerged Worlds massive open online course (MOOC) run by the University of Southampton through the FutureLearn platform. It attracted 20, 852 participants between June 2014 and February 2016 (Sturt, Dix and Grant, 2017) and over 27,398 participants to date. While participants hail from across the globe, the number of participants is relatively low in comparison to other archaeological and non-archaeological MOOCs, for example an archaeology MOOC by Brown University reached 30,000 people in its first two years (Alcock, Dufton and Durusu-Tanrıöver, 2016), and the FutureLearn course on the Archaeology of Portus also run by the University of Southampton had approximately 30,000 registered participants since its start in

2014 (E. Gandolfi, thesis in preparation). It is difficult to say whether this indicates a relative lack of interest in maritime archaeology and shipwrecks, or whether it is due to differences in promotion of the courses and running dates. Gandolfi's research indicates that in the Portus MOOC the majority of participants are over 65 with a higher education qualification, this suggests that the majority of participants have a high level of education and significant leisure time, they are actively searching for further education courses (and the majority come from teaching and education backgrounds) rather than being people who stumble across them due to their interest in particular areas of archaeology, the statistics are likely to be similar for the maritime archaeology MOOC.

Although the lack of socio-economic data for underwater cultural heritage has been raised as an issue several times since 2011 (Claesson, 2011; Firth, 2015), there has been limited action to try to gather further socio-economic data. As a result we cannot say for sure what value wrecks have to the wider economy. However, shipwrecks clearly have a cultural importance which is also tied into aspects of identity and commemoration. These factors are important to take into consideration when determining appropriate management strategies for potentially polluting wrecks.

5.4.4 Wider Public

It is difficult to understand how wider society values wrecks as there is very little information regarding the interest in wreck and value of wreck to wider stakeholders beyond the immediate owners, in salvage or as cultural heritage. Underwood's (2015) research discussed previously at section 6.2, did identify that the British public were interested in high profile wrecks, however, they appeared to have little interest in shipwrecks as a wider resource. His research is the most recent and comprehensive study of public (and heritage professional's) attitudes towards shipwrecks as part of underwater cultural heritage.

One area which has tangentially examined public attitudes to shipwrecks is the field of marine social science, although studies are limited as this as marine social science is to some extent still an emerging field. Fletcher *et al.* (2009) conducted a study at the National Maritime Museum which surveyed 138 respondents to determine their priorities in relation to, and awareness of, marine environmental issues in the UK. They identified that the UK public perceived marine pollution as being the greatest threat to the marine environment (40.8% of respondents) and that it was of most interest to them (16.1% of respondents). Meanwhile both shipwrecks and naval history were only of interest to 1.1% of the respondents. Essentially, while the UK public had a genuine interest in the marine environment, their interest in wrecks and maritime heritage was minimal. There is likely to be some bias in that the survey was clearly designed to look at environmental issues so respondents were geared already towards pollution as an issue, however, the numbers are still somewhat depressing statistics for maritime heritage professionals and archaeologists. Particularly as these interviews took place at the National Maritime Museum which attracts a proportion of the population that is most likely to have an active interest in naval history and shipwrecks.

A more recent study carried out by Carpenter *et al.* (2018) examined public perceptions of management priorities for the English Channel and consisted of an online survey to gather responses from 1000 respondents each from the south coast of the UK and the North coast of France. The data showed that the public primarily visited the coast for recreation purposes (80% of respondents). When questioned on 17 priorities for improving the English Channel environment both the English and French public gave high priority to ensuring clean water and beaches (priority 1), protecting plants and animals (priority 2 and 4) and marine pollution prevention (priority 5), but low priority to promoting cultural heritage within the English Channel region (priority 15). While shipwrecks are featured under the broader term of heritage in this instance we can see that protection of the marine environment and pollution prevention are considered to be higher priorities than cultural heritage. This is an important distinction when dealing with polluting wrecks, as it demonstrates that while there may be some resistance to intrusive remediation by interested heritage parties, the wider public is most likely to place a higher priority and importance on remediation of prospective pollution from wrecks than on their cultural value.

Another potential source of information for public interest in shipwrecks is data taken from Google Trends, the data discussed here was captured on the 9th August 2019. The Google value represents search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. A score of 0 means that there was not enough data for this term.

The general web search (Figure 71) includes data dating back to 2004, however, the search in science only (Figure 72) dates to 2014 in the Google data. The data in Figure 71 seems to start at a high value in 2004, this is possibly because Google's data collection was different in the early years. However, two distinct peaks can be seen both in Global searches and UK searches in the data. The first in 2012 likely relates to the centenary of the sinking of the Titanic, and the re-release of the film. The peak in 2019 in the UK is somewhat less explainable, it could relate to news articles around the Black Sea Maritime Archaeology Project being released (BBC News,

2018) or to a surge in searches for shipwreck relating to the video game Assassin's Creed Odyssey which was released in October 2018.

To remove some of the uncertainty regarding the data, and to remove reference to video games, the data was restricted to the term shipwreck under the category of science from the past 5 years. The results in Figure 72 show that there is a continued global interest in wreck over this period and that a key peak occurs in both the UK and global dataset between the 21st and 27th October, 2018. This at the same time as the release of the news articles relating to the Black Sea Map project finding the 'world's oldest intact' shipwreck (BBC News, 2018), the presence of the peak in both data seems to suggest that it was in fact the Black Sea project rather than the release of Assassin's Creed Odyssey that we are seeing in Figure 71. The peak in November 2015 may relate to the find of gold in the *Capitani*a wreck (Lee, 2015) , followed by the battle for the gold in the *San Jose* shipwreck (Drye, 2015). The UK peak in April 2015 is likely to relate to the sinking of a migrant ship in the Mediterranean with the loss of over 700 lives (Kingsley and Kirchgaessner, 2015). This would seem to indicate that with the exception of the April 2015 peak, that there is in fact a healthy public interest in shipwrecks not only in the UK but across the globe, even if the interest is tied into media events such as the re-release of Titanic or high profile news stories (i.e. the Black Sea MAP), which confirms Underwood's 2015 findings.

The Google Trends data is relatively useful in understanding that there is some interest in wreck by the wider public in the UK however, as it does not give absolute values it can only give an indication rather than any concrete evidence of interest, as there is no way to accurately correlate the data with activities relating to historic rather than current wrecking events. A much more detailed analysis of public interest in wreck could be carried out in the future using technology to scrape news and web articles, any comments, and the number of times they are shared or liked on social media. This data could then be statistically analysed to gain an in-depth understanding of public perception of wreck and their sentiments in relation to topics like salvage, however, this would form an entire thesis in itself and is therefore beyond the scope of this thesis.

The fact that the "related queries" section in Google Trends from the initial data in Figure 71 contained relatively few searches for real-world shipwrecks (at the time of writing: 6 of 25 in 'Top', and 5 out of 25 queries in 'Rising'), but many searches for shipwrecks in Assassin's Creed and other video games is also perhaps telling (8 of 25 in 'Top' and 18 of 25 in 'Rising'). As shipwrecks are inaccessible to the majority of the population, 3D digital recording of and engagement with wrecks in a digital manner through video games, virtual dive trails and virtual reality is becoming increasingly popular (James, 2018; McCarthy *et al.*, 2019). Harnessing this technology and interest may be beneficial in terms of managing memorialisation and enabling archaeological recording, investigation & dissemination where certain potentially polluting wrecks may require intrusive remediation or salvage.

As has been demonstrated above attempting to determine public interest in wreck outside of heritage based studies is complicated. Social science studies seem to suggest that the wider public places greater value on other aspects of the marine environment such as pollution prevention than on shipwrecks. This is particularly interesting in the case of potentially polluting wrecks where they both pose a pollution threat and have an intrinsic heritage value. Data from Google Trends shows that there is interest both globally and in the UK in shipwreck, but that these tend to be related to high profile shipwreck projects with a strong media presence. Additionally, Google Trends shows that the vast majority of shipwreck related searches are being undertaken for virtual wrecks, which while not particularly helpful for this analysis, does pose interesting questions in relation to the future of archaeological dissemination and engagement, as well as alternatives for presenting and digital “preservation” of polluting wrecks that might need to be removed or mitigated in ways that would be destructive. It remains difficult from the current research to determine what public risk tolerances might be in relation to potentially polluting wrecks, and this is an area that would benefit from further examination.

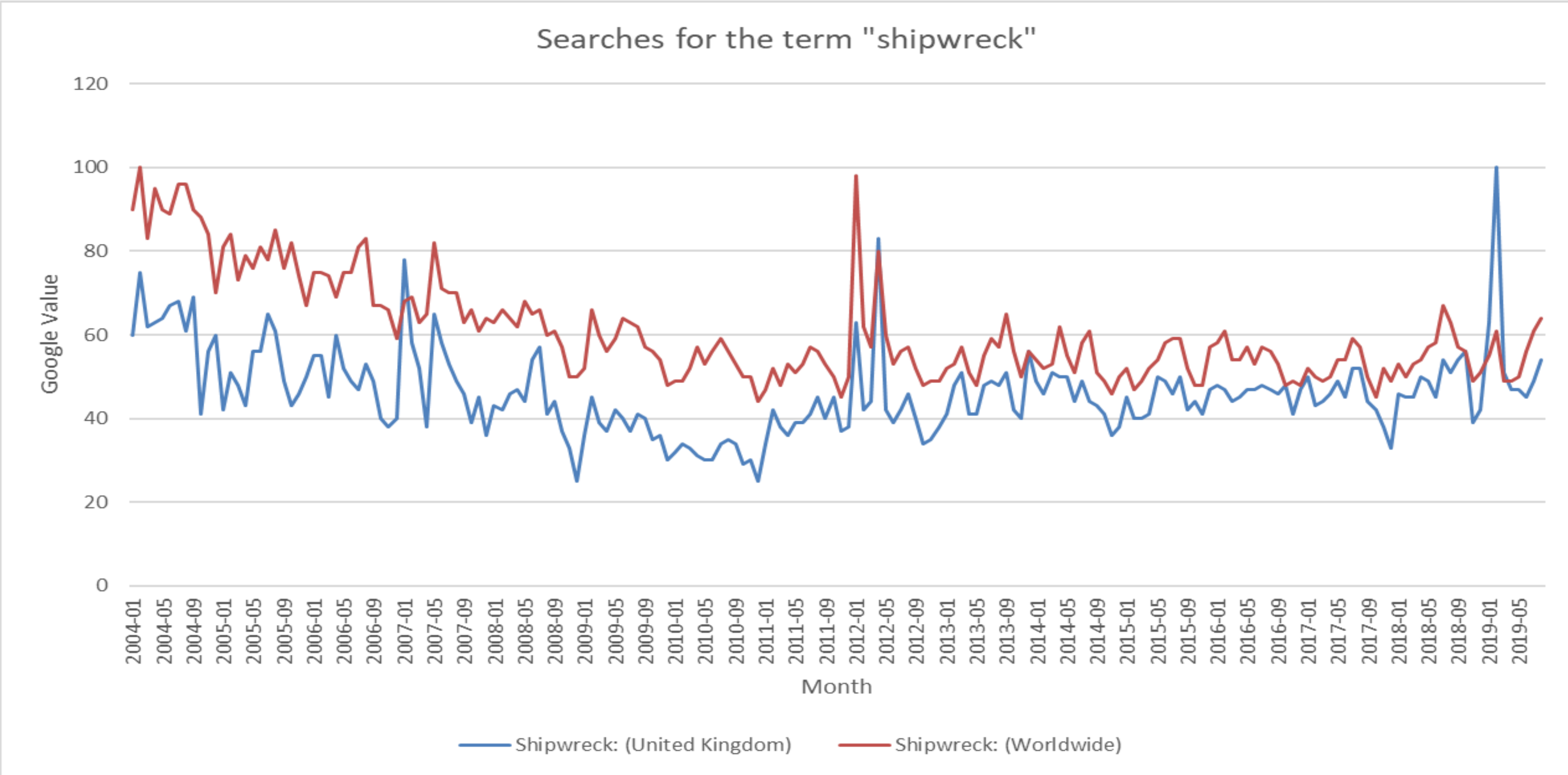

Figure 71 Trends in general web searches for the term "shipwreck" (author's own image).

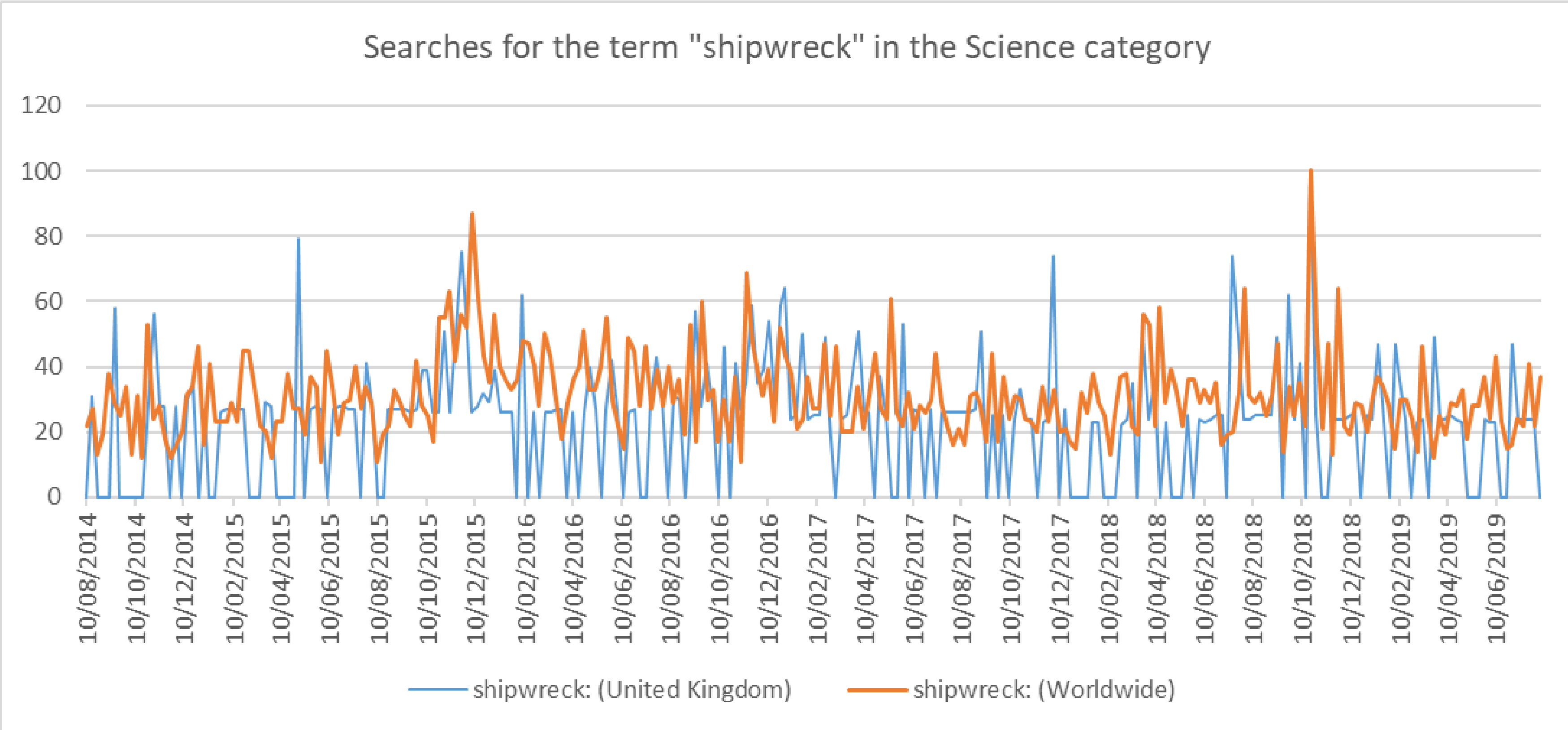

Figure 72 Trends in searches for the term "shipwreck" in the Science category (author’s own image).

5.5 Summary

Managing the risk from potentially polluting shipwrecks requires an in depth understanding of the various stakeholders that have both an interest in wreck, and who might be affected in the event of a pollution event from wreck. Often only those stakeholders with a management responsibility are involved in risk management decision making, however, this can result in risk management strategies that are not palatable to the wider stakeholder community, or at worst actively damaging to their interests. Evidence from coastal management and marine spatial planning examples demonstrates that engaging with wider stakeholders beyond those with a management interest actively supports better management of the environmental, socio-economic and political risks involved in managing marine assets, which includes potentially polluting wrecks.

At present the inclusion of stakeholder analysis and socio-economic data in existing risk assessments for potentially polluting wrecks is severely limited. Only the recent paper produced by CEFAS (Goodsir *et al.*, 2019) uses this data, and their research is only focused on one wreck. Other studies have examined whether or not wrecks are located in within areas of conservation, or in proximity to ports (Masetti, Calder and Alexander, 2012) but not looked at the range of other socio-economic data available. As has been demonstrated in this chapter there is a range of publicly available data that can be used to improve our understanding of the potential impact of a polluting event from shipwrecks, and to understand which stakeholders are most likely to be affected.

The assessment presented in this chapter allows us to identify areas where there are high concentrations of potentially polluting wrecks, and where these coincide with areas that will experience high economic or social losses in the event of a pollutant release from wreck. This provides better data on the potential consequences of a pollutant release, and to reduce the uncertainties that are present in the existing risk assessments around potential impacts of pollution release.

The amalgamated results of the assessments presented in this chapter are contained in the attribute table for the PPWD4 refined shipwrecks shapefile. The data can be used to form better judgements about the potential socio-economic impacts of both the individual wrecks and the database as a whole. Various social and economic benefits are derived from coastal and marine resources and industries, these include better health prospects, employment opportunities, regeneration, and leisure and relaxation among many others. Pollution from wreck may inhibit or remove these benefits resulting in reduction of socio-economic amenities both at sea and on the coast.

In terms of environmental impact, a basic assessment shows that 387 of the 953 wrecks are located within marine conservation or protected habitat areas. These wrecks are of priority importance in terms of investigation and remediation as there is a legal requirement to protect habitats and seabirds in these areas.

Navigation routes through the English Channel, and the straights of Dover in particular are in an area of high density of potentially polluting wrecks. Specific wrecks within areas of high vessel transit density have been identified in the amalgamated results. Pollution from wreck in this region could have a severe economic impact given the high intensity of shipping in the area and the consequences could be felt internationally. The density of fishing is also high in the English Channel with a high level in and around Cornwall and Dorset, and very high level in and around the Dover straits. Fishing is likely to be severely affected by pollution but also has the potential to damage wrecks and release pollution from potentially polluting wrecks.

While both offshore development sites and dredging sites contain potentially polluting wrecks these both require licences so are less likely to impact on wreck. Data from both industries could be used to help identify additional potentially polluting wrecks and monitor existing sites. Increasing development and use of the seabed makes discoveries of new potentially polluting wrecks more likely. Pollution from wrecks that have released their pollutants into the seabed are of particular concern for dredging and aggregates industries, and further work may be required to determine how much pollution is likely to still be found in sediments around shipwrecks that have already succumbed to corrosion.

Aquaculture sites on the west coast of Scotland are particularly vulnerable to wreck related pollution, and the aggregated risk from multiple vessels of less than 100GT is of primary concern in this region. Shellfish production sites in the south of England are also at risk from potentially polluting wreck related pollution from vessels of over 100 GT, however, they are fewer and contribute significantly less to the regional economy than Scottish sites.

With the exception of port facilities there is likely to be limited impact on CNI facilities in the UK from potentially polluting wreck pollution. The distances of the PPWD4 refined wrecks to sites of CNI has been included in the attribute table of the PPWD4 refined shapefile for further analysis if required, and may benefit from further analysis once pollutant spill and trajectory modelling has been undertaken for certain wrecks. The impact on ports could be severe particularly for those ports that are reliant on fishing industries and the marine leisure industry, which are both likely to be highly affected by pollution events.

The coastal community data shows that the coastlines of Cornwall, East Anglia, Lincolnshire and certain port cities are likely to be both socially and economically vulnerable to pollution from wrecks, these areas also have a high density of potentially polluting wrecks making pollution encounter in these areas more likely. East Anglia and the south coast of England are most likely to experience significant impact on their tourism due to the high visitor numbers to these regions and the high density of potentially polluting wrecks along the south coast, which in turn is likely to impact more widely on the UK's tourism economy. As we know from previous polluting incidents elsewhere, there is significant social, economic and political fallout from pollution events that impact on tourism. The loss of revenue, jobs, and the subsequent reputational damage lasts far longer than the pollution clean-up. Coastal areas are already relatively deprived in comparison to other areas of the UK and recover far more slowly from economic and social setbacks.

The datasets relating to tourism, coastal communities and beach activities require the prior use of pollution spill modelling in order to make best use of the data. While a broad assessment has been made in this chapter for these datasets using the density of potentially polluting wrecks from the database, this is relatively coarse and does not indicate the impact individual wrecks might have. The datasets have a level of resolution that could provide quite accurate estimates of the level of socio-economic impact at individual wreck level once pollution spill modelling has been undertaken. This will therefore be most useful as a secondary or tertiary assessment rather than forming part of the initial risk assessment process. There are also limitations to the data, with datasets such as the MMO's marine activity models, and the coastal community data being currently limited to England only. However, these datasets could be extended to the rest of Britain to provide further insight into the potential socio-economic impacts of potentially polluting wrecks.

Recreational diving has the potential to cause pollution release from wrecks, but is also likely to be highly affected in the event of a pollutant release. Additionally, the potential danger from potentially polluting wrecks which carry ERW has been discussed. Wrecks located within normal diving water depths have been identified, and these wrecks may pose significant risk to divers. Engaging with divers as stakeholders is recommended as those that wreck dive will be able to provide ad hoc monitoring on the condition of wrecks, as well as any pollution they may contain. Additionally, divers are more likely to have specific understanding of the environment and access to some of these wrecks, which in turn can be fed into the decision and risk assessment process. Divers are also likely to be vocal about any management strategies that negatively impact on their enjoyment of wreck so engaging with them as stakeholders early will ensure that any management decisions take into account their views and prevent unwanted fallout at a later date.

A key finding from this research is that clustered concentrations of vessels that are less than 100GT can have a significant impact on local economies and society, particularly in areas with high levels of tourism expenditure and visitor numbers, and where aquaculture is the primary maritime activity. To date all of the risk assessments for polluting wrecks have failed to consider the aggregated impact of smaller vessels and this is the first study to examine the potential consequences from pollution resulting from these vessels. It is clear that this is an area that warrants further investigation.

Examining all of the datasets together provides a stark picture of the threat from potentially polluting wrecks in UK waters. Those areas of the UK that are least resistant economically to marine pollution are the most likely areas to experience pollution from wreck based on the concentration mapping data. Areas such as Cornwall, and the East Coast of England stand to be severely economically and socially impacted from polluting events in those regions. Wider social upheaval is likely in all other coastal areas which are reliant on tourism, marine trade and fisheries. This research does however, allow us to target future research into polluting wrecks in those areas that are likely to be most affected, or where there are the highest concentrations of potentially polluting wrecks.

The economic impact of a pollutant release from a wreck or the slow release of pollution from multiple wrecks over time will result in the potential loss of billions to the UK economy, particularly if the pollution event takes place in the south or south west of England or in the Dover Straights.

Socially, there is an increasing awareness of marine pollution by the wider public, and the acceptability of not remediating wrecks is likely to be lessening. Particularly as increasing technological advances both open up the marine space to the public to experience in new ways, but also result in new methods, equipment and capability for remediation of wrecks. As demonstrated by Fletcher *et al* (2009) the public are acutely aware of and concerned about pollution, and less concerned about the shipwrecks that are the source of the pollution. However, there are stakeholders that will be reticent about wholesale wreck removal as a solution to pollution due to the commemorative, and heritage aspects of shipwrecks. Any risk management strategy for polluting wrecks will require input from wider stakeholders to ensure that the resulting mitigation and management measures are socially and politically acceptable, and to ensure that they are appropriate for managing the risks without negatively impacting stakeholders.

This assessment represents the first study to comprehensively examine these socio-economic datasets in relation to the whole database of potentially polluting wrecks in the UK. It provides a clearer understanding of the prospective socio-economic impacts of pollutant release from wreck in the UK, as well as an understanding of the relevant stakeholders with a prospective interest in the management of potentially polluting wreck or who might be affected by management decisions.

This assessment relies on the accuracy and availability of various third party spatial datasets and there are some areas that do not currently have available data. Much of this assessment has been limited to England as the datasets for Scotland, Wales and Northern Ireland were either not available, or were only accessible through online platforms and not in a format suitable for assessment. Data sharing across the UK governments for marine planning and assessment purposes must be encouraged to allow for comprehensive research to take place. The collection and production of open source marine datasets is increasing, therefore it is likely that in the future a further, more nuanced, assessment will be possible. While spatial data analysis can help with the desk based risk assessment process, and indeed the results in this chapter show the utility of various publicly available datasets, these also need to be considered against stakeholder values and beliefs, in order to accurately inform risk management decision making and risk communication.

Further research into stakeholder views and risk tolerance is recommended, while certain view points and considerations are presented here it was beyond the scope of this research to conduct in-depth stakeholder surveys, therefore the analysis is unlikely to encompass the full spectrum of stakeholder opinion and fears regarding potentially polluting shipwrecks and their management. This research does identify the gaps in the current available data and demonstrates the need to conduct further surveys to understand stakeholder perceptions, resilience to pollution and cultural associations with wreck to provide additional insights to those discussed here. One aspect that is not possible to draw out in the current assessment is the different values and social weight given to competing stakeholder interests which is critical for making risk management decisions and this is one of the many areas that requires further examination.

Chapter 6 Discussion

The issue of potentially polluting shipwrecks is a global one. All seas are connected and the pollution from wrecks has the potential to impact the environment, public health and economies around the world. Indeed as discussed in Chapter 2 shipwreck pollution events such as the *Torrey Canyon* (Jacobsson, 2017; Wells, 2017) and the *Amoco Cadiz* (O'Sullivan, 1978; Grigalunas *et al.*, 1986) have already occurred, resulting in significant environmental, social and economic damage. Consequently, there has been a growing awareness of the risk from legacy shipwrecks that contain polluting materials, and there have been a number of examples of polluting legacy wrecks such as USS *Mississinewa* (Gilbert and Nawadra, 2003), USS *Arizona* (Russell and Murphy, 2010; Rissel, 2012), HMS *Royal Oak* (Gerdes, Martin and Sell, no date) and SS *Jacob Luckenbach* (Hampton *et al.*, 2003).

Pollution release from such wrecks is increasingly likely over time caused by the ongoing corrosion of wrecks in seawater. In addition, the increasing industrial development and use of marine space and resources will mean that any polluting event in the future will likely have a greater social and economic impact than that which has been suggested in this study. Therefore the longer we wait to remediate these wrecks, the more likely we are to experience a pollution event from wreck, and the more serious the consequences are likely to be.

In the vast majority of the literature the global number of potentially polluting wrecks is stated as being 8,569. This has been taken from research conducted by Monfils et al (2005). There has been no attempt since then to reassess this number despite additional wreck databases being made available. This study collated and analysed potentially polluting wreck numbers from regional and global attempts to quantify wrecks, and demonstrated that the number of potentially polluting wrecks is likely to be significantly higher than the 8,569 proposed by Monfils et al (section 2.3). However, the true global number of potentially polluting wrecks remains elusive due to the lack of availability and transparency of global wreck datasets.

Despite the global threat from potentially polluting wrecks, it is currently only possible to examine potentially polluting wrecks at a national or regional scale due in part to the lack of availability of data at a global level. Once a clearer understanding of the regional threats from potentially polluting wrecks is known, this will then feed into wider global assessments. Consequently the research presented in this thesis has aimed to address the following UK focused research question:

> What is the existing management and assessment process for potentially polluting wrecks in the UK, how can this be improved upon, taking into account practical, social, legal and ethical considerations?

Within this overarching research question were a number of sub-questions that needed to be resolved in order to contribute to our understanding of the wider question, namely:

- Is there a requirement to remediate potentially polluting wrecks in the UK?
- How many potentially polluting wrecks are there in the UK?
- What is the risk from potentially polluting wrecks in the UK?
- What are the consequences of potentially polluting wrecks in the UK?
- Is the current management strategy for potentially polluting wrecks suitable?
- What could be done moving forward?

This chapter discusses these questions in relation to the results from the preceding chapters in order to demonstrate that this research successfully addresses the overarching research question.

To some extent the research work undertaken in this thesis represents a fact finding mission to determine a baseline understanding of the legal requirements surrounding polluting wrecks, the availability and quality of data relating to wrecks, and to critically analyse the wreck research that has taken place in the UK. This may seem a relatively simple task, however, as has been proven during this research little is known conclusively about the potentially polluting wreck portfolio in the UK. The few assessments that have been undertaken into the subject consist of unpublished government commissioned risk assessment reports (ABPmer, 2010; Maritime Archaeology Ltd and SeaZone Ltd, 2011) or are focused on specific (known to be polluting) wrecks (Gerdes, Martin and Sell, no date; Wyse and Leary, 2016; Alexander, 2019; Goodsir *et al.*, 2019). This fact-finding is therefore entirely new research and is critical as a first stage towards ensuring suitable management of these wrecks. It necessitated an interdisciplinary approach to understand the full scope of the problem, and this research is the first comprehensive review and assessment of the issue of the management of potentially polluting wrecks in the UK.

6.1 Is there a requirement to remediate potentially polluting wrecks?

Determining the requirement to remediate wreck depends on a number of factors, including whether there is a legal obligation to undertake the remediation. Without a legal obligation to remediate wrecks, it is unlikely that those responsible for managing wrecks will be willing to undertake that remediation unless other societal pressures force them to do so.

An analysis of the legislation was undertaken in Chapter 3 which identified that while there is no legislation that directly concerns pollution from legacy wreck, the UK does have a legal requirement to achieve good environmental status within their waters under the EU Water Framework Directive. Pollution from wreck will likely impact the UK's ability to achieve a good environmental status, although the definition for how to measure good environmental status has yet to be properly defined (Lyons *et al.*, 2017; Vethaak *et al.*, 2017; Elliott *et al.*, 2018). The UK also has a requirement to protect certain birds and habitats from pollution, and we know from the GIS analysis presented in Chapter 5 that there are 387 wrecks located within marine protected and conservation zones. While none of this legislation is binding with regards to a requirement for remediation it does suggest that there is a moral requirement at least to remediate polluting wrecks.

There is, however, an obligation to recover waste under the Waste Framework Directive, and the case of the *Erika* demonstrates that this could apply to legacy wrecks at the point where they begin to release contamination and become polluting. There is potentially a legal obligation to remediate wrecks that are polluting, but not an obligation to remediate those which have yet to pollute under this Directive. This legislation also only applies to wrecks causing oil or HNS pollution, but not to munitions and it has not been tried in court in relation to legacy wreck pollution.

While there are many studies that examine the legal regime and liability for modern polluting wrecks (De La Rue and Anderson, 2009; Tsimplis, 2014; Zhu and Zhang, 2016; Love, 2017) it has been demonstrated that this legislation does not apply to legacy wrecks. The only work that has examined the legal implications of polluting legacy wrecks in the UK to date is the research undertaken by Liddell (2014). His analysis identified that the government is likely to be liable for pollution from wrecks to which it has title. Liability for wreck pollution is expected to be assigned under common law, it would therefore be up to the owner of the wreck to demonstrate that they have taken all reasonable precautions to prevent and/or remediate any pollution from their wreck. However, no claims have been brought to court for legacy wreck so this remains untested.

Given both the obligation to remove waste under the Waste Framework Directive and the likelihood of liability being assigned to the owner under common law it stands to reason that the owner of wreck has a legal requirement to remediate wreck once it becomes polluting. There would appear to be no obligation to prevent pollution, other than that liability may be conveyed through common law if the owner is proven to not have taken reasonable effort to remediate their wreck. This therefore has particular repercussions for owners of wreck, as they must be pro-active in investigating and managing their potentially polluting shipwrecks. An added motivator for wreck owners is that, as discussed at section 2.6, it will be far cheaper to remediate wrecks that have yet to pollute, than to clean up a polluting incident for which they may subsequently be liable.

Regardless of the legal obligations to remediate wreck it is likely that any wreck owner may become subject to political and social pressure to remediate their wreck(s) if pollution occurs. This is supported by the research conducted by Fletcher *et al.*, (2009) in their National Maritime Museum survey where respondents cared most greatly about pollution and had limited interest in shipwrecks. It is also supported by previous polluting shipwreck management experiences as detailed in Chapter 2.

Public awareness of the risks of marine environmental issues has grown over time and as identified by Covello and Mumpower (1985) the public have come to expect that something can and should be done to prevent pollution risks being imposed upon them, and that the government in particular should protect them from these risks. There is therefore an argument for the existence of an ethical obligation in addition to the legal obligation for wreck owners (particularly the government) to remediate polluting wrecks, and to prevent pollution from wrecks occurring where possible.

6.2 How many polluting wrecks are there?

Quantification of potentially polluting wrecks is the first step in understanding the scale of the polluting wreck problem in the UK, it is the basis upon which management decisions can be made. However, quantification of the number of potentially polluting wrecks in the UK has proven to be problematic. A recurring theme throughout Chapter 4, and indeed the thesis is the deficit of accurate or suitable resolution datasets, and this is also the case when attempting to quantify the number of polluting shipwrecks.

The UKHO’s shipwreck dataset consists of 15,554 shipwrecks, and forms the baseline for subsequent polluting wreck assessments is based on information collected during hydrographic surveys over decades. Primarily aimed to capture information for navigational safety, the shipwreck information in the database is limited and often inaccurate. A significant proportion of UK waters have not been surveyed at a resolution to identify or locate shipwrecks appropriately, and therefore there is the potential for a greater number of wrecks to exist within UK waters than is currently recorded in the UKHO dataset.

Two primary wreck databases have been compiled by government departments to attempt to quantify the number of polluting wrecks in the UK, in order to support further risk assessment. A full analysis of these datasets was undertaken in this research, in order to determine the reliability of the baseline data that has been used in the UK's risk assessments to date.

The MoD, MCA and DEFRA commissioned the first database (PPWD3) of potentially polluting wrecks which was based on the UKHO data, but also included additional data gathered from the NMR and historical records (ABPmer, 2010). This database contained 9,838 records in the UK counter pollution zone for wrecks that had a history that would suggest they might be polluting (e.g. oil propulsion or carrying hazardous cargo). Unfortunately this research identified that there are issues with this database in relation to accuracy of location information, and the database was only partially populated with data. Only 75% of the records had enough information to allow for further risk assessment.

The MoD commissioned the PPWD4 database which was built on the PPWD3 database (Dellino-Musgrave and Merritt, 2011), therefore the errors noted above were carried through. Additional research was conducted on military wrecks, but not on civilian wrecks to determine their polluting potential. This research identified that the database contains 9,938 wrecks within the UK counter pollution zone. Analysis of these wrecks demonstrated that the vast majority were lost during the World Wars (see 4.2.6.2), and therefore lends weight to the assertion that the MoD and DfT are most likely to be the owners of a large proportion of these wrecks. The analysis also showed that a 227 vessels in the database are under 100GT and would therefore normally be removed from risk for polluting wrecks, despite the fact that the majority of these wrecks are located in shallow water where they still present a significant risk.

Differences were noted between PPWD3 and PPWD4, with lack of correlation on wreck location for approximately 2, 600 records. In addition both databases contained wrecks that were unlikely to pollute as they had no polluting cargo or fuel based propulsion. To give a more accurate number of polluting wrecks in UK waters a further refining of PPWD4 was undertaken to provide a list of only those wreck that had a potential to pollute. This work which was undertaken manually, and required normalisation of the vocabulary used in the database, resulted in a list of 953 potentially polluting shipwrecks in the UK. However, consideration should be made for the fact that this was based on refining a dataset that we already know is derived from UKHO databases where survey data is lacking, and that 25% of its records were missing information. Therefore it is possible that the number of polluting wrecks in UK waters may be slightly higher than this figure, however, this analysis does provide the most accurate figure for potentially polluting wreck numbers in UK waters based on the information and data available at this time, and it is this dataset that was taken through to further examine aspects of polluting wrecks in this thesis.

While 953 wrecks is considerably less than the 9,838 records originally present in this database, it still represents a significant number of shipwrecks that may need remediation or further assessment. 690 of these wrecks were located within existing survey datasets, however, the majority of these datasets were not of sufficient resolution to determine condition or allow for accurate identification of shipwrecks. A review of the 953 wrecks identified that 64% of the wrecks were located in 50m of water or less, and are relatively close to the shore. These wrecks are most likely to have a significant social and political as well as environmental impact if they pollute. Approximately half of the wrecks were British with the rest being vessels of other nations. This raises interesting questions about liability for these wrecks, as they may be owned by foreign governments, and further research is required to determine if the UK should be managing these wrecks on their behalf or not.

Given that much of the baseline data is lacking in the above assessments there is a clear argument for further historical research to be undertaken to fully complete the databases with wreck information, and to undertake further survey to locate wrecks in UK waters. Without this data the quantification of wrecks remains uncertain, and this uncertainty will affect any subsequent risk assessment work that is undertaken. The lack of a basic knowledge of shipwreck numbers and locations on which to undertake further work is understandably problematic as it affects the ability of wreck owners to make decisions about managing their wrecks with any level of certainty about the potential outcome. The need for additional hydrographic survey of these wrecks and the seabed more generally is critical.

6.3 What is the risk from polluting wrecks?

Risk assessment is a key tool for determining priorities and making management decisions, however, the quality and utility of a risk assessment is dependent on the quality of the information that is fed into it. Lack of basic knowledge about wreck location, condition and cargoes as described above means that realistically the output from any risk assessment will have large margins for error and be unsuitable for guiding decision making.

In the UK there have been three risk assessments produced for government departments (ABPmer, 2010; Maritime Archaeology Ltd and SeaZone Ltd, 2011; Goodsir *et al.*, 2019), two of which were based on the PPWD3 and PPWD4 databases discussed above. As previously described, the data behind these is lacking in some areas and therefore needs additional research and further locational information for the wrecks. At present the risk assessments give a mostly inaccurate risk determination for potentially polluting wrecks in the UK due to the epistemic and aleatoric uncertainties that exist.

While studies have attempted to improve the gaps in knowledge that contribute to epistemic uncertainties, these have largely been unsuccessful when not examining wrecks on an individual basis. Attempts at risk assessment have included probabilistic, Bayesian and fault tree assessments (Symons *et al.*, 2014; Landquist *et al.*, 2017) and fuzzy logic (Ventiko*s et al*, 2013). However, none of these adequately address the uncertainties present in the system, and are therefore unlikely to provide a useful basis for management decision making. This is confirmed the recent work conducted by Alexander (2019) on the SS Richard Montgomery, which identified that there are too many uncertainties associated with the wreck to determine its risk. There may be potential for further data and information to be collected in the future for those factors where uncertainty exists, however, at the present time any risk assessment is unlikely to be particularly helpful.

The most recent UK based risk assessment produced by CEFAS (Goodsir *et al.*, 2019) focused on a specific wreck with available data to remove many of the uncertainties that exist within the wider wreck database. The output was a best, medium and worst case scenario for the wreck, which enables management decisions to be made, although the use of the precautionary principle in most risk management cases means that decisions are usually made on the worst case scenario regardless of other options available.

This demonstrates that while risk assessments on the wider database may not be possible, it is possible to use them on individual wrecks where there is sufficient data. Unfortunately, the application of individual wreck risk assessments across the full 953 wrecks identified by this research as requiring further investigation is likely to be costly and time consuming. Additionally, it relies on bathymetric data being available at a suitable resolution for each of the 953 wrecks, and resource within the marketplace to be able to conduct the historical research and risk assessments.

To determine whether the wrecks could be individually assessed in relation to the available bathymetry an assessment of CHP datasets was undertaken which identified 690 of the wrecks were located within CHP surveyed areas. It was not possible to use GIS to correlate shipwreck location with geomorphological features that would potentially confirm a shipwreck location in the bathymetry due to the transformation issues in the database. Manual analysis of a select group of wrecks identified poor resolution in most of the existing CHP data meaning it was not possible to use to confirm the condition or identity of a wreck. However, the collection of modern higher resolution datasets is ongoing and this data may be able to inform future decision making for these wrecks as the coverage of high resolution data improves. Individual risk assessments are therefore likely to be feasible only once additional dedicated bathymetric data has been collected for many of the 953 wrecks in the list.

Ultimately, this research has identified that due to the inherent uncertainties around shipwreck location and condition, the existing broad scale risk assessments for UK wrecks cannot give any meaningful output to aid in decision making. This is also likely to be the case for risk assessments conducted in other states, and only those risk assessments conducted on specific wrecks with known cargo, conditions and locations, and available survey data are likely to be successful. This means that the focus needs to shift from trying to risk assess these wrecks, to determining the most efficient way in which to gather further data that can feed into management decision making.

6.4 What are the consequences of polluting wrecks?

By identifying the issues in the basic datasets that underpin the UK risk assessments it has been possible to determine areas of weakness within the existing assessments. Additionally through examination of the uncertainties that exist around potentially polluting wrecks it has been possible to determine that at present these wrecks are impossible to risk assess at a level that will provide meaningful results for decision making purposes. Attempts to improve these assessments through analysis of additional bathymetry data demonstrated that at present there is not enough data of suitable resolution to improve on the locational and condition related uncertainties associated with the wreck portfolio as a whole. Essentially despite their best efforts to risk assess their vessels, the MoD are still “flying blind”, although perhaps not as blind as other management stakeholders who are less engaged with this subject – they are at least aware of the issue.

When risk assessments fail to provide answers, the key driver behind management decisions must then rest with the social, economic and political impact of a pollution spill, as it is these pressures that drive remediation. The data analysis undertaken in Chapter 5 demonstrates that there are numerous stakeholders that are likely to be affected in the event of pollution from wreck and these effects are economic and social. These economic and social effects of pollution will drive the political push for remediation of these wrecks and the growing public awareness of marine pollution and the drive to prevent further pollution is also likely to feed into this political pressure.

This study examined a number of publicly available spatial datasets for the UK and determined that there is a significant threat from potentially polluting wrecks in UK waters. Of the 953 wrecks examined 387 were located within marine conservation or protected habitat areas, it is absolutely clear that we have a requirement to protect these areas under existing legislation, therefore these wrecks are likely to be a priority for further assessment.

This research also identified areas of high density of potentially polluting wrecks around Cornwall, the Thames Estuary and Dover straights and in Orkney. A medium density is found around ports on the East and South coasts. A higher density of wrecks means they are more likely to suffer a polluting incident. Cornwall in particular is also home to communities that are least resilient in the event of a polluting incident and the social impact of pollution in this region would be significant.

In addition to the environmental and social impact caused by a polluting event in UK waters, the economic impact is likely to be in the billions once lost revenue, damages and loss of amenity costs from industrial and non-industrial activities are taken into account. Pollution events in the Dover Straight and the approaches to harbours would also have an impact on vessel navigation and international trade, which would have political ramifications and a knock on effect to supply chains.

A key finding from this research is that while wrecks of less than 100GT have historically been excluded from assessments of potentially polluting wrecks, we do find that there are concentrations of these wrecks which may have an aggregated polluting impact that is equivalent to a larger vessel. It was also noted that even a small vessel pollution leak would have dire consequences for aquaculture sites. There is therefore a need to include these wrecks in future assessments regardless of their tonnage as their potential impact is not inconsequential.

This study identifies those coastal communities and industries in the UK that would be most impacted by a pollutant release. It has also identified which wrecks are most likely to suffer from external interference which could cause a polluting event, therefore helping to reduce uncertainty about the probability of a pollutant release. These wrecks are located in high areas of fishing density, within accessible diving areas, or in areas where there is significant vessel traffic.

Previous polluting wreck studies have typically assigned a probabilistic value to expected impact and consequences of wreck pollution based solely on expert advice. This study is the first to examine the full wreck dataset against the available socio-economic data to give a more accurate picture of the expected consequences and impact. The consequences of pollution from wreck include loss of social amenities, loss of habitats and significant environmental damage, as well as economic costs that are in the billions. The findings of this assessment confirm those of Matt Skelhorn's research, that economic damage of a pollution event from wreck far outweigh the cost of investigating and remediating wrecks before they can pollute (see section 2.6).

Ultimately, the results from the GIS assessment aid in decision making around ongoing management plans as it allows for decisions to be made with regards to where to collect additional data, which wrecks might warrant a more focused risk assessment, and where to focus efforts to remediate wrecks.

Other social and political factors that impact on polluting wreck management are unquantifiable as they relate to stakeholder perceptions and perspectives on both wreck and pollution. While the research presented at section 5.4 clearly shows that there is a heritage interest in wrecks, and that there is also a commemorative and memorial aspect to many of these wrecks it is not clear how this translates in the event of a polluting incident, and to what extent the wider public has an interest in polluting wreck management.

These socio-economic and political aspects of polluting shipwrecks are not currently accounted for in existing assessments. This is problematic as it is clear from previous polluting wreck management that it is the social and political pressures that determine whether remediation is likely to take place, and not the environmental impact of a wreck. Therefore an understanding of the political, ethical and social environment that exists around polluting wrecks is likely to be far more influential than the risk assessment.

There is therefore a need for further research to be undertaken into stakeholder perspectives and risk tolerance, and what stakeholder factors need to be considered when managing pollution from wreck. As identified at section 2.5 stakeholder engagement, appropriate risk communication and openness about the limitations of prospective risk management strategies is critical in preventing loss of public trust in manager's capability to manage risks, and in turn therefore will impact the ability of risk managers to mitigate or remediate risks.

6.5 Is the current management of potentially polluting wrecks suitable?

The research into the legal factors around potentially polluting wrecks identified that there is a requirement to remediate polluting wrecks and that owners of wreck are likely to be responsible for remediating their wrecks. Determining ownership of wreck can be complicated, however, as discussed in section 3.6 the majority of potentially polluting wrecks sank during the World Wars, and therefore the government is likely to have responsibility for many of these as they either fall under the ownership of the MoD, or were insured under War Risks Insurance with their ownership now resting with DfT. There are also a number of other management bodies, such as the MMO, Marine Scotland, heritage agencies and harbour authorities that might have an impact on how a polluting wreck is managed.

In the UK current management strategies are largely reactive, which may not be suitable for managing these wrecks moving forward as they decay further over time. However, the weight of evidence presented in this thesis demonstrates that you cannot risk assess potentially polluting wrecks on a broad scale due to both aleatoric and epistemic uncertainties. Consequently risk assessments are only useful on an individual wreck basis and are not useful for decision making with respect to management of the wider portfolio of potentially polluting wrecks present in UK waters. A pro-active management strategy will involve undertaking individual risk assessments of priority wrecks, further background historical research, and additional seabed survey data collection, which is likely to require more resources than are currently available in the marketplace. This means that at present, until there is enough resource and further data is gathered to reduce these uncertainties a reactive strategy is the only practicable option for managing these wrecks.

This research identified that the policies and approaches of the MoD and DfT to potentially polluting wrecks have differed significantly (section 3.6). The MoD has clearly engaged with this issue and while the risk assessments commissioned by the MoD have been found to be problematic for decision making, they have at least identified their wrecks that are likely to pose a pollution threat. I would suggest that their current management strategy is enough to demonstrate that they have taken reasonable steps to prevent pollution from their wrecks, within the bounds of what is achievable given the current state of knowledge. However, as demonstrated in Chapter 5 there are additional data sets that can help further inform their risk management and further steps that could be taken to aid in their wreck management decision making.

DfT are only recently starting to fully engage with this issue and as yet have no specific policies relating to polluting wrecks. Individual wreck owners/insurers have not engaged with the issue of potentially polluting wrecks in any meaningful way and are likely to either have abandoned their interests in potentially polluting wrecks or be unable to pay the costs for remediation which will result in the tax payer ultimately picking up the tab for their remediation. In any event, there should be some attempt by the relevant authority to track down non-governmental owners of potentially polluting wrecks to try and establish their ownership of the vessel and to make them aware of the potential liability associated with these wrecks.

At present the default position for DfT and independent wreck owners is to rely on the UK's counter pollution National Contingency Plan in the event of a pollution event. This is not a pro-active strategy and it is unlikely that the MCA's counter pollution team have the capacity to handle potentially multiple wreck pollution events alongside their other day to day responsibilities. It could therefore be argued that the DfT and individual wreck owners are not taking all reasonable precautions to prevent pollution from their wrecks, and if a wreck they own pollutes and the case is taken to court it is possible that they might be considered liable. DfT therefore need to undertake further steps to demonstrate that they are managing their wrecks appropriately, and from recent communication it would appear that further work is currently being planned (section 3.6.2).

This disjointed management of government owned wrecks would appear to be inefficient, and potentially costly to the tax payer if work is reproduced and repeated in each department. Therefore while the MoD's approach to their wrecks may be suitable, the approach of the government as a whole with respect to polluting wrecks is likely to be considered to be lacking. A coherent approach to government wrecks, with greater communication between departments or even with responsibility falling under a single department, would allow for these wrecks to be considered holistically and prevent disparities in management approaches towards polluting wrecks in the UK. It is also likely to ensure that stakeholder engagement around issues of heritage, commemoration and risk communication are simplified and consistent across the government wreck portfolio.

Government agencies and departments are also continuously collecting data on the marine and natural environment, social and economic data and pollution data (e.g. EMSA CleanSeaNet) which if made open and available, or at least better shared within government would allow for further research on this topic. The devolved nature of the UK government also contributes to the difficulty of obtaining datasets for use in marine assessments, a coherent approach across government towards data publishing and accessibility would also improve research and ultimately management of polluting wreck.

Regardless of current wreck management strategies, all parties with a management stake in potentially polluting wrecks must ensure that they remain abreast of new technologies and appraised of the latest available datasets to inform their management decisions. As data sharing and technological capabilities improve there is likely to be more information available to feed into the decision making process. Ignoring these developments will result in their management strategies being considered obsolete or insufficient to prevent or mitigate pollution from their wrecks.

Finally, given that risk assessments are not a functional management tool for these wrecks there needs to be more of a focus by wreck owners to understand the socio-political factors and stakeholder perceptions that impact on wreck management as these are likely to be more influential in determining risk management strategies, and in ensuring their success than traditional risk assessment methods.

6.6 What could be done moving forward?

Moving forward a coherent and joined up approach to polluting wrecks by government departments is recommended for efficiency and to prevent stakeholder confusion around management and remediation strategies. There is generally a need for greater communication between government, the public, industry and academia around the issue of polluting wrecks. At present polluting wreck studies occur in silos rather than seeing the problem as a global issue that could be tackled jointly with collaboration. Collaborative approaches will also help to prevent issues such as the one identified in this research where while many have studied *how* to risk assess polluting wrecks, few have asked if it *possible* to risk assess them. The interdisciplinary nature of the problem requires multiple perspectives and approaches to tackling the issue of polluting wrecks.

Further data should be collected that helps inform management decisions regarding these wrecks with the aim towards improving assessments in the long term. To build upon the work that has already been undertaken in the UK additional historical research should be conducted on the PPWD4 wrecks that are non-military and those which are missing basic information. The 690 shipwrecks in the refined dataset of potentially polluting wrecks identified in this research which have CHP bathymetry data coverage should be analysed in further detail alongside the bathymetry data which will hopefully allow their location to be confirmed, and where there are high resolution datasets it may allow for the condition of some of these wrecks to be determined.

Further research is particularly required on wrecks with HNS and munitions related cargoes as while oil pollution from wreck has been extensively studied and the environment has mechanisms to recover from oil spills, it is unknown if the same can be said for HNS and other substances, it is possible that these may pose more of an environmental threat than oil pollution (see sections 2.1.2, 2.1.3, 2.1.4). It is also difficult to assess these wrecks on a wider basis due to the variability of their cargo or contents, therefore these wrecks need to be assessed individually to determine their potential threat and impact.

In an ideal world with unlimited time, resources and finances the best way forward would be to take the UK's shipwreck dataset back to basics, with a focus on wreck location, wreck identification and wreck condition through additional seabed survey and historical research. This would then provide a solid foundation on which to build further assessments and to conclusively identify where shipwrecks that might pollute are located and what condition they are in. This might be incorporated with an outreach component that mirrors the collaborative information gathering seen on wrecksite, allowing the public to contribute photographs and information to the wreck record, which would give a more complete picture of the condition and background to each wreck. There is a clear need for a publicly available non-commercial wreck database for shipwrecks both globally and in the UK. This would require significant survey resources, as well as researchers and ongoing management of the record and database which would require long-term financing. However, the data would be useful for many different applications and research and is likely be less than the remediation costs of wreck that has polluted.

Moving forward there is the potential to use data from satellite detection of oil spills and the data provided by CleanSeaNet to locate wrecks that are already polluting, as well as to use machine learning to identify and map shipwrecks on the seabed and correlate these datasets. As technology improves, further data and new approaches are likely to become available that can be used to reduce uncertainty in assessments of polluting wreck and to aid in decision making.

The socio-economic data presented in this thesis demonstrates that by understanding potential consequences, we can focus future study and individual risk assessments on those wrecks that may cause the greatest impact or in areas that are likely to suffer the effects of pollution most. This allows decisions to be made about where to collect further data and what regions or areas may be a priority for further work. Those areas that are most vulnerable to pollution from wreck and which have high densities of potentially polluting wrecks should be a priority for further survey work and data collection. The assessment presented in this thesis was predominantly focused on England due to data availability, therefore this should be extended to all of UK waters. Additional work could be undertaken to remediate wrecks in these areas, or alternatively to ensure that these areas are more resilient in the face of potential pollution.

Given the unknown risk from polluting vessels, a resilience rather than a risk mitigation approach may be more applicable for managing polluting wrecks in the UK. This means ensuring that those areas and stakeholders that are least resilient have the tools and capability to respond to and recover from polluting events. This includes ensuring that the UK’s contingency plans in the event of pollution are robust and have enough resources to respond in the event of multiple pollution events from wreck. It also requires greater outreach and stakeholder engagement to manage expectations, and undertake risk communication among the wider public. Where intractable risk exists it is possible for communities and stakeholders to be resilient and to prepare for risk events, but in order to do this they must have an understanding that the risk exists and that all appropriate and practicable measures have been taken by those responsible to try to prevent the risk from occurring. As has been demonstrated throughout this thesis, the stakeholder engagement on this subject at present is limited, however, it is of crucial importance for managing the impacts of polluting wrecks moving forward. Consequently, further research into stakeholder risk tolerance and perspectives on polluting shipwrecks should be undertaken.

Ultimately the ability of wreck managers to adequately manage their wrecks relies on the quality of the information available. At present, and as demonstrated in this thesis, it is difficult to make management decisions on the UK's wreck portfolio using the current information. Indeed this thesis has highlighted a wide range of issues that limit our ability to understand these wrecks sufficiently to remediate them. Additional research into a number of areas is required to be undertaken concurrently in order to inform management decisions. We should therefore invest more in research to reduce the uncertainties that we can reduce, and to identify new ways of examining and managing these wrecks.

Chapter 7 Conclusions

7.1 Research Outcomes and Contribution

The aim at the start of this research was to build upon and improve the risk assessments that were already in place and which had been provided, along with the shipwreck databases, by the MoD. Through review of the existing literature it was clear that a reactionary management strategy for polluting wrecks was not sufficient to manage the risks from polluting wrecks which would inevitably release their pollution into the marine environment unless pro-active intervention took place. The plan was to design an updated, spatially integrated risk assessment that would include socio-economic data (omitted from most of the existing assessments), and incorporate bathymetric data to better define location and condition of wrecks. This would, it was hoped, demonstrate that it was possible to undertake pro-active assessment and move the UK towards active rather than passive risk management. It was expected that with modern datasets and a new approach to risk assessment the conclusion would be that the existing management and assessment process could be improved through use of this new risk assessment

While ultimately the research presented in this thesis, and its findings have successfully answered the overarching research question and provided us with a good understanding of the state of polluting wreck management in the UK and what can be done moving forward, the way in which the conclusions were reached was unexpected.

In archaeology we are often presented with highly detailed 3D and seabed models of shipwrecks built using bathymetric data. Combined with an understanding that our seabed in the UK is routinely mapped and that there is ongoing bathymetric data collection we tend to assume that a high level of resolution of data is widely available, particularly in the waters of an island nation such as the UK. The introduction of marine spatial planning also contributes to our assumption that we have a good understanding of the marine environment in the UK and that the datasets available are also of good quality. However, as has been demonstrated by this research, there is in fact a lack of reliable locational data for shipwrecks, high resolution bathymetric data is only available for 22% of UK waters and there are many other unquantifiable environmental factors that impact on a shipwreck's likelihood to pollute.

Despite our increasing development and engagement with the marine and maritime environment, and the significant technological advances which have made more data available, this research identified that at present the data availability in the UK is not suitable for reducing the uncertainties in the risk assessments. It is therefore not possible to risk assess potentially polluting wrecks in a manner that would inform management decisions. This is at odds with the wider literature which focuses on designing new ways to risk assess wrecks, however, it is supported by Alexander's recent research (2019).

For wreck managers who, as determined by this research, do have a legal requirement to remediate their wrecks, the options are therefore limited by the inability to risk assess and prioritise shipwrecks for further study. The spatial assessment of socio-economic data in Chapter 5 has highlighted areas of the UK which are most likely to experience wreck pollution, and which are the most and least resilient to pollution events. This therefore allows wreck managers to target data collection in those areas where there is the highest likelihood of pollution and the least social and economic resilience. This offers a new method for prioritising wrecks for further research without relying on a risk assessment.

This research also demonstrates that social and political factors have significant influence on wreck management and there needs to be further stakeholder engagement in order to manage wrecks effectively. This becomes particularly important as the social and political impacts are most likely to drive remediation given the inability to adequately risk assess polluting wrecks. Further work is therefore required to understand stakeholder risk tolerance and perspectives on the issue of potentially polluting wrecks.

Finally, this research identifies that there is significant disparity between wreck managers in their awareness and approaches to polluting wreck management. It is clear that wreck management in the UK can be improved upon through analysis of socio-economic and other available datasets. While the MoD does have a suitable management strategy in place, DfT and independent wreck owners do not, and are potentially unaware of the threat their wrecks pose and their legal responsibilities. There is therefore clearly a need to consolidate or homogenise polluting wreck management within the UK to prevent confusion among stakeholders. Wreck managers should also seek new ways to inform their decision making and embrace new technologies and data as they become available.

Where previous studies have focused on the technicalities of designing risk assessments or in the reduction of specific areas of scientific uncertainty, this work reframes the focus of study towards understanding the potential social and economic impacts, and re-introduces the human element into the management process. By shifting our focus from wrecks to people we can begin to examine these wrecks in a new manner. One that doesn't require a full knowledge of the wreck dataset and doesn't need to resolve all of the uncertainties present in the risk assessment to deliver a meaningful result.

This research has a wider impact beyond polluting wreck management, in that it highlights deficiencies in the available marine data for the UK. As increasing development of the marine space takes place, and as we look to the marine environment for additional resources in the future, this lack of data will have an effect on our ability to understand and manage the social, environmental and cultural impacts of marine projects in the UK. The inability to risk assess shipwrecks is likely to apply to other structures, habitats and projects where the data does not support viable assessment. Ultimately we will need to collect vastly more data than is currently being collected, and/or we need to find new and more appropriate ways of assessment in order to ensure sustainable management of the wider marine and maritime resource.

7.2 Limitations to this study

The research undertaken in this thesis has been interdisciplinary, taking research methods and information from various disciplines. This approach is necessitated by the complex nature of the problem. The research presented is to some extent an overview of the various issues and facets of the management of polluting wreck in the UK. While it does focus on risk management it also touched on a number of other aspects that should be explored in further detail but which were outside the scope of this thesis.

This study is limited to UK waters and does not consider the moral, ethical or legal requirements to remediate UK wrecks in other states or international waters. This was beyond the scope of this thesis due to time and data constraints, but it is an area that warrants further research.

Clearly the primary limitation of the study is a lack of available data or the quality of the data. The refined dataset produced and which was subsequently used to undertake the socio-economic study relies on the accuracy of the PPWD4 database and the UKHO database on which it was originally based. Therefore any inaccuracies in those databases in terms of wreck location and information are likely to have carried through into this assessment. As further data is gathered this assessment can be updated to update or amend wreck location information and to improve the assessment. The assessment demonstrates the successful application of the method and the relevance of alternative ways to examine these wrecks but does not claim to be fully accurate, based as it is on previously described datasets.

Analysis of the bathymetry data for the refined PPWD4 wrecks within CHP coverage was not possible within the scope of this thesis. While a selection of wrecks were examined by Lenvin (2019) there is further scope to review all of the data to further inform the location and condition of these wrecks where the resolution of the data allows. This could then be fed into the spatial assessment.

7.3 Future work

In addition to those areas identified above and in section 6.6 that would benefit from further study there are some key areas that warrant further research. Clearly there is a need to develop an accurate and open shipwreck database which includes the historical research and locational confidence based on bathymetric data. Further work in this area is particularly required in those areas identified in the spatial assessment as being the least resilient to pollution, and in those areas where there are the greatest density of potentially polluting wrecks. Further bathymetric survey data of UK waters where there is currently no or limited data is also critical if we are to understand the marine environment and the potential impact of polluting wrecks.

While this study has proven that there are socio-economic datasets available to help assess wreck pollution, many of the available datasets when the assessment was run were only available for English waters. The socio-economic assessment would therefore benefit from the inclusion of Scottish, Welsh and Northern Irish datasets when they become available for some aspects of the assessment. There are likely to be other social and economic datasets at a finer resolution that could also be fed into this assessment to give a more nuanced output than that presented in this thesis.

As has been demonstrated in this thesis, stakeholder engagement is key to appropriate management of polluting wrecks. The unquantifiable aspects of stakeholder perceptions around wreck removal, commemoration and heritage were touched on in this thesis but would require in depth stakeholder surveys and analysis to truly draw out the nuances of these subjects as they relate to wreck pollution and risk tolerances. Wreck owners need to engage in risk communication with their stakeholders, this will ensure that management of these wrecks is socially and politically acceptable both now and in the future.

Given the limited studies in the UK on potentially polluting wrecks there remains a vast amount of further research that could be done moving forward, including bathymetric data collection, archival research, stakeholder surveys, environmental surveys, on-site investigation, and alternative decision analysis. Future research requires the input of social scientists, archaeologists, pollution specialists, maritime lawyers, historians, and physical, data and computer scientists. As technology improves it is opening up new avenues for research into polluting wrecks such as the use of machine learning to analyse large datasets of satellite imagery for oil spills, or the scraping of social media information to inform sentiment around shipwrecks. The scope to apply new and emerging technologies to this problem is significant.

It is hoped that in utilising an interdisciplinary approach in this thesis it has proven the benefits and applicability of approaching this subject from alternative perspectives. Any future work should be undertaken from an interdisciplinary stance, with the potential for multiple researchers from different disciplines to be involved in a single overarching project to examine the problem holistically, and to make best use of new and emerging theory, practice and technological developments in their respective areas.

Appendix A Decision No 2455/2001/EC- Annex X

L 331/4 EN Official Journal of the European Communities 15.12.2001

ANNEX

'ANNEX X

LIST OF PRIORITY SUBSTANCES IN THE FIELD OF WATER POLICY (*)

	CAS number (¹)	EU number (²)	Name of priority substance	Identified as priority hazardous substance
(1)	15972-60-8	240-110-8	Alachlor	
(2)	120-12-7	204-371-1	Anthracene	(X) (***)
(3)	1912-24-9	217-617-8	Atrazine	(X) (***)
(4)	71-43-2	200-753-7	Benzene	
(5)	not applicable	not applicable	Brominated diphenylethers (**)	X (****)
(6)	7440-43-9	231-152-8	Cadmium and its compounds	X
(7)	85535-84-8	287-476-5	C_{10-13}-chloroalkanes (**)	X
(8)	470-90-6	207-432-0	Chlorfenvinphos	
(9)	2921-88-2	220-864-4	Chlorpyrifos	(X) (***)
(10)	107-06-2	203-458-1	1,2-Dichloroethane	
(11)	75-09-2	200-838-9	Dichloromethane	
(12)	117-81-7	204-211-0	Di(2-ethylhexyl)phthalate (DEHP)	(X) (***)
(13)	330-54-1	206-354-4	Diuron	(X) (***)
(14)	115-29-7	204-079-4	Endosulfan	(X) (***)
	959-98-8	not applicable	(alpha-endosulfan)	
(15)	206-44-0	205-912-4	Fluoranthene (*****)	
(16)	118-74-1	204-273-9	Hexachlorobenzene	X
(17)	87-68-3	201-765-5	Hexachlorobutadiene	X
(18)	608-73-1	210-158-9	Hexachlorocyclohexane	X
	58-89-9	200-401-2	(gamma-isomer, Lindane)	
(19)	34123-59-6	251-835-4	Isoproturon	(X) (***)
(20)	7439-92-1	231-100-4	Lead and its compounds	(X) (***)
(21)	7439-97-6	231-106-7	Mercury and itrs compounds	X
(22)	91-20-3	202-049-5	Naphthalene	(X) (***)
(23)	7440-02-0	231-111-4	Nickel and its compounds	

	CAS number (1)	EU number (2)	Name of priority substance	Identified as priority hazardous substance
(24)	25154-52-3	246-672-0	Nonylphenols	X
	104-40-5	203-199-4	(4-(para)-nonylphenol)	
(25)	1806-26-4	217-302-5	Octylphenols	(X) (***)
	140-66-9	not applicable	(para-tert-octylphenol)	
(26)	608-93-5	210-172-5	Pentachlorobenzene	X
(27)	87-86-5	201-778-6	Pentachlorophenol	(X) (***)
(28)	not applicable	not applicable	Polyaromatic hydrocarbons	X
	50-32-8	200-028-5	(Benzo(a)pyrene),	
	205-99-2	205-911-9	(Benzo(b)fluoranthene),	
	191-24-2	205-883-8	(Benzo(g,h,i)perylene),	
	207-08-9	205-916-6	(Benzo(k)fluoranthene),	
	193-39-5	205-893-2	(Indeno(1,2,3-cd)pyrene)	
(29)	122-34-9	204-535-2	Simazine	(X) (***)
(30)	688-73-3	211-704-4	Tributyltin compounds	X
	36643-28-4	not applicable	(Tributyltin-cation)	
(31)	12002-48-1	234-413-4	Trichlorobenzenes	(X) (***)
	120-82-1	204-428-0	(1,2,4-Trichlorobenzene)	
(32)	67-66-3	200-663-8	Trichloromethane (Chloroform)	
(33)	1582-09-8	216-428-8	Trifluralin	(X) (***)

(*) Where groups of substances have been selected, typical individual representatives are listed as indicative parameters (in brackets and without number). The establishment of controls will be targeted to these individual substances, without prejudicing the inclusion of other individual representatives, where appropriate.
(**) These groups of substances normally include a considerable number of individual compounds. At present, appropriate indicative parameters cannot be given.
(***) This priority substance is subject to a review for identification as possible "priority hazardous substance". The Commission will make a proposal to the European Parliament and Council for its final classification not later than 12 months after adoption of this list. The timetable laid down in Article 16 of Directive 2000/60/EC for the Commission's proposals of controls is not affected by this review.
(****) Only Pentabromobiphenylether (CAS-number 32534-81-9).
(*****) Fluoranthene is on the list as an indicator of other, more dangerous Polyaromatic Hydrocarbons.
(1) CAS: Chemical Abstract Services.
(2) EU-nummer: European Inventory of Existing Commercial Chemical Substances (EINECS) or European List of Notified Chemical Substances (ELINCS).'

Appendix B Environmental Quality Standards

WQS taken from CSVs available at Surface Water Pollution Risk Assessment for Your Environmental Permit retrieved 04/05/2018. Published 01/02/2016 by UK Government.

Table 10 Estuaries and coastal water priority hazardous substances, priority substances and other pollutants

Substance	AA-EQS (micrograms per litre)	MAC-EQS (micrograms per litre)	Animals and plants (micrograms per kilogram)
Alachlor	0.3	0.7	-
Anthracene	0.1	0.1	-
Atrazine	0.6	2	-
Benzene	8	50	-
Benzo(a)-pyrene (BaP) (see PAHs below for AA and biota EQS)	-	0.027	-
Benzo(b)-fluor-anthene (see PAHs below for AA and biota EQS)	-	0.017	-
Benzo(k)-fluor-anthene (see PAHs below for AA and biota EQS)	-	0.017	-
Benzo(g,h,i)-perylene (see PAHs below for AA and biota EQS)	-	0.00082	
Brominated diphenylether - total PBDE (or congener) numbers 28, 47, 99, 100, 153 and 154	-	0.014	0.0085 in fish
Cadmium and its compounds - dissolved	0.2	-	-
Carbon tetrachloride	12	-	-
Chlorfenvinphos	0.1	0.3	-
C10-13 chloroalkanes	0.4	1.4	-
Chlorpyrifos (chlorpyrifos-ethyl)	0.03	0.1	-
Cyclodiene pesticides - total aldrin, dieldrin, endrin and isodrin	0.005	-	-
DDT total	0.025	-	-
Para-para-DDT	0.01	-	-
1,2-dichloro-ethane	10	-	-
Dichloro-methane	20	-	-
Di(2-ethylhexyl)-phthalate (DEHP)	1.3	-	-
Diuron	0.2	1.8	-
Endosulphan	0.0005	0.004	-

Substance	AA-EQS (micrograms per litre)	MAC-EQS (micrograms per litre)	Animals and plants (micrograms per kilogram)
Fluoranthene	0.0063	0.12	30 in crustaceans or molluscs
Hexachloro-benzene	-	0.05	10 in fish
Hexachloro-butadiene	-	0.6	55 in fish
Hexachloro-cyclohexane	0.002	0.02	-
Indeno(1,2,3-cd)-pyrene (see PAHs below for AA and biota EQS)	-	-	
Isoproturon	0.3	1	-
Lead and its compounds - dissolved	1.3	14	-
Mercury and its compounds - dissolved	-	0.07	20 in fish
Naphthalene	2	130	-
Nickel and its compounds - dissolved	8.6	34	-
Nonylphenol (4-nonylphenol)	0.3	2	-
Octylphenol (4-(1,1',3,3'-tetramethyl-butyl)-phenol)	0.01	-	-
Pentachloro-benzene	0.0007	-	-
Pentachloro-phenol	0.4	1	-
Polyaromatic Hydrocarbons (PAH) - Total of Benzo(a)-pyrene (BaP), Benzo(b)-fluor-anthene, Benzo(k)-fluor-anthene, Benzo(g,h,i)-perylene and Indeno(1,2,3-cd)-pyrene	0.00017		5 in crustaceans or molluscs
Simazine	1	4	-
Tetrachloro-ethylene	10	-	-
Tributyltin compounds (tributyltin-cation)	0.0002	0.0015	-
Trichloro-benzenes	0.4	-	-
Trichloro-ethylene	10	-	-
Tricholoro-methane (chloroform)	2.5	-	-
Trifluralin	0.03	-	-

Table 11 Estuaries and Coastal waters specific pollutants and operational environmental quality standards

Substance	AA-EQS (micrograms per litre)	MAC-EQS (micrograms per litre)	Category
Abamectin	0.003	0.01	O
Ammonia - un-ionised	21	-	SP
Arsenic	25	-	SP
Azinphos methyl - dissolved	0.01	-	O
Bentazone	500	-	O
Benzyl butyl phthalate	0.75	10 (95th percentile)	SP
Biphenyl	25	-	O
Boron	7,000	-	O
Bromine - total residual oxidant	-	10	O
Bromoxynil	100	1,000	O
Carbendazim	-	-	SP
Chloride	-	-	O
Chlorine	-	10 (95th percentile concentration of total residual oxidant)	SP
4-chloro-3-methylphenol	40	-	O
Chloronitro toluenes	10	-	O
2-chlorophenol	50	-	O
3-chlorophenol 4-chlorophenol - total or individual monochlorophenols	50	250	O
Chlorothalonil	-	-	SP
Chlorotoluron	2	-	O
Chlorpropham	10	40	O
Chromium (III) - dissolved	-	-	SP
Chromium (VI) - dissolved	0.6	32 (95th percentile)	SP
Cobalt - dissolved	3	100	O
Copper - dissolved	3.76	-	SP
	(((DOC/2)-0.5)*2.677)+3.76)	-	SP
Coumaphos	0.03	0.1	O
Cyanide	1	5 (95th percentile)	SP
Cyfluthrin	-	0.001 (95th percentile)	O
Cypermethrin	0.0001	0.0004 (95th percentile)	SP
Demetons	0.5	-	O

Substance	AA-EQS (micrograms per litre)	MAC-EQS (micrograms per litre)	Category
Diazinon (sheep dip)	0.01	0.26 (95th percentile)	SP
Dibutyl phthalate	8	40	O
3,4-dichloroaniline	0.2	5.4 (95th percentile)	SP
Dichlorobenzene - total dichlorobenzene isomers	20	200	O
2,4-dichlorophenol	0.42	6 (95th percentile)	SP
2,4-dichlorophenoxyacetic acid (2,4-D)	0.3	1.3 (95th percentile)	SP
Dichlorvos	0.04	0.6	O
Diethyl phthalate	200	1,000	O
Diflubenzuron	0.005	0.1	O
Dimethoate	0.48	4 (95th percentile)	SP
Dimethyl phthalate	800	4,000	O
Dioctyl phthalate	20	40	O
Doramectin	0.001	0.1	O
EDTA	400	4,000	O
Fenchlorphos	0.03	0.1	O
Fenitrothion	0.01	-	O
Flucofuron	-	1 (95th percentile)	O
Fluoride - dissolved	5,000	15,000	O
Formaldehyde	-	-	O
Glyphosate	196	398 (95th percentile)	SP
Hydrogen sulphide	-	10	O
Ioxynil	10	100	O
Iron - dissolved	1,000	-	SP
Ivermectin	0.001	0.01	O
Linuron	0.5	0.9 (95th percentile)	SP
Malachite green	0.5	100	O
Malathion	0.02	-	O
Mancozeb	2	20	O
Maneb	3	30	O
Manganese	-	-	SP
MCPA	80	800	O
Mecoprop	18	187 (95th percentile)	SP
Methiocarb	-	-	SP
Mevinphos	-	-	O
Nitrilotriacetic acid (NTA)	3,000	30,000	O
Omethoate	-	-	O
PCSDs	-	0.05 (95th percentile)	O
Pendimethalin	-	-	SP
Permethrin	0.0002	0.001 (95th percentile)	SP

Substance	AA-EQS (micrograms per litre)	MAC-EQS (micrograms per litre)	Category
pH	-	6-8.5 (95th percentile)	O
Phenol	7.7	46 (95th percentile)	SP
Pirimicarb	1	5	O
Pirimiphos-methyl	0.015	0.05	O
Prochloraz	4	40	O
Propetamphos	0.03	0.1	O
Propyzamide	100	1,000	O
Silver - dissolved	0.5	1	O
Sulcofuron	-	25 (95th percentile)	O
Sulphate	-	-	O
Styrene	50	500	O
Tecnazene - total	1	10	O
Tetrachloroethane	-	-	SP
Thiabendazole	5	50	O
Tin (inorganic) - dissolved	10	-	O
Toluene	74	370 (95th percentile)	SP
Total anions	-	-	O
Triallate	0.25	5	O
Triazaphos	0.005	-	O
Tributyl phosphate	50	500	O
1,1,1-trichloroethane	100	-	O
Triclosan	0.1	0.28 (95th percentile)	SP
Triphenyltin and its derivatives	-	0.008	O
1,1,2-trichloroethane	300	-	O
Vanadium	100	-	O
Xylene	30	-	O
Zinc - dissolved plus ambient background concentration. For saltwater, an Ambient Background Concentration of 1.1 µg/l is recommended.	6.8	-	SP

Appendix C DfT Correspondence

Redactions have been made to protect personal information of those contacted.

C.1 Freedom of Information Request

Maritime & Coastguard Agency

[redacted]
Maritime & Coastguard Agency
Spring Place
105 Commercial Road
Southampton
SO15 1EG

Mrs Camila Moore
[redacted]
Email: cicm1n115@soton.ac.uk

Website: www.dft.gov.uk/mca/

Our Reference:
ID 3322- IA email dated 21 Jun 19

12 July 2019

Freedom of Information Act Request – ID3322

Dear Mrs Moore,

Thank you for your FOI request of 11 June where you requested information to support your research into, "...*historic polluting wrecks*..."

In your request you have asked questions relating to:

"...*DfT's management of pollution from historic shipwrecks which sank prior to the introduction of modern marine environmental legislation, and where ownership of the wreck is not possible to determine or where the wrecks have been abandoned. What is the DfT's plan or strategy for managing these shipwrecks? What policy or documentation does the DfT hold in relation to the management of historic polluting wrecks?*"

Wreck generally and potentially polluting wrecks specifically are not managed by DfT or by the Maritime and Coastguard Agency (MCA). While their locations are known, they are not routinely monitored, with one exception. The wreck of the SS RICHARD MONGOMERY is actively monitored though not in respect of its potential for pollution.

If wrecks meet the criteria set down under the "Protection of Wrecks Act 1973" there is a degree of management for other purposes. Section I of this Act covers Historic Wrecks and is managed by "Historic England". They manage the protected wrecks from a historical value standpoint not a pollution one. Section II of the act relates to dangerous wrecks. There are only two wrecks protected under this legislation the "RICHARD MONTGOMERY" noted above and the "Castilian". The "RICHARD MONTGOMERY" is under constant monitoring but this is due to the explosives onboard.

If a wreck begins to pollute and where owner is unknown then the MCA's Counter Pollution and Salvage Branch will activate an appropriate response to contain and recover the pollution. This may extend to appointing a salvor to remove the source of pollution and even the wreck itself.

If you are unhappy with the way the Agency has handled your request or with the decisions made in relation to your request, you may complain within two calendar months of the date of this letter by writing to the FOIA Unit at:

The FOIA Unit
Maritime & Coastguard Agency,
Bay 3/08, Spring Place,
105, Commercial Rd,
SOUTHAMPTON,
Hampshire.
SO15 1EG.
E-mail: InformationAssurance@mcga.gov.uk

Please remember to quote the reference number above in any future communications.

In the event that you are not satisfied with the decision resulting from our internal review you can apply to the Information Commissioner for a decision notice. The Information Commissioner can be contacted at: Information Commissioner's Office, Wycliffe House, Water Lane, Wilmslow, Cheshire, SK9 5AF.

If you wish to discuss any of the above, please contact me.

Please remember to quote the reference number above with the subject line FOIA Comment/Complaint in any future communications.

Yours sincerely,

Head of Branch – Counter Pollution and Salvage.

C.2 DfT Wrecks Policy Response

Camilla Moore

Subject: FW: PPW policy query

From: [redacted]
Sent: 24 July 2020 17:08
To: Moore C.I.C. <C.I.C.Moore@soton.ac.uk>
Cc: [redacted]
Subject: RE: PPW policy query

Hi Camilla,

To confirm: we're content with the version below as final and hope the thesis in general is coming together.

We realise there's a lot to consider and you're likely to be busy at the moment finalising the thesis.

If, however, it were possible at some stage to share the text and your analysis/comments on DfT wrecks, particularly in advance of any publication, we'd be interested to see them, and would also look consider how they might help us inform future policy design.

Best wishes,

[redacted]

[redacted] **| Wrecks Programme Manager, Strategic Planning and Risk | Transport Security Operations Centre | Aviation, Maritime, International and Security, Department for Transport**
2/24 | [redacted]

From: Moore C.I.C. [mailto:C.I.C.Moore@soton.ac.uk]
Sent: 21 July 2020 13:22
To: [redacted]
Cc: [redacted]
Subject: RE: PPW policy query

Hi [redacted],

Thanks for coming back to me on this, yes that is exactly the sort of thing I was after. I'll await the official version before I finish that section of the thesis.

Many thanks
Camilla

From: [redacted]
Sent: 17 July 2020 16:42
To: Moore C.I.C. <C.I.C.Moore@soton.ac.uk>
Cc: [redacted]
Subject: RE: PPW policy query

Hi Camilla,

I hope you're keeping well. This isn't the final version of our updated statement for potentially polluting DfT wrecks, but just checking the sort of thing that you were looking for?

1

The Department for Transport is aware of the over-arching environmental risk of its 4,500 WW1 and WW2 wrecks portfolio. It is therefore planning a proactive management approach collaborating with appropriate HM Government partners, and has secured funding to put out a future tender for an environmental pilot audit survey on the portfolio. The aim of this survey will be to generate an understanding of the scope and scale of the environmental risk associated with DfT WW1 and WW2 wrecks, which will enable options for mitigation to be put in place. The Department is also conducting a digitisation project of the records of its wrecks portfolio, currently only accessible on paper, which will facilitate the effective completion of the environmental audit pilot survey through more efficient record access. This project has been temporarily paused due to the contractor's Covid-19 business restrictions, and DfT are looking to resume this work at the earliest opportunity.

Best wishes,

[redacted] | **Wrecks Programme Manager, Strategic Planning and Risk | Transport Security Operations Centre | Aviation, Maritime, International and Security, Department for Transport**
2/24 | [redacted]

This email has originated from external sources and has been scanned by DfT's email scanning service.

Appendix D PPWD4 Refined Data

D.1 Vessel Type

Table 12 Refined PPWD4 Vessel Type

Vessel_Type	Total	Percentage
Cargo Vessel	261	27.4%
Steamship	173	18.2%
Submarine	159	16.7%
Tanker	89	9.3%
Destroyer	62	6.5%
Maritime Craft	41	4.3%
Cruiser	17	1.8%
Battleship	16	1.7%
Torpedo Boat	13	1.4%
Tug	9	0.9%
Liner	8	0.8%
Barge	7	0.7%
Drifter	7	0.7%
Minelayer	7	0.7%
Minesweeper	6	0.6%
Container Ship	5	0.5%
Ferry	5	0.5%
Battle Cruiser	4	0.4%
Collier	4	0.4%
Landing Ship Tank	4	0.4%
Ordnance Vessel	4	0.4%
Anti Submarine Vessel	3	0.3%
Barque	3	0.3%
Dredger	3	0.3%
Fishing Vessel	3	0.3%
Gunboat	3	0.3%
Service Vessel	3	0.3%
Aircraft Carrier	2	0.2%
Corvette	2	0.2%
Frigate	2	0.2%

Vessel_Type	Total	Percentage
Hopper Barge	2	0.2%
Lighter	2	0.2%
Oiler	2	0.2%
Ordnance Ship	2	0.2%
Platform Supply Vessel	2	0.2%
Rescue Vessel	2	0.2%
Coaster	1	0.1%
Escort Vessel	1	0.1%
Hospital Ship	1	0.1%
Landing Craft	1	0.1%
Lighthouse Tender	1	0.1%
Livestock Ship	1	0.1%
Lugger	1	0.1%
Mine Carrier	1	0.1%
Motor Gunboat	1	0.1%
Naval Support Vessel	1	0.1%
Paddle Steamer	1	0.1%
Pilot Vessel	1	0.1%
Schooner	1	0.1%
Sewage Dumping Vessel	1	0.1%
Torpedo Boat Destroyer	1	0.1%
Warship	1	0.1%

D.2 Vessel Nationality

Table 13 Refined PPWD4 Nationality of Vessels and whether the country is a signatory to the UNESCO convention (UCH).

Nationality	Total	Percentage	UCH
British	500	52.5%	N
German	177	18.6%	N
Dutch	54	5.7%	N
Norwegian	43	4.5%	N
Greek	20	2.1%	N
Unknown	19	2.0%	N
Panamanian	17	1.8%	Y
Swedish	17	1.8%	N
Danish	16	1.7%	N
American	15	1.6%	N
French	10	1.0%	Y
Spanish	8	0.8%	Y
Belgian	7	0.7%	Y
Liberian	5	0.5%	N
Antiguan	4	0.4%	Y
Honduran	4	0.4%	Y
Russian	4	0.4%	N
Cypriot	3	0.3%	N
Irish	3	0.3%	N
Italian	3	0.3%	Y
Maltese	3	0.3%	N
Canadian	2	0.2%	N
Finnish	2	0.2%	N
Icelandic	2	0.2%	N
Polish	2	0.2%	N
Bahamas	1	0.1%	Y
Barbadian	1	0.1%	Y
Ecuadorean	1	0.1%	Y
Israeli	1	0.1%	N
Japanese	1	0.1%	N
Malaysian	1	0.1%	N
Marshall Islands	1	0.1%	N
Pakistani	1	0.1%	N

Nationality	**Total**	**Percentage**	**UCH**
Portuguese	1	0.1%	Y
Romanian	1	0.1%	Y
Somalian	1	0.1%	N
Swiss	1	0.1%	N
Ukranian	1	0.1%	Y

Appendix E Wrecks in Offshore Development Areas

Table 14 Refined PPWD4 Wrecks in Offshore Development Areas

UKHO_Id	Vessel_Name	Nationality	Yr_Loss	Construction	Vessel_Type	Cargo_Type	Depth	Latitude	Longitude
4336	Ragnhild (Possibly)	Norwegian	1917	Steel	Steamship	Fuel Oil & Coke	46	55.23161	-1.4165
2975	HMSM K17	British	1918	Unriveted Iron	Submarine	None	49	56.25755	-2.1932
2973	HMSM K4 (Probably)	British	1918	Iron And Steel	Submarine	Unknown	50	56.25855	-2.1922
9456	HMSM C 29	British	1915	Iron And Steel	Submarine	Unknown	33	53.88445	1.5047
4947	U 66	German	1917	Unknown	Submarine	Unknown	25	55	2
28364	Vulcan Service	British	1990	Unknown	Service Vessel	Locked Radiation Bunker	33	53.04833	3.0272
20012	Glenarm Head (Possibly)	British	1918	Steel	Steamship	Armament	46	50.64306	-0.1888
20001	Pagenturm	British	1917	Steel	Steamship	Armament	44	50.63361	-0.2155
9266	HMSM	British	1941	Iron And Steel	Submarine	Unknown	15	53.16569	1.1019
14829	Neg Chieftain	Panamanian	1983	Unknown	Tug	Unknown	4	51.32013	1.45798
1306	Llanishen (Probably)	British	1940	Unknown	Steamship	Elec Ins's, Wire, Fire Hoses, Bottles, Ink	44	58.27048	-2.7488

Appendix F MMO Coastal Communities Data

Table 15 MMO Coastal Communities Data (England)

	East Midlands	East of England	London	North East	North West	South East	South West	West Midlands	Yorkshire and The Humber	Total Communities per category
A1 Coastal Retreats: Silver Seaside	24	97	0	35	83	190	269	0	57	755
A2 Coastal Retreats: Working Countryside	61	115	0	19	39	61	123	4	75	497
A3 Coastal Retreats: Rural Chic	1	99	0	27	78	135	223	9	36	608
B1 Coastal Challenges: Structural shifters	35	86	0	169	232	112	158	0	158	950
B2 Coastal Challenges: New Towns and Ports	0	195	3	247	205	320	239	0	7	1216
B3 Coastal Challenges: Striving communities	4	82	0	366	444	127	112	0	109	1244
C1 Cosmopolitan Coast: Reinventing resorts	6	47	0	58	132	160	181	0	48	632

	East Midlands	**East of England**	**London**	**North East**	**North West**	**South East**	**South West**	**West Midlands**	**Yorkshire and The Humber**	**Total Communities per category**
C2 Cosmopolitan Coast: Coastal professionals	1	138	1	84	131	398	286	0	23	1062
D1 Coastal Fringe: Prosperous suburbia	2	256	7	127	321	440	277	1	47	1478
D2 Coastal Fringe: Working hard	11	203	4	272	398	381	267	0	79	1615
Total Regional Communities	145	1318	15	1404	2063	2324	2135	14	639	

Glossary of Terms

Aleatoric .... Relating to chance or indeterminate events, in this thesis is used to describe uncertainties where the events are unpredictable and unquantifiable.

Automatic Identification System AIS is a system that uses vessel transceivers and satellites to monitor vessel location and tracking with the aim of preventing collisions at sea.

Bathymetry .... Is the measurement of water depth using acoustic techniques which produce a relief map of the seabed

Benthic .... Occurring on the seabed/bottom of the ocean

Dispersant .... A chemical mixture that aids in the breakdown of oil into smaller droplets to disperse it into the water column.

Epistemic .... Relating to knowledge, in this thesis is used to describe uncertainties where we are missing information or knowledge about shipwrecks.

Explosive Remnants of War Explosive Remnants of War (ERW) is an overarching term that includes fused munitions that were deployed but failed to function as intended (referred to as unexploded ordnance (UXO)), munitions that were fused but never fired (e.g. weapons stored or transported as part of armouries on board a vessel), or munitions that were unfused (e.g. in order to be disposed of at sea).

Gross Value Added .... GVA is the difference between output and consumption for an industry and is used to measure the size of an economy.

Shapefiles .... The shapefile format is a digital vector storage format for storing geometric location and associated attribute information. The shapefile format stores the data as primitive geometric shapes like points, lines, and polygons. These shapes, together with data attributes that are linked to each shape, create the representation of the geographic data.

Tort...................................... A civil wrong arising from an act or failure to act, independently of any contract, for which an action for personal injury or property damages may be brought.

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